A TREATISE ON
CERAMIC INDUSTRIES

E. BOURRY

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CERAMIC INDUSTRIES

A COMPLETE MANUAL FOR
POTTERY, TILE, AND BRICK MANUFACTURERS

BY

EMILE BOURRY

A REVISED TRANSLATION FROM THE FRENCH

WITH SOME CRITICAL NOTES

BY

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THREE HUNDRED AND EIGHT ILLUSTRATIONS

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TRANSLATOR'S AND REVISER'S PREFACE.

The lack of technical treatises devoted to Ceramics in the English language has long been a serious drawback to the progress alike of the student and the manufacturer, and in view of this fact, and also that during the last few years an increasing interest has been manifested in systematic ceramics, it has been felt that the reissue of such a work as this might prove opportune.

M. Bourry's work has long been recognized as a standard work by the practical potter, who finds that the exhaustive researches of Seger demand more time for study than he can devote to such matters, whilst other works lack the good classification and concise method of statement which is one of the happiest features of M. Bourry's able book. Unlike many other works, it also treats, with equal fullness, of the manipulation of every class of ceramics from the common brick to the finest porcelain, and thus enables the reader to compare the effect of the general principles governing the results of most diverse manufactures.

As the book is intended as a manual for practical men rather than a hand-book for the scientist, no attempt has been made in translating to revise the chemical nomenclature except where the subject seemed to be of special interest, and in most cases the popular names of chemicals have been retained.

Obsolete theories have in some instances been omitted, and the general descriptions have been shortened as much as was thought to be possible without sacrificing clearness of expression or omitting important facts. At the same time, no attempt has been made to materially alter M. Bourry's original work. For this reason many of the statements made must be accepted on their own merits and not as necessarily representing the reviser's opinions. For the same reason, many illustrations in the original have been retained, though they represent French and not English machinery. In a few cases, illustrations of modern English machinery have been substituted.

In a number of instances, special notes have been added where they appeared to be desirable.

Although they are not assisted by the respective governments as are so many students and factories in Europe, many British manufacturers have awakened to the importance of basing their operations on more systematic and scientific methods, and it is hoped that the present edition of M. Bourry's work may prove as useful as was the first edition in this respect.

Failing to recognize that there is much which is technically common to all pottery manufacture, the British potter has imagined that his experiences were usually unique, and, therefore, to be kept absolutely secret. This is unfortunate, but the present willingness of numerous manufacturers to combine in pursuing such technical research as related to subjects and methods common alike to all their manufactures, is a step forward in the right direction, though it can never replace the necessity for highly specialized study, the results of which must, under present commercial conditions, often remain unpublished.

If some qualified English writer were to publish a book somewhat on the lines of the present one, but giving in greater detail the various methods of working in this country, the labour and disappointment necessarily connected with a translation—however good—would be avoided, and the advantage to the industry as a whole thereby gained must be apparent. A number of such works are available to French and German potters, but, hitherto, the demand for such a book has not been sufficient to justify its publication. Meanwhile, the reception accorded to the first English edition of the present work encourages the publishers to re-issue it in its present revised form.

ALFRED B. SEARLE.

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CONTENTS.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER I.

DEFINITION AND CLASSIFICATION OF CERAMIC WARE.

Definition.—In nature is a great number of rocks or earths which, when mixed with water, form plastic bodies which can be easily moulded into shape and can retain the shape given to them. These bodies when dried, and afterwards heated to a sufficiently high temperature, lose their plasticity and become hard bodies, the shape of which cannot be altered by small pressures. These minerals are designated under the general name of *clays*.[1]

Clays, whether pure or mixed with other substances, on the addition of water and suitable treatment, form what is known as "plastic bodies". These are termed "green ware" when they receive the form of the piece to be manufactured, and "biscuit" after they have been subjected to the process of firing. The word "body" has obtained in ceramics an illogical signification (but sanctioned by custom), designating both the plastic mass and the substance which has become hard through firing.

The ware can be covered before or after firing with a coating of "glaze," which vitrifies under the influence of heat, the object of this glaze being either to decorate the ware or to render it impermeable to most liquids.

All the various kinds of ware obtained by these processes—bricks, tiles, pipes, terra-cotta, earthenware, stoneware, and china—are included under the general name of pottery, or ceramic ware. They can be (1) formed only of a body, or (2) composed of a body and a glaze, or (3) made of a body covered with a second body and the whole covered with a glaze.

Ceramic products supply the most diverse needs of man and enter as important factors into the construction and decoration of buildings; they supply the most varied domestic requirements; and are indispensable for building furnaces of all kinds, for the manufacture of chemical productions; they render important services to agriculture and sanitation, in the draining off of water and sewage; horticulture makes considerable use of them; and finally they lend themselves to the creation of decorative pieces, uniting the art of sculpture to that of the painter. Thus, pottery is an essential element to civilization, of the same value as wood or metal, and more important than glass or natural stones.

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[1] This "definition" must not be applied too rigidly, as many substances which are not clays are included in it, and some clays are not sufficiently plastic to be included in it.—A. B. S.]

The variety of application entails diversity in the methods employed in the manufacture from the humble workshop of the primitive potter, to the use of large machines and complex appliances, putting into action all the resources of industry and science. Again, the potter's aim is sometimes to produce a cheap piece of goods, at other times he endeavours to produce works of art in which the price of the raw material cannot equal one-thousandth part of the value which the artist's talent has bestowed upon the finished article.

Yet, notwithstanding the great variety, ceramic products form a very distinct group in the midst of other productions of industry and art, because their manufacture is in all cases based upon the chief property of clay—the capability of forming with water a plastic body which becomes hard under the influence of heat.

In this way, ceramic products are quite distinct from those of glass, in which the plasticity necessary for shaping is obtained when the mass is in a state of pasty fusion, and not by a cold shaping of a plastic body. They are also distinguished from cements and other analogous agglomerated wares which harden by the "setting" together of the components, and not by the action of heat.

There are, however, two exceptions to this general characteristic of pottery:—

(1) Certain china ware of which the body does not include clay and which is properly termed "glass," and

(2) Certain refractory wares in which clay is replaced by other agglutinants which really form part of the mass.

These wares are, however, classed as pottery, because they are produced by the usual processes employed in its manufacture.

General Principles of Classification.—The variety of ceramic products demands a method of classification which will group together all pottery ware having analogous properties, but they present themselves as a continuous series from the most common terra-cotta to vitreous china, each differing so slightly from those immediately preceding, and following it, that it is impossible to determine clearly the points of transition. Thus, terra-cotta and stoneware are quite distinct, as much from the point of view of ceramic qualities as from their value, and it is of interest to clearly differentiate them, though they are both "pottery".

In order to manufacture stoneware, the ware must be raised to a sufficiently high temperature to cause vitrification of the body; if this is not produced, the ware is simply terra-cotta. If the temperature in the oven is distributed irregularly some of the articles may be stoneware, others terra-cotta, with others in all the intermediary stages. Some pieces can even be stoneware on one side and terra-cotta on the other.

Another difficulty of classification exists in the relative value of the distinctive properties of the ware, a value which is not the same for different trades. Thus the chemical composition of a body is of minor importance in ordinary bricks, but it is of predominating importance in refractory fireclays. It also matters little, ceramically, whether a piece of stoneware has a coating of glaze or not, whereas a piece of pottery while unglazed is terra-cotta, but becomes earthenware as soon as it possesses a glaze.

A general classification cannot therefore be based on one determinate property without taking others into consideration, but should confine itself to determining as exactly as possible the principal kinds of pottery, and to classifying those which, by the similarity of their properties, have most in common with each other.

The distinctive characteristics which serve to differentiate pottery ware can be divided into four classes:—

(1) Differences which are apparent in the physical properties, e.g. whether a body is vitreous or porous, impermeable or permeable, transparent or opaque, hard or soft, white or coloured, fine or coarse grained, matt or glazed, the glaze itself being hard or soft, transparent or opaque, etc.

(2) Differences in form and use.

(3) Differences in the chemical composition of the body and of the glaze.

(4) Differences in the process of manufacture.

The differences in the first group have the advantage of being easily and rapidly observed, and also enable the ceramist to judge to some extent the chemical composition, and the mode of manufacture, so that they form the foundation of all classifications of pottery.

The establishment of a classification based solely on chemical composition has been attempted, but is unsatisfactory because it does not take into account the physical properties, or the influence of firing on the ware.

Among the ancients, and up to the middle of the eighteenth century, there was no classification but only a naming of pottery ware. This method was sufficient so long as the ceramic industries remained strictly localized, but resulted in an inextricable confusion from the day when attempts made to imitate Chinese porcelain caused a stir in Europe and produced new kinds of pottery. Thus, the most authentic writers of the seventeenth and eighteenth centuries constantly confuse the terms Faience and Porcelain because of the custom of calling all kinds of ware by the name of the pottery momentarily popular. At this period, also, the expressions such as "opaque porcelain" and "iron stone" appear as substitutes for the term "earthenware," which had then fallen into discredit but again became fashionable in the nineteenth century.

Brongniart in his masterly "Treatise on the Ceramic Art" gave, in 1844, the first rational classification, and this has been universally adopted as far as its principal divisions are concerned.

Brongniart divides all pottery into two classes: that which has a soft body, and that which has a hard body, according as this body is capable of being scratched or not by iron. The second group is at once subdivided into two classes, according as the body is opaque or transparent. By this means three large classes are obtained:—

(1) Pottery ware with a soft body.

(2) Pottery ware with a hard, opaque body.

(3) Pottery ware with a hard, transparent body.

These three divisions are subdivided into nine orders, according to the chemical composition of the glaze.

The following table, containing Brongniart's observations, summarizes this classification :—

Classes.	Names and Characteristics.	Orders.	Names and Characteristics.
1st Class.	Pottery of soft body which can be scratched by iron : sandy-clayey, calcareous (generally fusible at china heat).	1st Order.	Fired clay : sandy-clayey body, matt surface, without any glaze. Subdivisions :— (*a*) Plastic ware (moulded). (*b*) Utensils, bricks, crucibles (moulded). (*c*) Matt ware, jars, urns.
		2nd Order.	Lustred ware : slightly glazed, silico-alkaline.
		3rd Order.	Glazed ware : lead glaze.
		4th Order.	Enamelled pottery : common earthenware, stanniferous glaze, roof-tiles, quarries, bricks, etc., with vitreous glaze.
2nd Class.	Pottery of hard, opaque body ; that is to say, not able to be scratched by steel : silicious, infusible, clayey.	5th Order.	Fine earthenware : colourless body, vitro-plumbiferous glaze.
		6th Order.	Ceramic stoneware : coloured body, without glaze or silico-alkaline glaze.
		7th Order.	Hard china : kaolin body, felspar, glaze.
3rd Class.	Pottery of hard, transparent body: sandy clay, alkaline, can be softened.	8th Order.	Natural soft china ; clayey phosphatic, kaolinic, vitro-plumbiferous glaze.
		9th Order.	Artificial soft china : Marno-saline body, fritted vitro-plumbiferous glaze.

The chief objection to this classification refers to the division of earthenware into two distinct classes, of hard and soft bodies, in the first of which is included enamelled pottery, called also "common faience," and tin enamelled earthenware, and in the second, fine pottery pipe clay, flint ware. But the inferiority or distinction of a piece of pottery does not belong to the greater or less hardness and whiteness of the body, and these are no longer regarded as distinguishing characteristics as Brongniart supposed at the time when he made his classification.

Among earthenware manufacturers of decorative earthenware the glazing is the chief element ; the body is only a support, and its defects are concealed, if necessary, by the use of slip, or opaque enamel. This kind of pottery has not, therefore, commercially the high importance which Brongniart assigns to it.

The position of some bodies which cannot be scratched by iron, e.g. certain vitrified bricks and quarries, is also anomalous.

Salvetat proposed, about 1857, to base a classification on simple pottery (without glaze) and compound pottery (body and glaze), and to subdivide these classes into (1) opaque and (2) transparent, further subdivisions taking into account first the composition of the body, and then that of the glaze.

This classification is the most extensive and the most dogmatic, but is impracticable, unnatural, and impossible to justify.

In Germany Knapp's classification has been adopted. It can be summarized as follows:—

1. *Solid (dense) Pottery.*

A. China :—
  (1) With glaze.
  (2) Without glaze.
B. Stoneware :—
  (1) With glaze.
  (2) Without glaze.

2. *Porous Pottery.*

A. Earthenware :—
  (1) Fine with transparent glaze.
  (2) Common, with opaque glaze.
B. Ordinary pottery ware.
C. Bricks, tiles, refractory wares.

In this classification the importance of the glazes is equally exaggerated. Moreover, a piece of "fine" earthenware has not of necessity a transparent glaze, nor common earthenware an opaque glaze.

Kolbe based his classification on the raw material of the body, then on the examination of the surface of the pottery, and divided ware into clayey pottery, and kaolin (or porcelain clay) pottery.

This classification is not very practical, as it is not of necessity revealed by the physical properties of the body, nor by its chemical composition, and a body which is both clayey and kaolinic would not find a place. There is also a possibility of confusion in the value attached to the words "soft" and "hard," which for clayey pottery denote the physical hardness of the body, and for kaolinic pottery are concerned with its resistance to the action of heat.

Bruno Kerl adopts a classification which is derived from those of Brongniart and Knapp:—

I. *Porous Pottery.*

1. Bricks, tiles, terra-cotta.
2. Refractory ware.
3. Artistic pottery.
4. Common pottery.
5. Ordinary earthenware.
6. Fine earthenware.
7. Pipes.

II. *Impermeable Pottery.*

1. Stoneware.
  (*a*) Ordinary.
  (*b*) Fine.
2. China.
  (*a*) Hard.
  (*b*) Naturally soft.
  (*c*) Artificially soft.

This classification is excellent, though it makes a distinction between artistic and common pottery, which is very difficult to determine, and creates an exclusive class for "pipes" without assigning any place to "parian".

Division into Two Main Classes: Permeable and Impermeable Pottery.—The author (E. Bourry) prefers to divide pottery into permeable and impermeable wares, this qualification naturally being only applicable to the body and not to the glaze, which is always impermeable. Permeable pottery absorbs a certain quantity of water while impermeable pottery absorbs only a very little or none, so that the permeability can be measured by plunging the body into water, and noting the weight of water absorbed at the end of a given time. The methods by which this trial is made, as well as the limits within which the permeability can vary, will be dealt with later.

Permeable pottery showing an earthy fracture, rough to the tongue, is generally soft, and can usually be scratched by steel.

Impermeable pottery is compact, of vitreous fracture, smooth to the tongue, and cannot be scratched by steel.

In permeable pottery, pure clay, rendered more or less fusible by fluxes, plays the part of an agglomerate; whilst impermeable ware is a species of glass capable of assimilating in its mass non-vitrified material. All impermeable pottery before firing is permeable pottery; it only becomes impermeable at a temperature which causes its mass to soften and vitrify. If, on the other hand, porous pottery is heated to a temperature at which it becomes impermeable it usually loses its form; it is then transformed into a vitreous slag.

Subdivision into Five Groups: Terra-cottas, Refractory Fired Bodies, Earthenware, Stoneware and China.—Permeable pottery is divided into three groups: (I) Terra-cottas, (II) Refractory fired bodies, and (III) Earthenware. The fusibility of the body, as well as the presence or absence of glaze, thus serves to distinguish these three kinds of pottery.

Terra-cottas comprise all permeable ceramic products not covered with glaze, the body of which cannot be heated to a temperature higher than that of firing hard porcelain (1375° C.) without losing its form or becoming vitrified. Usually they are rather soft; some among them, however, cannot be scratched by iron, or even sometimes by steel. Their colouring varies usually from light yellow to red and reddish-brown; occasionally they are grey or black, and in some cases white.

Refractory fired bodies are always matt, and can be raised to the temperature at which hard porcelain is fired without losing their shape or beginning to vitrify. They can always be scratched by steel, and usually by iron. Their colour varies from yellowish- or brownish-white to yellow or light grey; in exceptionable cases they are black.

Earthenware comprises all permeable pottery with a coating of glaze. The body is soft or hard, white or coloured yellow or red.

Impermeable pottery is divided into two groups: (IV) Stoneware, (V) China. The measure of the porosity of the body will in both cases decide the class to which these kinds of pottery belong.

Stoneware is pottery of coloured opaque body, although sometimes only slightly yellowish, greyish or bluish. It may be matt or covered with a glaze.

China is translucent, of white body, matt or with glaze. The body is sometimes artificially coloured for decorative purposes.

The distinction between these two groups lies in the translucency of the body. This is fairly clear, and the possibility of confusion only arises in the cases of certain fired bodies, which, when almost vitrified, resemble stoneware, and of certain kinds of earthenware of hard, slightly translucent body, which could be grouped with china.

The following table shows the relationship between the author's and Brongniart's classifications :—

BOURRY.	BRONGNIART.
I. Terra-cottas	1. Terra-cottas. 2. Smeared pottery work.
II. Fired refractory bodies	——
III. Earthenware	3. Glazed pottery. 4. Enamelled pottery. 5. Fine earthenware.
IV. Stoneware	6. Ceramic stoneware.
V. China	7. Hard china. 8. Naturally soft china. 9. Artificially soft china.

CHAPTER II.

BRIEF HISTORY OF CERAMICS.

By making use of the fairly plastic deposits of the overflow of the Nile the Egyptians in very ancient times manufactured bricks of rough earth and fired them as soon as they had discerned the property clay possesses of hardening under the influence of heat. In some borings made by Linant Bey, debris of fired bricks were found at a depth of twenty-five to thirty feet below the level of the valley of the Nile, and this discovery with the progressive elevation of the soil from the overflows suggests that the beds containing those bricks were deposited 10,000 years or more ago. According to Mariette Bey, there are found in the tombs of the Memphite period (5000-3000 B.C.) vases of terracotta which were intended to contain provisions for the deceased. Also, on the walls of the tombs of the Beni-Hassan pictures have been discovered portraying scenes from the life of Egyptian potters, modelling vases and firing them in an oven, at a time corresponding to the Theban Period (3000-1700 B.C.). To this period is also attributed the discovery of glazes and the manufacture of the first pieces of earthenware found in the pyramid of Saggarah. Between 1700 B.C. and 500 B.C. the art of earthenware manufacture acquired a rare perfection, as is shown by the decorations of the temple of Tell-el-Yadouai built by Rameses III.

Whether the Chaldeans and Assyrians had borrowed their processes from the Egyptians, or whether they themselves had discovered these is not certain, but it is known that after having for a long time used crude bricks in their buildings they erected the palaces of Crœsus at Sardis, of Mausolus at Halicarnassus, and of Attalus at Tralles in beautiful, red, fired bricks. The ruins of Nineveh and Babylon consist of accumulations of fired bricks of a yellowish-white colour, sometimes covered with blue, bluish-grey or yellowish-white glazes. Tombs made of a single piece of ware, or formed by two pieces cemented together, evince the skill already reached by Chaldean and Assyrian potters at this remote period.

It is possible that the Indian races learnt the manufacture of fired bodies and glazes from the Assyrians and Chaldeans; in the Vedic hymns mention is made of pottery.

The Persians, successors to the Assyrians, carried the manufacture of monumental earthenware to a high degree of perfection. The body employed by the ancient Persians was extremely silicious, having the appearance of a piece of soft stone. The slightness of its plasticity naturally rendered its moulding very difficult. The bricks which serve as a support for the glaze are apparently formed of a mass of sand together with a little clay. The ornamentation has probably been sculptured by hand, either on the green or fired body. The glazes are very alkaline, possessing much brilliancy with white, yellow, or blue colourings. At a later period the Persians used more plastic bodies, from which they were enabled to make vases and dishes.

It is curious that Greeks and Romans, whose intercourse with the Persians was so frequent, never borrowed the magnificent art of enamelling from them. Possibly the Greek desire for purity and delicacy of form caused them to dislike an enamel which would clothe an object with any pasty subject; but this could scarcely apply to the Romans, who, on the contrary, were very prone to adopt the usages of the nations whom they conquered.

The art of faience was introduced into Europe from Persia by the Arabs and Moors after it had been ignored by all the classic nations and the Middle Ages. Towards the eleventh century when the Arabs were superseded by the Moors, a new kind of manufacture appeared in Spain which was distinguished from the Persian wares chiefly by the metallic lustre of the glaze. The manufacture of the celebrated Hispano-Moresque faience, wall tilings, dishes and vases, frequently having great purity of form, became concentrated in the Island of Majorca, at Malaga, and at Manises, near Valencia. The celebrated vases which adorn the Alhambra at Granada, and are considered masterpieces of Moorish ceramic art, were probably manufactured at Malaga about 1320.

The conquest of Spain by the Christians struck a fatal blow to this fine industry, and it declined rapidly and disappeared entirely from the localities it had rendered famous, leaving the honour of inheriting this glorious art to Italy.

The Phœnicians and Greeks neglecting glazes, manufactured terracottas, which afterwards had such a pure artistic characteristic and caused the spread of the art of fired bodies among all the nations bordering on the Mediterranean, and of those in the North of Europe.

The Greeks are important because of the perfection of form they were able to give to their pottery, and the Romans because they were the creators of the industry of fired wares for the purposes of construction, and because Southern Italy was the country from which originated "Campanian" ware, which will always remain the most perfect model of pottery in fired body. In addition to the admirable purity of form, the Greek potters used fairly fine clays, probably washed and fired at a rather high temperature, which gave a special hardness and fineness. They either polished the surfaces before firing, in order to give a kind of "finish" to the fired pottery, or used the process of decoration known as "slipping," which consists in putting on to the body ornamentation made by means of another body of a different colour. Later, they covered the fired bodies with a lustre glaze which by its strongly alkaline composition determined the vitrification of the surface. These lustres were coloured red by oxide of iron, or dark brown by a mixture of the oxides of iron and manganese.

According to the Chinese, the first pieces of pottery were manufactured by Kouen-Ou who lived during the reign of the Emperor Hoang-Ti (2698-2599 B.C.), but their great discovery, that of impermeable pottery (stoneware and china), is much more recent; the first mention of it being made in a work published under the Emperor Wan-Ti (175-151 B.C.).

The aborigines of America manufactured remarkable terra-cottas, and in certain districts of Mexico and Central America the origin of this manufacture dates probably from more than 1000 B.C. The manufacture of terra-cotta was thus invented by three different peoples —the Egyptians, the Chinese, and the Mexicans (Aztecs)—at the beginning of their respective civilizations, that is to say, at periods too remote for accurate dates to be assigned to them.

Up to the fifteenth century the only glaze known was of a plumbiferous nature. Its transparency allowed the yellowish or red colouring of the body to be seen. The origin of its use is unknown, but it is generally admitted that it was known to the Egyptians, Greeks and Romans, and though little used by them was handed down to the thirteenth century, when it became more largely employed.

About the eleventh century the potteries of Italy became the most renowned in Europe. The intercourse between Italians and the East gave them a knowledge of Arabian faience and metallic lustres, which they strove to equal. For many centuries they were content to be imitators, but in 1440, Luca della Robbia, a native of Florence, made use of stanniferous, opaque enamels for the production of a new kind of ware, which for three centuries held the chief place in ceramic art. Della Robbia was a sculptor, and his object in covering fired bodies with enamel was to render them imperishable. His principal works are statues, or groups covered with enamels of a uniform colour, chiefly white and blue, sometimes green, rarely brown or yellow. The great discretion used in his colours and the purity of style shown in his shapes, marks his work with a peculiar characteristic of serenity which is not found among his successors. At his death Luca was succeeded by his nephew, Andrea, who had seven sons, five of whom became distinguished ceramists. They produced bas-reliefs, friezes, statues, medallions, and altar-pieces remarkable for the perfection of the technical processes displayed. "The enamel on them," says M. Garnier, "is very smooth and without any cracks; the clay is well fired, and the shrinkage has been so cleverly calculated that the parts which compose the bas-reliefs and statues of large dimensions are adjusted and placed together without leaving any gap."

At the end of the fifteenth century the manufacture of a new stanniferous faience developed considerably throughout the whole of Italy. This was known by the name of "majolica," a corruption of the name of the Island of Majorca. This designation has been the cause of much discussion as to whether the Italians received their inspiration from the Moors of Spain or the Arabs of the East. It seems probable that they came under the influence of both.

At Faenza, in the Marches, which has given its name to the French word "faience," from 1487, were manufactured wall tiles; later it became known for its blue decorations on a blue enamel of another shade (berettino), and the presence of red tints in the painting.

At Urbino in the second quarter of the sixteenth century lived many ceramists whose names are worthy to be preserved. Guido Durantino and Francesco da Rovigo before 1545, Orazio Fontana at the end of the sixteenth century, Antonio Patanazzai at the beginning of the seventeenth. At Urbino, reproductions of the pictures of Italian masters, and particularly of Raphael, were first made. Here also were manufactured grotesque pieces, ornaments in relief, salt-cellars, inkstands, and vases fashioned by Battista Franco, and executed by Orazio Fontana, which are considered the masterpieces of the factory in this town.

The most illustrious artist of Pesaro was Gironimo Vasaro, famous for vessels and metallic lustres. The manufacture ceased here at the beginning of the sixteenth century.

Of all the localities of the Duchy of Urbino, Castel-Durante has had the most active manufacture, if not the most artistic. It only ceased at the beginning of the eighteenth century. Its faience ware was distinguished by a large and bold design, a brownish colour, generally with blue or yellow grounds.

Italian ceramists raised themselves to the highest degree of their art, and evinced a professional skill of a high kind in extracting from the materials they employed their fullest worth, but their work after having reached its culminating point in the middle of the sixteenth century declined rapidly, and disappeared almost entirely at the beginning of the seventeenth century.

French Faience.—The use of lead glazes seems to have spread in France during the twelfth century. They were used first of all to cover bricks and paving tiles and later in the manufacture of vases of various shapes. From 1225 a factory for this kind of ware existed at Troyes, another at Pontaillier, near Dijon, and others later at Paris and Saintes. But lead glazes were most used at Beauvais, and in the neighbouring localities of Savignies and La Chapelle-aux-Pots. From the sixteenth century, however, glazed pottery lost its artistic nature, and was only employed for domestic wares. For this purpose the use of glaze has continued till our own day, but this has a tendency to disappear and be replaced by an impermeable body.

The first pieces of faience of purely French origin are those named after Oiron, and were remarkable for the white ivory tint of their very hard body and the lightness and finish of their decoration, whilst their forms resembled those of goldsmiths' work. This remarkable manufacture died out without leaving any trace, and without exercising any influence on the development of French ceramics.

Bernard Palissy settled about 1542 at Saintes (Charante-Inférieure), and there discovered the composition of white enamel, doubtless of Italian origin, patterns of which had come into his possession some years previously. By means of experiments, which were frequently impeded by poverty, he succeeded in producing faience of an original character, which attracted the attention of many great nobles, and particularly that of the High Constable de Montmorency. After many years devoted to ceramic work, in 1562 he established himself at La Rochelle, and afterwards at Paris, where he enjoyed the protection of Catherine de Medici; but after the death of his protectress was imprisoned and died at the age of 80.

According to Blondel, Palissy produced wall tiles, stove tiles, a beautiful example of which can be seen in the old collection of the Comte de Pourtalés, vases decorated in various styles, ewers, vases, cups, salt-cellars, ink-pots, candlesticks, and even statuettes; but his most remarkable works are his "rustic figulines," dishes with ornamentations of fishes, serpents, frogs, crayfish, lizards, shells and plants. They were not made for use, but as show pieces for the sideboards which were at that time greatly in fashion.

Palissy insisted on keeping to himself the secret of his remarkable works. "Thus the art which he had so painfully learnt disappeared almost entirely with him, his immediate successors producing only works of mediocrity, relatively dull, without any ingenuity, and made from old moulds."

It was not till 1602, Conrade Brothers began to manufacture faience at Nevers, following the process which they had learnt to make use of in Italy. The family died out in 1677, but other factories were established at Nevers, the most important being directed by the Custade family.

"The productions of this period," says M. Garnier, "are remarkable for their free and ingenious execution and especially for the beautiful blue often accompanied by maganese."

In 1673 the first manufactory of faience was established at Rouen by Louis Poterat, who created the Rouen style, which takes first rank among French faience, and by many is preferred to the most beautiful productions of Urbino. "These are designs without relief, forming cartouches and scallops, which, being distributed symmetrically over the surface of the pieces, radiate round the centre if it is a dish or plate, but, in the case of vases, descend from the edge and spread over the centre. This kind of decoration is usually in blue on enamel white, but yellow, green and red are met with on these pieces" (Darcel).

The Moustiers factory of faience was founded about 1680 in a small town of the Basses-Alpes by the family of Clérissy, who produced an original decoration very singular in style, and founded a school whose influence was felt in every factory from the South of France to Spain.

The Hannong family, who were very eminent ceramists, founded at Strasburg, in 1709, a factory which remained till about 1790. Contrary to preceding manufacturers, the Hannongs, following the processes used for porcelain, painted their decorations on the fired enamel and not on the raw enamel. M. Garnier says: "The faience wares of Strasburg are distinguished by the beauty and purity of their enamel, by their elegant and fantastic forms, and especially by the vivacity and freedom of their colours, notably purple and carmine".

To these four great centres of French faience ware—Nevers, Rouen, Moustiers, and Strasburg—each of which had its peculiar characteristic, should be added a great number of other manufactories which are more or less connected with them. To cite the best known—Marseilles, Montpellier, Bordeaux, Lunéville, Niderviller, St.-Amand, Sceaux, Lille, Epinal, etc.

The manufacture of stanniferous enamelled faience, which had attained so much splendour for so long a time, began to decline in the eighteenth century. The older were closed and the newer ones were cut out by porcelain and porcelain imitations which emanated either from the factories recently established at Paris and in many parts of the kingdom, or were imported into France through the agency of the East India Company. In addition to this, a new kind of pottery having its origin in England accounted for this in a great measure.

German, Dutch and Other Faience.—Fired bodies covered with lead enamels developed largely in Germany during the close of the Middle Ages, being used for architectural pieces as well as for vases, etc.

Nuremburg was already celebrated for its pottery ware when, in 1503, Hirschvogel, who was sent on a mission to Italy, there learnt the secrets of the manufacture of majolica. In the eighteenth century Nuremburg also manufactured dinner ware, or show pieces usually decorated with loose bouquets; but the finest fire grates date from the sixteenth century, and by the eighteenth century this manufacture had fallen into decay.

Among other German factories of faience, Ansbach (Bavaria) made fairly good imitations of the productions of Rouen; Höchst-on-Main (1720-49) used a decoration which resembles that of porcelain; Frankenthal imitated the wares of Strasburg; and Bayreuth made pieces of services and vases, generally with blue decorations.

Towards 1584 there was founded in the Netherlands an earthenware manufactory, which by the end of the seventeenth century became of considerable importance, both for its output and the artistic value of the ware. Under the strict supervision of the Guild of St. Luke, the Delft productions rendered the name of that town famous. The earlier factories of Delft experienced the same fate as the French ones and disappeared about 1800.

Among the numerous ceramists who contributed to the fortune of Delft were Herman, Adrian and Gerrit Pietersz, Albrecht de Keyzer, Abraham de Kooge, Frederick van Frytom, van Eenhoorn and Augustijn Reygens.

Delft manufactures are divided into three periods. In the first the decoration of an ordinary character is in camaieu blue with dark places, inclining to a violet-brown, showing compositions of several parts. The second is characterized by a notable improvement of the same process, and by a remarkable imitation of Japanese porcelain. In the third period, which dates from the end of the seventeenth century, the manufacture became principally commercial, and a multitude of goods were produced of the most varied kinds, and some perfect imitations of porcelain ware from China, Japan and Saxony.

Amongst other places which, especially in the eighteenth century, possessed factories of stanniferous ware, were Talavera, in Spain, which gave its name to stanniferous faience in its native country; and those of less importance of Alcora and Seville. In Switzerland the factory at Zürich was celebrated chiefly for its stoves, and that of Thun for its decorations by means of drops of various coloured glazes. In Sweden the crockery ware of Rörstrand imitated Marseilles and Strasburg in the matter of decoration, and likewise the porcelain ware of Saxony; that of Marienborg was influenced in its decoration by Strasburg. Factories also existed at Bruges and Liège in Belgium.

English Faience.—The manufacture of lead-glazed pottery and of enamelled ware seems to have been but little developed in England. Faience was imported from Delft, which name was employed to designate all stanniferous pottery, though there existed a factory at Lambeth, on the outskirts of London, founded by the Dutch and those at Burslem in Staffordshire. Hence when, in 1770, Astbury, the son of a Burslem potter, noted by chance the whiteness of a silicious powder used by a veterinary surgeon, it occurred to him to mix this powder with the faience body. The success produced realized his hopes, the body became whiter, was remarkably hard, and lent itself to all kinds of decoration.

Numerous manufactories making use of this discovery were established at Burslem, Hanley, Newport, Leeds, Liverpool, Fulham and Lambeth. Of these, that of Leeds was the most celebrated, and it was not long before its productions were sent all over Europe. The ware was generally of a common kind, but was brought to a high degree of perfection by Josiah Wedgwood, the most celebrated English ceramist, who was born in 1730 at Burslem, and was the son of a potter in this town. After having had several partners, he founded, in 1759, a factory in his native town, where he manufactured pottery with a cream-coloured body, which achieved a considerable success, and being patronized by Queen Charlotte, became known as Queen's ware. Afterwards, associating himself with Thomas Bentley, he devoted his time to the imitation of antique art, and manufactured vases, cameos, medallions, the execution of which was as remarkable as it was careful.

The wares produced by Wedgwood are classified, according to Professor Church, as follows: Cream faience for dinner ware, painted in colour, or printed in black or red, rarely enriched with gold; black pottery ware in the form of vases, medallions, busts, services of various coloured and gilt decorations; red pottery ware for imitating cameos; fine faience of a white body; marbled pottery imitating marble, granite, agate (stoneware); and finally decorated pieces with light relief on a greyish-blue ground in the form of vases, candlesticks, small snuff-boxes, boxes, buttons, and especially bas-relief imitations of the antique, from models by the sculptor Flaxman.

By the end of the eighteenth century the manufacture of the new kind of faience had supplanted stanniferous faience, and at the beginning of the next century it ruled supreme, and all countries of Europe paid tribute to the faience manufactures of Staffordshire.

Stoneware.—The history of the manufacture of stoneware is much shorter and less eventful than that of faience. This kind of pottery was known to the Chinese many centuries before our era. Certain Egyptian pottery can also be included in this category, together with a few specimens of glazed pottery which were manufactured during the Middle Ages, though the regular manufacture of this pottery did not begin in Europe before the fifteenth century, where it was probably first carried on at Raeren, an old Parish of the Duchy of Limburg. About the same time a similar manufacture existed at Frechen near Cologne. The wares of both factories were of a yellowish body, covered with a dark brown glaze; and consist chiefly of vases, jugs with ornamentation in relief representing scenes of hunting, dancing, peasants and Biblical subjects. A stoneware manufactory at Siegburg, opposite Bonn, produced matt stoneware of a slightly greyish body; but it was at Hoehr and Grentzhausen, near Coblentz, that the factories existed whose wares, wrongly known as "Flemish Stoneware," had the widest reputation. The body is greyish or bluish, decorated with blue, violet, or brown enamels, forming a rich ornamentation on forms which are generally elegant.

At the end of the seventeenth century a manufactory also existed at Creussen, not far from Bayreuth, for stoneware with a brown body and black glaze, used for small figures or coats-of-arms in relief, painted in light colours.

In France the manufacture of stoneware was carried on early in the sixteenth century, at Savignies and La Chapelle-aux-Pots, near Beauvais. These wares, of a greyish or bluish body and a uniform blue glaze, enjoyed a wide reputation in the North of France until displaced by faience, after which, towards the end of the seventeenth century, the manufacture was confined to domestic goods.

About 1690, the brothers Elers, of Nuremburg, established themselves at Bradwell in England, and there founded a factory for stoneware of a red body, then of a yellowish-white, with salt glaze. The reputation of their potteries soon became the means of rival factories being established, among which was that of Fulham, founded by John Dwight, who from 1721 manufactured jugs, dishes, goblets, of a brown glaze, decorated in relief, with hunting subjects and grotesque figures.

The manufacture of stoneware made considerable progress in England, due in part to the researches of Josiah Wedgwood, and many manufactories in Staffordshire produced at the same time faience and stoneware; but a new era begins in the manufacture of stoneware in 1819, when Doulton established the works at Lambeth.

Oriental Porcelain.—The earliest manufacture of Chinese porcelain ware dates back to about 200 B.C. It has a greyish body, very slightly translucent, and the glaze is usually crazed.

Under the dynasty of Ting (A.D. 621-945) there was a considerable improvement in the manufacture, the body became whiter, the crazing disappeared, and the glaze, though generally of a greyish-green, is sometimes blue. This progress continued under the following dynasty, the body becoming fine and translucent, yellow and green colourings being added to the blue. From this period (A.D. 945 to 1368) also date the first "flammes," and the famous development of Nanking pottery.

Under the double dynasty of the Ming (1368-1488 and 1488-1643) Chinese pottery acquired the qualities which have rendered it famous. The style of decoration is sober, the colouring pure, and the forms often elegant. Under the Chinthe-Khang-Hu (1643-1662) and the Yung-Thing dynasties (1662-1736) pink, red, and violet colourings were adopted.

Since the dynasty of Kieng-Long (1736) Chinese porcelain has maintained its present familiar appearance. The decoration, composed chiefly of figures, has become more and more exaggerated and the gilding, which was at first used in moderation, has ended by overrunning the whole of the decoration. Chinese pottery artists delight in the most extraordinary exhibitions of skill, and art is compelled to give place to cheap commercial productions.

In China the manufacture of porcelain has always been confined, almost exclusively, to the provinces of Kiang-Si, Canton being the place of export.

The Japanese annals relegate the origin of Japanese porcelain to the first century B.C., but manufacture only began in the beginning of the seventeenth century, and it is only towards the middle of the nineteenth century that Japanese art has obtained a notable amount of independence. The body appears to be whiter and more translucent, and the decoration more careful and less heavy in style than that of Chinese work.

The first pieces of Chinese porcelain which came to Europe were brought by the Arabs in the twelfth century, but their place of origin was unknown until the Venetian Marco Polo's voyage to the extreme East, in 1295, and Chinese porcelain was only brought regularly to the European markets during the fourteenth century.

European Porcelain.—Throughout the seventeenth century strenuous efforts were made to reproduce Chinese porcelain, but without success, because nothing was known of the raw material (kaolin) which Nature had placed so liberally at the disposal of the Chinese, but in 1709 Böttcher, assisted by the advice of Tschirnhaus, succeeded in manufacturing porcelain in the Castle of Frederick Augustus II at Meissen, Saxony.

In spite of the extraordinary means employed at Meissen to guard the secret of the new manufacture, a foreman, Stöpzel, succeeded in escaping and founded a factory of porcelain at Vienna, in Austria, and was in his turn betrayed in 1740 by a workman named Ringler, who sold the process to the celebrated manufacturer of faience of Höchst-on-Main. After many years' sojourn at Höchst, Ringler joined Hannong of Strasburg, and in 1775 founded the factory for porcelain at Frankenthal; then those at Nymphenburg, near Munich (1756), and at Larisburg, near Stuttgart (1758). Ringler's recipes were stolen by several of his workpeople and sold throughout Europe at very high prices, with the result that factories were founded at Doccia, near

Florence, Berlin (1750), St. Petersburg (1772), Copenhagen (1773), Rübensgrün, in Bohemia (1790), etc. The porcelain factories of Thuringia, Sitzerode, Volkstedt, Limbach, etc., the earliest date of which is 1762, were founded by the chemist Macheleidt, who appears to have independently discovered the manufacture of hard porcelain.

The researches undertaken throughout Europe to manufacture china proved fruitless through want of kaolin, but resulted in the manufacture of a new kind of pottery—soft porcelain, a material somewhat resembling glass—in 1693 by Chicaneau. Another manufactory of the same kind existed at Lille from 1708 to 1720. In 1735 factories of soft porcelain were established at Chantilly and Mennecy, near Essonne, and later, those of Sceaux, Tournay, Strasburg, St. Armand, Arras, and Vincennes.

In 1745, the last named was purchased by Louis XV, who transported it to Sèvres in 1756.

Notwithstanding the considerable progress which the manufacture of French soft porcelain made, the Sèvres factory, in 1761, purchased the secret of the manufacture of hard porcelain from Hannong of Strasburg, who had recently become the proprietor of the celebrated porcelain manufactory of Frankenthal. The first trials were only made in 1765 at Bagnolet by Guettard, who had just discovered near Alençon a bed of rather impure kaolin, but the product was grey and of a poor quality.

About the year 1765 Mme. Darnet, the wife of a surgeon at St.-Yrieix, by chance discovered the famous kaolin beds situated near this town, and so caused the total abandonment of soft porcelain, and assured the supremacy of hard porcelain in France.

In England a kind of soft porcelain was made about 1745 at Chelsea, but the first regular manufacture of English soft porcelain, in 1751, is due to Chaffers of Liverpool, who used phosphate of lime as a flux. The discovery of the vast Cornish beds of kaolin, in 1768, improved the manufacture which was introduced into Staffordshire in 1772, and while in France the discovery of kaolin had induced the abandonment of soft porcelain, the latter continued to be manufactured in England to the exclusion of hard porcelain.

Modern Ceramics.—This brief summary of ceramics brings us to the beginning of the nineteenth century, to which belonged the task of uniting the different branches of the ceramic art, of substituting for tradition and the secrets of manufacture the principles of science, of transforming the craft into an industry, and of placing the privilege of a few at the disposal of all.

At the beginning of the nineteenth century the terra-cotta employed in building had not made any marked process since the beginning of the fifth century, and its manufacture was carried on according to the traditions left by the Romans, who only employed it concurrently with stones, nearly always covering the pieces with glaze, and only very rarely making use of them for decorative purposes. But from the beginning of the Renaissance the position of terra-cotta became less subordinate; so that, whilst framework and decoration were always done in stone, in the smooth parts of the walls, bricks were left to show their natural colour.

In the North of France, the Netherlands, England, Germany and the United States, stone is often excluded, and terra-cotta, without any glaze, used entirely for the building and decoration, and whilst stone will remain one of the necessary elements in building, the use of ornamental bricks will spread more and more.

In iron-construction, which dates from the middle of the nineteenth century, and which had its origin in France, terra-cotta is called upon to play an important part, serving the purpose of filling the metallic skeleton, and of a decorative element in the same way as faience, stoneware, or porcelain.

The employment of mechanical presses, and of kilns fired at a more elevated temperature, have for the last forty years greatly improved the quality of solid bricks, particularly in Germany. The ornamental bricks now made in that country have a power of resistance, accuracy of form, and uniformity of colouring, which have never been excelled and seldom equalled. Hollow bricks were known long ago but were not used because of the difficulty of their manufacture, until Borie in 1885 invented a tool which has been the starting-point of their popularity. Simultaneously, roofing tiles, in the South of France especially, have attained a hardness and beauty of appearance which they never possessed in the preceding centuries.

The manufacture of drainage pipes, which have rendered such important service to agriculture, originated in England at the end of the eighteenth century, but it is only in the first half of the nineteenth that their use spread into Europe. The use of terra-cotta for domestic purposes tends, on the other hand, to diminish before the competition which is created by faience and porcelain. In spite of the imitations, made during the nineteenth century, of the beautiful decorative pottery of the Greeks, these tend to be confined to flower vases, and to a reproduction of statues, which, from an artistic point of view, leave much to be desired.

Refractory ware is an invention of the nineteenth century, during which scientific knowledge of the properties of raw materials and the accuracy attainable in the mixings, have created an industry which has rendered progress in metallurgy and the chemical arts possible. This industry originated in England, and spread into Belgium, France, Germany, and the United States—to mention only the chief manufacturing countries—but it is chiefly to Germany that the scientific researches into the properties of refractory materials at high temperatures are due.

At the beginning of the nineteenth century, faience manufactures were only carried on in England, where according to the processes of Wedgwood, faience of a hard body, concealing itself under the names, at that time much in fashion, of "iron stone" and "opaque porcelain," was manufactured. The great success of this kind of pottery at the beginning of the century was the cause of the establishment of similar faience factories in France, Germany, Belgium, Holland, Sweden, Denmark, and more recently in Spain, Russia, Italy, and the United States, but it was not until the second half of the century that this manufacture assumed any considerable importance on the Continent, being localized in several large factories. The English manufacture became concentrated in the Potteries (Staffordshire). The production of this ware, which is of considerable importance, has thus been preserved, and is the means of an active export trade.

European factories have, by successive improvements, notably increased the hardness and solidity of their wares, and have found out, by means of clever decoration, how to conceal the defective whiteness of the body.

More recently, several faience manufacturers have entered upon the manufacture of architectural decoration and wall tiles, thus forming means for the exterior and interior ornamentation of domestic and other buildings.

Stanniferous faience, which was in a state of decay at the beginning of the nineteenth century, has again been manufactured during the last sixty years. Its applications were at first confined to the manufacture of stoves; afterwards to imitations of old Moresque, Italian, French and Dutch faience, and finally in architectural decoration in combination with terra-cotta.

It was also reserved to Deck in the nineteenth century to revive the ancient Persian faience of a silicious body and transparent alkaline glaze, which owing to the brilliance and richness of its colours, is certainly the most beautiful which ceramic art has produced.

The manufacture of stoneware took refuge in England at the end of the eighteenth century; it was carried on extensively, and attained to an extraordinary degree of perfection, thanks chiefly to Doulton & Co., whose name is still connected with that kind of pottery. For the last fifty years factories have also increased in other parts of Europe and in the United States. At the present time artistic stoneware, manufactured principally in England, France, Japan, Germany, Belgium and the United States, enjoys extraordinary favour.

Stoneware has still another application, less brilliant but probably more lasting, in drain pipes and sanitary apparatus, thus making ceramics an indispensable auxiliary to the science of hygiene. Moreover, its use has become considerable in factories of chemical products, owing to its resistance to acids. Finally, it has caused the establishment of important works for the manufacture of paving tiles.

The manufacture of hard porcelain has continued to develop during the course of the century, the greatest centres of production being Limousin in France; Saxony and Silesia in Germany and Bohemia. Besides being used for dinner-ware and decorative pieces, it is also employed in laboratories, and, owing to its non-conductibility, in electric installations. Some applications of it have also been made to architectural decoration. The high temperature of the firing of its glaze, which greatly limits the number of the colours which can be used, has instituted a search for a more fusible composition in order to facilitate decoration. Some successful attempts in this direction have been made at the manufactories of Sèvres and Berlin.

The old soft porcelain, abandoned by the French at the end of the eighteenth century, is no longer the object of a regular manufacture, though English soft porcelain continues to be largely manufactured in Staffordshire, where it is, like faience, of great importance. During the last sixty years a new kind of porcelain, usually without glaze and resembling stoneware, has been made in several varieties known as Parian and Carrara.

Porcelain buttons are the monopoly of a few factories.

In spite of the progress already made, the final stage of development of ceramics has not yet been reached. In certain of its applications it seems to have arrived near perfection, but in others much still remains to be done, and the progress of other industries will give rise to new applications. Finally, there still exist many cases in which pottery could with advantage replace the materials now employed, on account of its indestructibility or the brilliance of its decoration.

CHAPTER III.

RAW MATERIALS OF BODIES.

1. CLAYS.

(a) *Pure Clay.*

IN ceramics under the general name of "clays" are included all the rocks or natural earth which, after mixing with water, form a plastic body, hardening under the influence of heat (see page 1). They owe these properties chiefly to hydrosilicate of alumina, which enters into their composition in varying proportions. Silica, alumina, and water form various combinations, but the one which, in the constitution of clays, plays quite the chief part is hydrated silicate of alumina represented by the chemical formula—

$$Al_2O_3,\ 2SiO_2,\ 2H_2O,$$

designated under the name of kaolinite in mineralogy, and pure clay in ceramics. Other hydrosilicates of alumina which can enter into the composition of clays must be considered under the same head as those other substances which mixed with "pure clay"[1] form numerous varieties of natural clays. Pure clay is formed, therefore, by 1 molecule of alumina, 2 of silica, and 2 of water, the corresponding weight in percentages being 39·77 per cent alumina, 46·33 per cent silica, and 13·90 per cent water. In a moist atmosphere, pure clay absorbs a certain further quantity of water, varying from 3 to 9 per cent, according to the hygrometric condition and size of the molecules.

It has not yet been possible to obtain pure clay synthetically, that is to say, by direct combination of its elements, alumina, silica and water.

When pure clay is heated sufficiently all hygroscopic water is eliminated at a temperature slightly higher than 100° C.; the "combined water" in the clay is first liberated at about 350° to 400° C. and continues slowly up to about 650° to 700° C. At this last temperature the hydrosilicate of alumina is completely destroyed, all its water has been eliminated, and the material remaining is composed of 46·19 per cent aluminium, and 53·81 per cent silica. It is, therefore, impossible

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[[1] No entirely satisfactory definition of "pure clay" exists, and the use of this phrase must be understood to refer to a hypothetical rather than to an actual substance, as the clays which correspond most closely to the formula given are deficient in plasticity.—A. B. S.]

to reconstitute the original hydrated compounds or to restore the plastic qualities of pure clay to this heated material.

If the temperature is raised to 700° or 800° C., the silica and alumina begin to form a new anhydrous silicate of alumina, the combination appearing to be complete between 1100° and 1200° C. Towards 1500° C. the first symptoms of vitrification appear, the mass grows soft, and ends by losing its shape and fusing.

The alkalies, soda and potash, in the clay on prolonged firing, attack the hydrosilicate of alumina and transform it into double silicates of potash or soda and alumina.

Dilute acids have no influence on pure clay, but in a concentrated form hydrochloric acid and sulphuric acid displace silica from its combination at a temperature of 250° to 300° C. They act in the same way, but more slowly, on anhydrous silicate of alumina.

The two physical properties characteristic of pure clay on which ceramic arts and industries are based are *plasticity*, which is obtained by mixing clay with water, and its *hardening*, under the influence of heat.

If an increasing proportion of additional water is added to a dry clay powder, that is a clay containing only hygroscopic water, a body is obtained which is more and more plastic until the quantity of water added is so large that the body becomes fluid, when the plasticity diminishes until it disappears.

For a long time the causes of this plasticity were unknown, but the recent researches of Johnson and Blake, and especially those of Bidermann and Herzfeld, have confirmed the view that it must be attributed to the extreme fineness and to the laminated forms of the grains of pure clay. Certain clays having exactly the same chemical composition can yet differ considerably from the point of view of plasticity. Microscopic examination has shown that these differences correspond to the variation in size of the grains of hydrosilicate of alumina, the plasticity becoming greater and greater in proportion as the volume of the grains diminish. Moreover, this property is not peculiar to clay, for all minerals, if reduced to a sufficiently impalpable power, by the addition of a liquid, produce bodies having a certain amount of plasticity. The fact is clearly explained by the molecular attraction which can only be obtained when the molecules are extremely close together, and the particles are consequently very minute.

The much greater plasticity of clay than other pulverulent minerals, proceeds from the fact that pure clay is in the form of lamellar crystals entangled with one another, so that the grains are closer together than if they were polyhedral or spherical, and this is equivalent to increasing their attraction to each other in a strong degree.[1]

The plasticity, instead of being a special property, is simply the result of molecular attraction, and all bodies which are made up of

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[[1] A more recent theory which is rapidly becoming popular accounts for the plasticity of clay by placing it amongst the *colloids* or amorphous substances. This opens up an enormous field for investigation and explains several properties of clay not previously understood.—A. B. S.]

laminated particles must become plastic when they are reduced to a sufficiently impalpable powder. This deduction has been verified by M. Vogt as regards mica, which is made up of thin layers, very laminated, and when reduced to the form of an impalpable powder, and water is added, a body having a plasticity which can be compared with that of clay is obtained.

From this it can easily be understood what happens when water is added to pure clay in the form of a dry powder. In the latter the crystals are mingled in all directions and have the maximum amount of space between them. By the addition of a sufficient quantity of water, the molecules of which take their place between the grains of clay, the latter are enabled to change their places to obey molecular attraction, and to move parallel to each other. This grouping is evidently assisted by the manual or mechanical kneading of the body, which fact explains the increase of plasticity which is observed every time a clayey body is subjected to mechanical treatment of a mixing nature.

It is also clear that if a certain quantity of water is necessary to allow the grains to become displaced, and consequently to give plasticity to the body, an excess of water by driving the grains further away diminishes their attraction, and at a certain limit ends by destroying it entirely.[1]

By mixing liquids other than water with clay powder, very different degrees of plasticity are obtained. Fatty liquids, such as oils, seem to make a more plastic body than water, especially if the clay has previously been dried to take away from it the hygroscopic water. On the other hand alcohol, ether and essence of turpentine produce bodies with little or no plasticity. On mixing a clay body with glycerine and water, the water becomes gradually absorbed by the glycerine, the clay loses its plasticity and becomes pulverulent.

If a clay body mixed with water is left in a dry atmosphere, the water evaporates in a progressive manner. As long as the body preserves a sufficient plasticity, the departure of the water results in the grains of clay coming closer together in the proportion of the volume of water taken away. This diminution in volume of the clayey body during the drying is known as "shrinking". When there is no longer sufficient water to allow the grains of clay to become displaced, the shrinking ceases and the evaporation of the last portions of water induces the formation of voids in the interior of the mass.

The dry body, thus obtained, no longer resembles the original powder; it forms a harder mass of a greater density, the displacement and rearrangement of the grains of clays parallel to each other, as well as the shrinkage during drying, having sufficiently drawn the grains together to allow the molecular attraction to continue after the departure of water in spite of the voids formed. This is not the case with other mineral powders, which do not possess the lamellar form of clay, and these, after having acquired a certain amount of plasticity

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[[1] Modern ceramists do not accept this explanation as being complete, but regard plasticity as far more complex than Bourry suggests.—A. B. S.]

by their mixture with a liquid, fall into powder when the liquid disappears.

A second shrinkage results during the firing, the silicate of alumina then formed being a hard amorphous body which constitutes the essential element of all ceramic products.

Formation of Pure Clay.—According to the ordinary theory, pure clay is the result of the decomposition, under the influence of water and carbonic acid, of certain eruptive silico-aluminous rocks, the composition of which can be represented by the general formula—

$$Al_2O_3,\ RO,\ nSiO_2,$$

Al_2O_3 representing the alumina, sometimes mixed with a small quantity of ferric oxide (Fe_2O_3), or rarely of manganese oxide (Mn_2O_3); RO can be potash, soda, lime or ferrous oxide (FeO), these bodies being generally mixed, but one of them always being in a preponderating proportion; finally $nSiO_2$ represents a variable content of silica.

The decomposition which takes place may be represented by the general formula—

$$\underbrace{Al_2O_3,\ RO,\ nSiO_2}_{\text{(silico-aluminous rock)}} + \underbrace{2H_2O}_{\text{(water)}} = \underbrace{Al_2O_3,\ 2SiO_2,\ 2H_2O}_{\text{(clay)}} + \underbrace{RO\ (n-2)\ SiO_2}_{\text{(silicate)}}$$

The silicate RO $(n-2)$ SiO_2 is generally partly soluble, so that after exposure to rain there only remains clay mixed with the RO insoluble bases and a certain quantity of free silica.

Among the silico-aluminous rocks, which produce clays, the most important are felspathic rocks, granites, porphyry, gneiss, eurites, mixtures of felspar with quartz, and sometimes with mica. Felspar itself is an anhydrous silicate of alumina and of alkalies (potash and soda). There are several varieties of felspar, the two principal of which are orthoclase with a base of potash, and albite with a base of soda.

The chemical formula of orthoclase is $K_2O,\ Al_2O_3,\ 6SiO_2$, or $K_2Al_2Si_6O_{16}$, corresponding to 65·4 per cent of silica, 18 per cent of alumina, and 16·6 per cent of potash.

The formula for albite is $Na_2O,\ Al_2O_3,\ 6SiO_2$, or $Na_2Al_2Si_6O_{16}$, or 68·57 per cent of silica, 19·62 per cent of alumina, and 11·81 per cent of soda. These two kinds of felspar are sometimes found mixed together.

In applying the preceding general formula to orthoclase it may be seen that decomposition might take place after the following manner:—

$$\underbrace{Al_2O_3,\ K_2O,\ 6SiO_2}_{\text{(felspar)}} + \underbrace{2H_2O}_{\text{(water)}} = \underbrace{Al_2O_3,\ 2SiO_2,\ 2H_2O}_{\text{(clay)}} + \underbrace{K_2O,\ 4SiO_2}_{\text{(potassium silicate)}}$$

Some chemists do not admit the formation of a substance with the formula $K_2O,\ 4SiO_2$ for an alkaline silicate the second result of the decomposition of the felspar, but state that the substance produced has the formula $K_2O,\ 3SiO_2$, the fourth equivalent of silica being found in the free state, so that it can either remain mixed with the clay, or be taken away by water at the same time as the alkalies.

This theory of the formation of pure clay by the decomposition of felspathic rocks is confirmed by numerous examples of rocks, the decomposition of which continues to take place at the present time.

When these latter rocks contain lime, carbonate of lime is also found and is carried away by the water and is then deposited in sedimentary beds, forming numerous calcareous beds, occasionally of considerable thickness, as widely distributed as those of clay. The important part which the decomposition of felspar plays in the formation of sedimentary beds can be estimated by observing that nearly three-fourths of the known surface of the earth is formed of gneiss and granite containing 60 to 90 per cent of felspar.

The variations in the composition of these rocks, as well as in the circumstances of the decomposition, also explain the formation of other hydrated silicates of alumina—halloysite, lenzenite, severite—having the same composition as kaolinite; allophane, which apparently corresponds to the formula SiO_2, Al_2O_3, nH_2O, pyrophillite, the composition of which is $5SiO_2$, Al_2O_3, H_2O, and hydrated silicate of alumina, probably $4SiO_2$, Al_2O_3, nH_2O, which is found in calcareous marls. It is also possible, as some geologists suppose, that some of these rocks may be distinct eruptive productions.

(*b*) *Natural Clays.*

Formation of Natural Clays.—In some clay beds, clay is found mixed with the debris of the rocks which have produced it; in others the clay instead of remaining intact in its original place, has been displaced by currents of water and carried to a short distance, where it forms sedimentary beds, more or less polluted by the impurities also carried along by the water; this, the *first phase* of the formation of relatively pure clays, being characterized by the decomposition of silico-aluminous rocks, and the deposition of the substances thus formed on, or at a short distance from, the place of formation. [These are termed *primary* clays. When pure they are termed kaolin, a name originally given by the Chinese (see page 30).]

The differences in the composition of the original rocks, as well as in the foreign matters which are found mixed with them, explain the considerable variations which are observable in the composition of primary clays, but these have properties by which they are easily recognized, especially when the pure clay can be separated by grinding and decantation. Clay obtained by this means is a whitish powder usually tinted yellow, light red, or grey, soft to the touch and slightly granulated, which, by the addition of water, forms a plastic body, emitting a characteristic earthy smell. Under the microscope it appears to be formed of thin flat crystals of kaolinite, mixed with a variable quantity of amorphous particles and debris of other rocks.

If the clay, instead of being simply displaced, is carried rapidly away by streams, or if some existing beds are invaded by water, those materials which are loosened and held in suspension are taken along; jostled, tossed, pommelled amongst the pebbles, and end by being pulverized and transformed into impalpable mud, which is deposited in the mouths of the stream of water, or in parts where the speed of the water is reduced after having left the heaviest rocks on the way.

Sometimes when these currents of water have hollowed their beds in the midst of rocks which are too hard to be sensibly affected by their course, the materials in suspension have remained free from any mixture, and on deposition have formed beds of almost pure plastic clay or china clay. But in the majority of cases the torrents traverse sandy, calcareous, or ferruginous ground, or have mingled with water containing mud of various compositions or vegetable debris. When still water is reached these materials held in suspension are deposited simultaneously, forming beds of very varied composition, superposed by layers which also differ among themselves according to the circumstances attending the passage of the water. In this manner are formed sandy, ferruginous, calcareous, peaty, and other secondary clays.

The formation of deposits of (secondary) plastic clay is not easy to study, though there are always impure clays being deposited at the mouths of certain rivers, in lakes or in the sea.

This *second stage* of the formation of clays is characterized by the mechanical pulverization of the kaolin, or clay rock, and the deposition of clays of the most diverse properties at a great distance from the place of original formation.

In this second phase, the hydrosilicate of alumina, under the influence of mechanical pulverization in the midst of the water, undergoes important modifications. Under the microscope, the crystalline structure is no longer visible and the material is composed almost exclusively of impalpable grains, very unctuous to the touch, and variable in colour. On the addition of water a very plastic and flexible body results, and this property easily enables clays to be recognized and distinguished from other minerals.

Materials Mixed with Clays.—The materials which, mixed with pure clay, form the numerous natural clays, can be classed under three divisions:—

(1) Undecomposed rocks, such as granite, porphyry, gneiss, quartz and mica.

(2) Other decomposition-products, as the carbonates of lime, magnesia and iron, oxide of iron, etc.

(3) Materials introduced by streams and deposited at the same time as the clay.

But it is preferable from a ceramic point of view, to substitute the following classification, based on the physical condition of the materials mixed with the clays:—

(1) Materials in impalpable grains which form an integral part of the clay, and which it is impossible to separate from it by simple washing; silicates of alumina, mica, hydrated and quartzy silica, carbonates of lime, magnesia, oxides and sulphates of iron, organic matters.

(2) Materials in the form of more or less fine grains spread through the clay with a fair degree of uniformity, but inseparable by slight washing: quartz, mica, felspar, carbonates or sulphates of lime or of magnesia.

(3) Materials of varied form disseminated irregularly in the clay, separable by washing or often even by sifting. These chiefly consist

of accidental impurities: stones, shells, gypsum, sulphur, and iron ore.

Materials not Separable by Washing.—*Silicates of Alumina.*—The silicates of alumina which can be found mixed with pure clay are very difficult to recognize, because there is no method by which they can be separated. Le Chatelier sought to distinguish them by the temperature to which they must be brought to induce their dehydration.

These researches are not of immediate practical importance, as the presence of other silicates of alumina in pure clay does not appreciably modify its plasticity, and on heating they give place to a mixture of alumina and silica, the exact proportion of which may be ascertained by analysis.

[Later observers question the truth of this statement.—A. B. S.]

Felspar and Mica.—It was at one time thought that the alkalies contained in clays were found exclusively in the state of impalpably powdered felspar, but Vogt has shown that this opinion is erroneous, and that they also exist in clays in a state of pulverulent mica.[1] He has proved that mica in coarse grains is not appreciably attacked by concentrated sulphuric acid, but it becomes so when reduced to an impalpable powder, so that when a clay is acted upon by this acid, it and the mica are dissolved and are separated from the felspar and quartz. This distinction is somewhat important, since the pulverulent mica is plastic, whereas the felspar powder is not.

The variety of mica occurring in clays is chiefly a potassic mica, known as "muscovite".

Silica.—This occurs mixed with clay, either in the form of amorphous hydrated silica or as quartz or crystalline silica. The presence of hydrated silica in certain clays is not absolutely proved; it is usually found in very small proportions, has little or no influence on the plasticity and decomposes to form amorphous silica at a temperature just above 100° C. Quartz or crystalline silica, on the contrary, is nearly always the result of the pulverization of the quartzose rocks. The coarser parts may be removed by washing or sifting, but some are so small that it is commercially impossible to separate them by this process; such silica is a non-plastic material.

Carbonate of Lime or of Magnesia.—Carbonate of lime mixed with clay may proceed from the decomposition and pulverization of limestone, or it may be deposited by water holding carbonate of lime in solution. Primary clays or kaolins do not usually extract more than 2 per cent of carbonate of lime from such solutions, but secondary plastic clays can absorb 10 to 20 per cent of it. Carbonate of lime diminishes the plasticity, though in a less proportion than quartz. Carbonate of magnesia is less frequently met with in clays; it proceeds from the destruction of magnesia rocks, and acts in many ways like carbonate of lime.

[[1] In 1910 the majority of British and German experts consider that the alkalies occurring in clays are in the form of felspar, whilst those of France maintain that they exist as mica. The truth is probably to be found in the suggestion that in some clays they exist as felspar, in others as mica, and in others again in both forms.—A. B. S.]

When these substances occur in grains of an appreciable size they are very injurious and render many clays unfit for use. During firing they become transformed into caustic oxides, which on cooling, increase in volume by absorbing moisture and cause pottery containing them to split. Carbonates are easily recognized by the effervescence which they produce on coming into contact with acids.

Iron Compounds.—These are found in clays, as anhydrous ferric oxide, or as hydrated ferric oxide and ferrous carbonate. They are obtained from the decomposition of ferruginous rocks, either by direct admixture or by penetrating into the clay in solution, in combination with organic acids, such as "humus". The carbonate of iron can only exist in clay free from contact with air; otherwise it is transformed into hydrated ferric oxide, the form in which it is chiefly found. The various compounds of iron colour the clay with different tints, which are transformed into yellow or red, the colour varying with the temperature to which the material is heated.

The compounds of iron do not appear to diminish the plasticity of the clay, and they increase its cohesion after firing. Some clays contain 2 per cent or more of these substances. Beds of ferruginous clay may be deprived, entirely or in part, of the iron compounds they contain, if they are for centuries washed by waters, coming down from the mountains or turfy deposits and containing organic acids in solution. This is the case, for instance, with the white clays of Vallendar, near Coblentz, and of Grossalmerode, in the Palatinate.

Sulphides of Iron.—Sulphides of iron appear to be formed in beds of clay by the action, on carbonate of iron, of sulphuretted hydrogen, which is evolved from organic materials in decomposition. These sulphides may be disseminated in the clay, but are usually found in groups or nodules.

Organic Materials.—Organic matter contained in clays may be derived from:—

(1) Infiltration of soil suspended in water into the bed of clay.

(2) The deposition of the clay in an estuary or marsh containing vegetable matter.

(3) Various bituminous rocks which become mixed with the clay.

In the first and third cases the proportion of organic matter is not usually large, but in the second it may become so. Generally speaking, organic substances tend to increase the plasticity, and greatly increase the quantity of water which the clay can absorb, and consequently its shrinkage. They are decomposed at a temperature below red heat and the carbon which remains is burnt off during the firing.

Various.—The presence of naturally occurring hydrate of alumina in clays has not been proved, and it is probable that the excess of alumina which has sometimes been found is due to some silicates richer in alumina than kaolinite.

Clays sometimes contain, though in very small proportions, sulphate of lime, baryta, phosphoric acid, fluorine, and some metallic sulphides. On rare occasions, and then in very small quantities, compounds of titanium, vanadium, molybdenum, copper, chromium, and some gold (metal) occur. Forbes found 0·62 per cent of titanic acid in a red clay, and Seger attributes to vanadic and molybdic acids the yellow and green tints observed on some pieces of terra-cotta manufactured from clays in the North of Germany. The clays forming the soil of the town of Philadelphia contain about one-millionth of their weight of gold.

Materials Separable by Washing.—*Felspar.*—This only occurs in considerable quantity in primitive clays, in particles of laminated form which can be scratched by quartz. Felspar fuses at porcelain heat, forming a milky glass. It is rich in potash and soda.

Quartz.—When this is in sufficiently fine grains it is a most excellent, non-plastic material. It mixes very well with clay, and reduces the plasticity and shrinkage, and thus assists the drying and firing. Its grains are either rounded, or broken irregularly, very hard, slightly transparent, and infusible at porcelain heat.

Mica.—This is found in the form of brilliant spangles, very small and flat, remaining for a long time held in suspension in water. It introduces alkalies into the clay in a small proportion. It acts as a non-plastic material, and its laminated form disunites the clay and destroys the cohesion.

Coarser Impurities.—The coarser impurities sometimes found in clays, introduced accidentally or irregularly dispersed, are not as a rule mentioned in analyses, as they are often picked out during the sampling. In preparing clays for use, such impurities may be removed by hand-picking, or, if unimportant, may be crushed to powder along with the clay.

Quartz or calcareous *stones* and flints are easily separated either by hand or by suitable machines.

Shells, of which the calcium carbonate is very objectionable, contaminate many clays and shales; they can only be removed by washing and then with difficulty. Sometimes there remains no more than the impression of the shell, the carbonate of lime being disseminated through the clay.

Gypsium is sometimes found in crystals of fairly large size, and in lumps which are easily separated.

Iron Sulphides, which are formed in the clay, do not remain dispersed, but become agglomerated in the form of nodules or brilliant crystals of a fairly pronounced yellow colour, with a metallic lustre. When these are large they are easily removed, when they are small and numerous they are difficult to separate. For coarse products they may often be left in the clay, though the sulphur is volatilized in the kiln and the oxide of iron left causes the materials around it to fuse, thus forming cavities, and a blackish slag.

Iron Ore, red hematite, and yellow limonite, are fairly frequent in plastic clays. The large pieces are easily separable; the others may act like sulphide of iron or may simply stain the clay a red colour.

Classification of Clays.—The same difficulties are met with in the classification of clays as have been noted in the classification of pottery. The varieties of clays are extremely numerous, forming a continuous series from "pure clay" itself, to the very complex materials into which pure clay only enters in a small proportion and about which there is some hesitation in classifying them under the head of clays at all. As in the case of ware, it is expedient to avoid making hard and fast lines of demarcation, and to be content with mentioning the principal types without being concerned with the exceptions.

For these reasons, a classification of clays based on their geological formation, however interesting it may be from a scientific point of view, has no value to potters, and it is therefore convenient to consider clays in the state in which they are found and not the conditions of their formation.

Clays can be divided into two classes, primary clays or kaolins, and secondary clays; this distinction being based on the physical properties of hydrosilicate of alumina. In primary clays the grains of pure clay, being relatively less fine, are less plastic, lighter and of a less unctuous touch than in secondary clays. The mere appearance and touch are usually sufficient for a ceramist to distinguish a primary from a secondary clay.

Clays are distinguished by the nature and contents of foreign substances mixed with the hydrosilicate of alumina. From this point of view there is occasion only to consider five substances: silica, whose chief action consists in diminishing plasticity; and four others—alkalies, oxides of iron, lime and magnesia, which, with the possible exception of ferric oxide, increase the fusibility.

Other substances occur in proportions too small to considerably modify the properties of clays sufficient to make it worth while to include them in a general classification.

The varieties of secondary, or plastic clays being very extensive they may be divided into three classes:—

1. Refractory clays,
2. Vitrifiable clays,
3. Fusible clays,

which, as their names indicate, are distinguished by the manner in which the clays resist the action of heat.

Kaolins.[1]—Kaolins or china clays are chiefly found in the form of lumps in the midst of pegmatites, gneiss, granites, porphyry and other rocks. More rarely they are found in sedimentary deposits. It is only exceptionally that they can be used in their natural state, because of the rocky materials, often containing iron compounds, which are mingled with them. A careful sorting by hand is usually necessary, and this is followed by a process of washing, so that the natural products are not usually employed in the manufacture of pottery.

[[1] Bourry and many other writers use the term "kaolin" in a general sense to indicate all comparatively pure clays, especially if they are but slightly plastic. China clay when refined is a typical kaolin in this sense. There are several objections to this use of the word, as it really indicates the place of origin and not the material (*kao-lin*=a high hill); and the terms "primary clay," for general use, and "china clay," for certain varieties, are more satisfactory, and these have been used where possible.—A. B. S.]

The principal kinds of china clay are the following:—

Pure China Clays do not contain more than 5 or 6 per cent of silica and 2 per cent of fluxes. They are always brought to this degree of purity by washing, and are sold in the form of a white powder, occasionally tinted faintly with yellow or red, and unctuous to the touch. After firing they form a body of milky whiteness.

They are used in the manufacture of porcelain and fine faience.

Alkaline China Clays.—The only difference between these and the preceding ones is a higher proportion of alkalies derived from felspar and mica which can reach 5 per cent. The proportion of oxide of iron is sometimes 2 per cent.

These clays are used for earthenware and fine pottery. They can be purified by very careful washing, which removes the greater part of the alkalies.

Silicious China Clays.—In these clays the hydrosilicate of alumina (true clay) is mixed with a considerable proportion of quartz or free silica, in the state of impalpable powder. The proportion of silica present depends greatly on the care bestowed in the washing. It may reach 20 or 25 per cent. These silicious china clays furnish a body of small plasticity, and are of a light granular texture; they are used in the manufacture of porcelain and certain kinds of faience, where a very plastic body is not required.

Alkaline Silicious China Clays.—Contain at the same time a considerable proportion of both alkalies and silica, and partake of the properties and uses of the two preceding kinds.

Ferruginous Primary Clays.—These clays contain a quantity of oxide of iron which is so large as to prevent an entirely white body being produced on firing, the iron acting as a staining agent.

When the proportion of iron is not too high these clays are utilized in the manufacture of porcelain and faience of inferior quality. Those having a greater proportion of iron can be used in the manufacture of refractory products, if they do not contain too much alkali.

The chief beds of china clays in *England* are at St. Austell (Cornwall) and at Wareham (Dorset).

Refractory Clays.—Are distinguished by a dull appearance without a sign of vitrification, which they preserve when fired at hard porcelain heat (1350° C.). [Since Bourry's time it has been customary in Germany and more recently in Great Britain to consider as refractory all clays which when made into the shape of Seger cones do not bend when heated to a temperature below 1650° C.—A. B. S.]

They can be divided into three classes:—

Pure Clays.—In which hydrosilicate of alumina is found mixed with only a few per cent of silica and some traces of fluxes. These clays are greyish-white, very unctuous, plastic in a high degree, producing, after firing, a body of fine "matt" white. Those found on the market have generally been washed; they are used for the manufacture of faience and certain kinds of porcelain. The beds of these are, relatively speaking, rare, and the variations in composition which are met with in the same deposit necessitate a careful sorting.

Many china clays may be included in this class of pure refractory clays.

Refractory Plastic Clays.—These are distinguished from the preceding by a slightly higher proportion of fluxes. The proportion of free silica can reach 20 per cent [or 57 per cent of total silica]. They have usually a grey or yellow tint and are rarely dark coloured. They are used in the manufacture of slightly coloured faience bodies and in that of refractory products. These beds are fairly numerous; some are homogeneous and rich, others, on the contrary, necessitate a careful sorting.

Refractory Silicious Clays.—These are distinguished from the preceding by a higher content of free silica, which may amount to 50 per cent or about 73 per cent in all. Their plasticity is naturally low and their texture more or less granular; their use is generally confined to the manufacture of refractory wares. The colour is generally greyish but is sometimes yellowish. The beds of these clays are relatively numerous.

Among the chief refractory clay beds in Great Britain are:—Devon: Newton Abbot. Dorset: Corfe Castle, Wareham. Worcester: Stourbridge. Northumberland: Newcastle-on-Tyne. Durham. Lancashire: St. Helens. Wales: Aberdare. Scotland: Garnkirk, Glenboig, Kilmarnock.

Vitrifiable Clays.—These clays become vitrified at porcelain heat (1350° C.), but usually remain porous at faience heat (1200° C.). They contain a higher proportion of fluxes than the refractory clays. They may be divided into plastic, ferruginous, and calcareous or alkaline clays, with intermediary kinds: such as alkaline-ferruginous-plastic clays. Two of these varieties from their use, and the number of their beds, deserve particular mention:—

Vitrifiable Alkaline Clays, whether plastic or silicious, serve as a base for the manufacture of artistic stoneware, sanitary ware, and for chemical industries and paving tiles. Their colour is generally deep bluish, inclining to violet or grey, and on firing they give a body of which the tint varies from bluish-white to a deep, pearly grey, or from yellowish-white to brown.

Vitrifiable Ferruginous Clays, are nearly always silicious, and can also be employed for the manufacture of sanitary stoneware, but are chiefly used for the making of paving tiles and vitrified bricks. They are of a yellow-red, orange-red, or brown colour, and produce a fired body of which the tint varies from brown to black.

Vitrifiable clays, as well as refractory clays, can be used in the manufacture of terra-cotta, providing that the temperature reached in the kiln is not too great.

The best known beds of vitrifiable clays, almost all alkaline, in Great Britain are:—

Wareham, Newcastle-on-Tyne, Longport, South Yorkshire, and the Midlands.

Fusible Clays.—These clays vitrify, losing their shape at a low temperature, such as that of the firing of faience (1200° C.). They always contain rather a large proportion of silica. Some are sufficiently plastic for use in the making of pottery ware, tiles, quarries, etc., while others, being too weak, can only be employed in the making of plain bricks. The chief flux present is lime, alkalies being usually in relatively small proportions. Among the numerous kinds of clay in this division four chief classes can be distinguished :—

Plastic Ferruginous Clays, very variable in colour, but generally rather dark, producing on firing a body the tint of which passes from orange-red to brown.

Plastic Calcareous Clays, which become effervescent in contact with acids, are very variable in colour, the fired body passing from orange to yellow, then to brownish- or greenish-yellow, according to the temperature.

Silicious Ferruginous Clays, in the form of crumbling earth, which effervesce in contact with acids and form wares having a similar colour to plastic calcareous clays.

Fusible clays are very scattered and are found in all countries.

2. Various Raw Materials.

Classification.—Materials other than clay and water which can enter into the formation of bodies may be divided into five classes, according to the object required in using them :—

(*a*) Materials similar to clay which can be substituted for it either entirely or in part.

(*b*) Agglomerative and agglutinative materials intended to remedy a lack of plasticity in the body.

(*c*) Opening materials for diminishing the plasticity.

(*d*) Fusible materials for increasing the fusibility.

(*e*) Refractory materials intended for diminishing fusibility.

(*a*) *Materials Similar to Clay.*

Clays can sometimes be replaced by other hydrosilicates of alumina, which also possess a certain amount of plasticity, and harden under the influence of heat. According to Le Chatelier, however, these minerals are not true silicates, but consist of true clay mixed with hydrates of silica or of alumina.

Halloysite, a white oily plastic material, of very variable composition, but containing usually 39 to 45 per cent silica, 24 to 40 per cent of alumina, and 10 to 26 per cent of water. Halloysite has often been employed, but without great success, in the manufacture of French porcelain.

Lenzenite, a similar substance, is sometimes used instead of refractory clay, although it is not particularly infusible.

Collyrite and *Allophane* contain, according to Le Chatelier, the same silicate of alumina, probably SiO_2, Al_2O_3, nHO.

Talc or *Steatite* is found in the form of soft friable rock, of slight plasticity. In a pure state it is represented by the formula 4MgO,

$5SiO_2$, nH_2O, but its composition varies according to its place of origin. It has been employed for the manufacture of large ceramic vases.

Magnesite has been used in Spain for the manufacture of porcelain.

Giobertite or magnesium carbonate, always mixed with a little silicate, has been used as a refractory material, and for the manufacture of porcelain ware.

Asbestos has of late been mixed with certain bodies because of its fibrous texture, for the purpose of giving a certain amount of cohesion. It is an anhydrous silicate of magnesia, lime and oxide of iron, the composition of which is variable.

(*b*) *Agglomerative and Agglutinative Materials.*

In the manufacture of refractory wares from silica, clay has sometimes been replaced by an agglomerant, such as lime, oxide of iron, calcium and magnesium chlorides, alum, and potassium sodium silicates.

When a body is not sufficiently plastic to bear shaping, and its chemical composition cannot be modified, artificial plasticity may be given by adding to the water of formation, some viscous substance which will disappear during the firing. For this purpose, glue, gum, lichen, tar, dextrine, soap, sugar-molasses, or a mixture of black soap and parchment glue, and of gum with black soap can be used according to the nature of the body and the ware required.

Such agglutinative materials have been largely used for the manufacture of French soft porcelain.

(*c*) *Non-Plastic or Opening Materials.*

In order to give the plasticity needful for the mode of working adopted, and to reduce the shrinkage, clays must often be mixed with non-plastic materials, or to employ a technical term—they must be "opened". From this point of view, a lean clay is an open one as compared with a fat clay, and silicious clays are often used to open the plastic clays.

The non-plastic materials used for this purpose may be divided into four classes :—

1. Silicious and sandy substances.
2. Calcareous substances.
3. Carbonaceous substances.
4. Pulverized fired bodies (called "grog," "rough stuff," or "grit").

Silicious Materials.—Silica in all its forms plays a very important part in ceramics. Not only does it serve as an opening material, but it acts either as a refractory material or as a flux, and is quite indispensable in obtaining the chemical composition required for pottery ware covered with certain kinds of glaze. It occurs both in a crystalline and an amorphous form.

Amorphous silica has a specific gravity of 2·2 to 2·3; it combines very easily with alkalies, and is produced in this form on the decomposition of all silicates.

Crystalline silica has a specific gravity of 2·6 to 2·7, and is not easily influenced by alkalies. It occurs quite pure in the form of rock crystal, almost pure in amethyst, chalcedony, quartz and flint, and mixed with other materials in sands.

Silica combines at a low temperature with potassium and sodium compounds and at higher temperatures with alumina, lime, magnesia and oxide of iron.

If crystalline silica (quartz) is heated several times and for twenty to twenty-four hours each time, to the temperature of a hard porcelain kiln, the gradual progress of the transformation of crystallized silica to amorphous silica can be traced (Seger).

This change produces a corresponding modification in volume, as an equal weight of amorphous silica occupies a volume 16 to 17 per cent greater than crystallized silica. This is of considerable importance in the manufacture of certain silicious wares; it explains the swelling and destruction in firing of wares rich in silica, and the absence of shrinkage of the silicate of alumina is compensated by the increase of volume of the silica.

In ceramic industries, silica is used as an opening substance in the form of quartz, flint and sand. Under other forms it serves more particularly as a refractory material.

Quartz is found in the form of rock, granite, gneiss, mica-schist, etc., but it cannot be extracted from these economically, and it is collected where these rocks have decomposed into their constituents.

Before use it must be pulverized. This is usually preceded by heating it to redness and quenching it suddenly in water. This treatment has the double advantage of transforming a part of the quartz into amorphous silica, thus diminishing its tendency to swell subsequently, and of rendering the stone more friable and more easy to crush.

Flint is found in the form of pebbles, black or red, weighing from a few grains to several pounds, in chalky ground. These pebbles may either be picked directly from the surrounding chalk or they may be gathered on the sea-shore or at the mouths of certain rivers (as the Thames) where the tides are constantly breaking up the chalk cliffs.

The most important source of flints is at the mouth of the Somme in France.

The grinding of the heated and water-quenched flints takes place either in a dry state in pulverizers lined with porcelain or stoneware to avoid contamination by iron, or by a wet method in grinding mills. The first process, a little more costly, produces the more valuable wares. This industry was formerly carried on solely at Runcorn and Newcastle-on-Tyne (England), but now the pebbles are similarly treated at St.-Valery-sur-Somme, and the powdered flint is exported.

Quartz and flint are only used as opening substances in the manufacture of fine pottery ware, particularly of faience; for commoner ware sand is used.

Sand is composed of quartz mixed with varying proportions of felspar, mica, oxide of iron, carbonate of lime or clay. When the proportion of these materials does not exceed two or three per cent, the sand is said to be quartzose; it is felspathic, micaceous, ferruginous, calcareous or clayey, whenever any one of these substances enters in greater proportion.[1]

Quartzose sand is pre-eminently an opening substance; it occurs in the form of coarse or fine grains with either round or sharp edges. Sharp-edged sand grains from quarries are preferable to round ones from rivers, as the former mingles better with the clay and adheres more strongly to it.

Unless the sand is sufficiently pure it must usually be washed.

Felspathic and micaceous sands introduce alkalies which act as fluxes as well as silica. Grains of felspar are to be preferred to spangles of mica. Sand very rich in mica must be rejected or washed, the lamellar form of the mica causing it to float in water, and so be easily separated. Sand containing iron compounds is much employed for terra-cotta manufacture.

Calcareous sand must only be used when the lime in it is in an impalpable form. The injurious action of the large lime-grains has already been noted.

Clayey sand is an excellent opening substance, although more plastic than quartz; it has also the advantage of being more readily mixed with the clay of which the articles are made.

Saline sands, of which the deposits are formed in salt water, introduce soluble salts into pottery ware, and produce, sometimes long afterwards, an objectionable efflorescence or "scum" on the surface.

Calcareous Materials.—Carbonate of lime, especially in the form of marl (or clay containing a large proportion of chalk or limestone powder), is sometimes used for opening clays, though the object of using this material is generally to obtain a more fusible body.

As opening substances, calcareous materials are undesirable. Carbonate of lime must necessarily be added in the form of an impalpable powder, or it will destroy the articles, and it is necessary that the temperature of firing should be sufficiently high to cause the formation of calcareous silicates.

Carbonaceous Materials.—In the manufacture of common fired bodies, most carbonaceous materials, of which the carbon disappears during firing, can be used advantageously as opening substances, but it is sufficient to mention coal and coke dust, cinders, ashes or iron slag, sawdust, straw, lignite, spent tan, etc.; these materials also facilitate drying, diminish shrinkage, assist in the uniform distribution of the heat, and render the fired bodies lighter, this last being often an advantage commercially.

The ashes of all these substances form fusible silicates, and produce specks and hollows in the fired bodies.

Pulverized fired bodies (called "**Grog**" or "**Rough Stuff**" or "**Grit**").—Firing transforms clays into opening materials which may be ground into grains of suitable sizes, according to the purpose desired. In this way "grit," "grog," or "rough stuff" is obtained.

[[1] Sand is the finer portion of material produced by climatic or fluviatile action on rocks. It has, therefore, no definite composition, as any rocky material in a sufficiently divided state may be regarded as sand.—A. B. S.]

This "grog" is a powerful and excellent opening substance. It has the advantage over sand of not swelling when heated and of being easily crushed and sorted into grains of different sizes. "Grog" has the further advantage of giving a more permeable mass than quartz and sand, and fired bodies which have been opened by this means afford a much greater resistance to sudden variations of temperature, a quality which is very important for certain refractory wares.

Grog is usually made by grinding fired bodies which have already been used, such as refractory bricks, broken saggars, crucibles, etc., for which there is no further use, but in works which manufacture a large quantity of best refractory wares these sources are insufficient, and some clay must be specially calcined and crushed. This method is indispensable for the manufacture of highly aluminous wares, such as are used in the construction of kilns for certain chemical or metallic industries. The employment of sand as an opening substance would be inadmissible in this case, as it would unduly increase the proportion of silica.

Plasticity could be destroyed by heating the clay to 400° C., but it is preferable to heat it to a temperature at least equal to that of the firing of the articles to be made from it in order to diminish the shrinkage.[1]

In grinding material for grog, mills which yield a large proportion of round grains are always preferable.

(d) *Fusible Materials.*

When raised to a sufficiently high temperature, which varies according to their composition and physical texture, clays gradually harden and become vitrified. There is often an advantage to be gained by lowering the temperature at which this hardening and vitrification takes place; more resisting wares can thus be obtained at a less cost for firing, or in faience wares the expansion of the body can be modified and made to correspond with that of the glaze.

Fluxes are substances which combine with the silica of the body to form multiple silicates, more fusible than clay. The chief fluxes are alkalies (compounds of potassium and sodium), lime, magnesia, and oxide of iron. To these must be added calcium phosphate in which both the phosphoric acid and the lime act as fluxes.

Fluxes may therefore be divided into alkaline, calcareous, magnesic, ferric and phospho-calcareous.

Alkaline Fluxes.—Alkalies may be introduced into bodies in three different forms:—

(1). As salts, derived from vegetable ashes or produced by the manufacture of chemical products.

(2) As silicates, or artificial borates or "frits".

(3) As felspars and felspathic rocks.

Alkaline salts are not employed directly, as such small proportions of them are needed to increase the fusibility of the clay, that their homo-

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[1] [A much higher temperature is preferable.—A. B. S.]

geneous mixture with the body is difficult and uncertain. Carbonates should be rejected because of the carbonic acid which they evolve during the firing, which tends to inflate the mass. Sulphates are preferable, but in addition to the other inconveniences just noted, they require a high temperature for their decomposition.

Frits.—On the contrary, are in constant use in the manufacture of glazes, though they are little used in body mixtures. They are manufactured by fritting together silica and alkaline salts, the glassy substance produced being then finely ground. Frits are sometimes replaced by glass which, because of its low price, can be used in the manufacture of common stoneware. Felspar and felspathic rocks are the most popular raw alkaline fluxes. They are widely distributed, but are rarely pure enough to be of use. Their colour is not a sign of purity. Certain white felspars become yellow, red, or black at a high temperature, while others which are strongly coloured when found, become white on heating. Felspars are heated strongly, and reduced to a fine powder, which is the form in which they are found in commerce.

Felspars are silicates of alumina and of alkalies, chiefly potash and soda. They generally contain a small proportion of oxide of iron, lime and magnesia, though in some cases the quantity of lime is too large to be neglected. The felspars of Norway supply the chief European potteries.

Among felspathic rocks *pegmatite* is the most in use. It is largely employed in France, where there are the important beds of St.-Yrieix, and in England, where it is known by the name of "Cornish Stone," and is found in Cornwall.

Porphyry, trachytes, basalts, and other analogous rocks have sometimes been utilized. Their composition is generally variable.

Calcareous Fluxes.—*Lime* is introduced into bodies as a flux in the state of calcium carbonate, sulphate or silica.

Carbonate of lime can only be used as a flux when the temperature of firing the pottery is sufficiently high to decompose and eliminate the carbonic acid. At a lower temperature it only serves as an opening substance. In making "mixtures" it must not be forgotten that there are for 100 parts in weight of carbonate, 56 of lime and 44 of carbonic acid.

The beds of carbonate of lime are very numerous. White marble and chalk are almost pure carbonates, calcareous heaps, limestones and marls are also used.

Marls are mixtures of carbonates of lime and clay. Le Chatelier and Vogt declare that the latter is not true clay but corresponds in reality with the formula Al_2O_3, $5SiO_2$, nH_2O.

The composition of marls is very variable. Calcareous marls containing from 20 per cent to 40 per cent of hydrosilicates of alumina (clay) are distinguished from clayey marls, in which this proportion reaches 70 to 80 per cent. They nearly always contain oxide of iron, to 7 or 8 per cent.

The plasticity of marls depends on the proportion of silica and alumina (clay), so that, generally speaking, clayey marls may be considered as relatively plastic substances, and calcareous marls as opening ones.

Sulphate of lime (plaster of Paris, gypsum) can only be used for pottery ware fired at a high temperature, because it is only decomposed with great difficulty.

Its only advantage over carbonate of lime is its relative solubility in water, which allows it to be mixed more easily in bodies. But it must not be employed simultaneously with a large proportion of alkalies or it may form alkaline sulphates, which are more difficult to decompose than sulphate of lime. This sulphate should be calcined before use in order to eliminate the water it contains.

Many mineral forms of sulphate of lime or gypsum contain impurities, such as clay, oxide of iron, gravel, carbonate of lime, sulphate of strontia.

Silicate of lime is obtained from the slag of blast furnaces. It also contains silicate of alumina, and frequently oxide of iron, magnesia, manganese, and various sulphates and sulphides.

These very variable and very impure products are used in the manufacture of "quarries," stoneware and imitation stoneware.

Various Fluxes.—*Magnesia* can be mixed with bodies either in the form of a double carbonate of lime and magnesia, which constitutes the natural rock known as dolomite, or in the form of silicate of magnesia or talc. Magnesic fluxes are used for the manufacture of some porcelain ware and sometimes enter into the composition of glazes.

Ferric Fluxes.—Oxide of iron only acts as a flux when it is in the form of protoxide (ferrous oxide, FeO). In the form of sesquioxide (ferric oxide, Fe_2O_3) its action is similar to that of alumina. It is only added to bodies for the purpose of colouring them.

Phospho-calcareous Fluxes.—Lime phosphate is generally made from the bones of animals, but native phosphorite may be used. The bones employed are chiefly those of the ox, those of horses and pigs being rejected because they give colour to the body. They are dried, cleaned by boiling in water, calcined until they are entirely white, then finally pulverized.

Phosphorite is a natural fibrous stone, containing up to 93 per cent of calcium phosphate.

Phosphate of lime is chiefly, if not exclusively, used in England for the manufacture of soft porcelain, where it is known as "bone ash".

Refractory Materials.—In ordinary clays, which are always silicious, silica is the refractory element, whereas for bodies which are destined to be vitrified (stoneware and porcelain) alumina plays this part.

Silica is generally introduced into bodies in the form of quartz, flint and gravel. These materials have already been mentioned under non-plastic substances, and it is not necessary to return to them.

Infusorial earth or "Kieselguhr" is another form of silica which is sometimes used. It is very light in the undried state, its weight being less than that of an equal volume of water; after drying it is reduced to less than one-half.

The composition varies greatly with the beds, but the silica has always a density of 2·2 to 2·3. As in this form it lends itself better to the formation of multiple silicates it is less refractory than quartz, whilst its exceptional lightness renders it very useful in the manufacture of refractory wares employed for the hearths of locomotive or marine boilers.

Gannister is the name given to a grit in England and the United States, which is found below the carboniferous formation; it can be used either by itself, or mixed with a refractory clay. [Its composition resembles silica with about 10 per cent of clay.]

Alumina can be introduced into bodies in the form of hydrosilicates of alumina, more aluminous than clay, which have been previously mentioned, or as bauxite, a rock of very variable composition, often mixed with strong proportions of oxide of iron.

3. Testing Raw Materials.

(*a*) *Testing Clays.*

Methods of Testing.—The tests to which clays can be subjected are of two kinds: (1) chemical and (2) physical or mechanical.

The object of chemical tests is the determination of the composition of clays.

(1) The composition of the clay can be investigated, and the nature and composition of the natural mineral substances, which by their mixture have formed it, determined.

(2) The ultimate composition may be ascertained without any account being taken of the form in which the various substances disclosed by analysis are combined.

(3) It may be ascertained if, and in what proportion, a certain substance is found in the clay.

The object of physical or mechanical tests is to determine the chief physical properties either in an absolute manner or by comparison, such as:—

(1) Determination of the texture of the clay, and particularly the coarseness of the grains which constitute it.

(2) Measurement of plasticity and shrinkage during firing and drying.

(3) Tests of fusibility, porosity and shrinkage at different temperatures.

Tests on the Constitution of Clays.—Unfortunately, tests made to ascertain the constitution of clays have still the character of scientific researches, and are but little used in the daily practice of manufacture.

The employment of washing for the separation of pure clay from other substances mixed with it has been much used, but it is difficult to know to what point the washing shall be carried, and the suggestion that all grains less than $\frac{1}{100}$th of a millimetre diameter shall be considered as clay is objectionable, as many materials mixed with clay (such as silica, alumina, lime, oxide of iron) can be found in the form of a powder so fine that it cannot be separated from clay by any mechanical process. Washing should therefore only be considered a means of determining the texture of the clay, and as giving a rough guide to its impurities, and not as a method of exact analysis.

In the present state of chemistry the best process[1] by which information on the constitution of clay can be arrived at, consists in submitting it to the action of sulphuric acid, first diluted, then concentrated. In subjecting a clay, reduced to as fine a powder as possible in a platinum crucible, for several hours at a temperature of about 100° C. to the action of sulphuric acid, diluted in five or six times its volume of distilled water, carbonates of lime and magnesia, hydrated oxide of iron, etc., are dissolved, and these can be separated according to the general methods of analysis. The residue after being duly filtered, washed and dried, comprises the clay, silicates, and silica. It is then placed in a platinum crucible, and subjected from fifteen to twenty hours to the action of boiling concentrated sulphuric acid. The hydrosilicates of alumina [clay] as well as the powdered mica are attacked and dissolved, and the residue is composed of free silica (quartz), coarse mica and felspar, and can be separated by cautious dilutions with water followed by filtration. The treatment with acid should be repeated on the residue until the weight remains constant. In this way the weight of hydrosilicates of alumina [true clay], mica, free silica [sand, quartz] and felspar is obtained.

There is no process for the separation of hydrosilicates of alumina from mica, and one must be content with analysing the mixture, and assuming the composition of the mica to be potassic mica (muscovite); the proportion of alkalies found is multiplied by 8·5 to convert it into mica; the state of combination of the remaining silica and alumina is set down as hydrosilicates of alumina [or "clay substance"]. Generally, if this process has been well carried out, the proportion of silica and alumina thus found corresponds with the formula of kaolinite. If such be not the case, and if a fresh trial gives the same results, it would be necessary to conclude that there are other silicates of alumina [in addition to pure clay].

The residue left by the concentrated sulphuric acid, and composed of quartz, felspar, coarse mica, can be again "washed" or elutriated, because, on account of its lamellar form, the mica remains for a longer time in suspension in water. A mixture of quartz and felspar is then obtained which it is impossible to separate mechanically, though an analysis of it would show approximately the amount of free silica if the felspar were assumed to be orthoclase.

The determination of the quantity of water removed on heating a clay to increasing temperatures also gives information as to its constitution. In heating a clay to 120° C. until two successive weighings, made an hour apart, indicate no further diminution of weight, a figure is obtained which includes hygroscopic water, the water from the hydrated silica, oxide of iron and the volative parts of organic substances. If this heated clay is then left for about ten days under an

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[[1] This process is far from accurate with many clays.—A. B. S.]

inverted glass vessel in a moist atmosphere, the increase of weight which it will evince will indicate the proportion of hygroscopic water alone.

Again, on heating clay which has been dried at 120° C. with air for a fairly long time, at a temperature from 600° to 700° C., the further loss of weight which will be observed corresponds to the water of the hydrosilicate of alumina [clay], hydrate of alumina, and to the carbon, etc., of the organic materials. By repeating the same operation in a crucible hermetically sealed, or better, in a tube traversed by a current of carbonic acid, the combustion of the carbon is prevented, and its weight can then be obtained by observing the difference. The temperature must not be raised above 700° C. or the decomposition of carbonates would take place. Finally, referring to the different hydrosilicates of alumina, Le Chatelier has demonstrated that all these lose their water of hydration between 400° and 700° C., with the exception of allophane and collyrite, which dehydrate at 120° C. This observation has enabled Vogt to demonstrate the presence of allophane in certain clays.

Chemical Analysis.—Although the preceding tests require much skill and practice in order that they may be carried out properly, the "ultimate" chemical analysis of a clay may be made by anyone accustomed to chemical manipulation. The following is an outline of the method most used[1]:—

One or two grammes of clay powder, dried at 120° C., are weighed accurately and mixed with five or six times their weight of carbonate of soda, which has been previously melted and pulverized. The mixture is placed in a platinum crucible, which is heated until the mixture is completely fused. After cooling, the crucible is placed in an evaporating dish and distilled water added and boiled until the material is completely dissolved. The crucible is then rinsed into the dish and removed. Hydrochloric acid is then added drop by drop, until all bubbling has ceased. The dish and its contents is heated slowly, so that all the water is evaporated without any "spitting" and the solid residue is maintained for two hours at about 105° C. It is allowed to cool and hydrochloric acid is again added, and the mixture is heated up to boiling, after which the liquid is filtered through paper. The silica remains on the paper while the bases are in solution as soluble chorides. When every particle of silica has been placed on the filter it is well washed and then dried and calcined, the weight of the residue, less that of the paper-ash, gives the weight of the silica contained in the weight of material tested. To confirm this it is well to boil this silica in a strong solution of carbonate of soda to see if solution takes place without any residue. If this is not the case the residue must be re-fused since the original fusion has not been complete.

The liquid which has passed through the filter is divided into two equal parts after having been diluted with water.

[[1] It must not be supposed that all the precautions necessary for accuracy are given.—A. B. S.]

Into the first, ammonia is poured, until the liquid becomes alkaline; the precipitate of alumina and oxide of iron is allowed to remain for several hours, in a warm place, till almost all the ammonia has evaporated. It is then poured on a filter, washed carefully with warm water, and the filter is dried, calcined and weighed. The weight obtained is that of the alumina plus oxide of iron.

The filtered liquid is heated until its volume is reduced by one-half and an excess of warm oxalate of ammonia solution is added. This forms a precipitate of oxalate of lime, which is filtered, washed, dried, and calcined to redness, to convert the oxalate into caustic lime, then rapidly weighed; this gives the lime present.

Lastly, the filtered liquid is cooled and treated with plenty of ammonia and a solution of phosphate of soda. Magnesia is precipitated in the form of ammonium magnesium phosphate, which is filtered, dried and calcined and weighed in the form of pyro-phosphate of magnesia.

The second part of the liquid preserved after the elimination of silica is employed for the determination of the oxide of iron. It is placed in a flask and, whilst boiling, small pieces of pure zinc are added until the liquid from being a melon colour becomes colourless and all the iron is in a ferrous condition. Then a standard solution of permanganate of potash is poured in, drop by drop, from a burette, and this remains discoloured so long as there is any iron in the form of protoxide. Directly the whole of the iron is transformed into peroxide the liquid assumes a pink tint. The volume of the permanganate solution so used is proportional to the amount of iron present, and knowing its strength the amount of iron can be calculated as ferric oxide. This amount deducted from the "alumina plus iron oxide" previously found gives, by difference, that of the alumina.

When it is desired to determine the alkalies, which ought always to be done, an accurately weighed portion of the very finely pulverized clay is placed in a platinum crucible, and mixed with pure hydrofluoric acid. After some hours of heating, sulphuric acid is added, and the liquid is evaporated to dryness. All the bases are then in the form of sulphates; they are dissolved in warm water, and if the operation has been well carried out, no residue should remain. On treating this solution with baryta-water the alumina, oxide of iron, lime and magnesia are precipitated together with the sulphate of baryta. The liquid is filtered, carbonate of ammonia is added and again filtered. The liquid is then evaporated and calcined to volatilize the ammonia salts. It is then treated with water, and with carbonate of ammonia in order to ensure the complete precipitation of earthy bases. After fresh evaporation and a slight calcination, the alkalies are dried and weighed in the form of carbonates, or the calcining can also be carried on in the presence of sulphuric acid, when the alkalies will be weighed in the form of sulphate of soda and potash.

In ordinary analysis there is no advantage in estimating the potash and soda separately. If, however, separation is desired, the alkaline carbonates would be dissolved in acidulated water and heated slowly, almost to dryness, after having added some bichloride of platinum solution and, after evaporation, some alcohol and ether. The sodium-platinum compound is soluble, but the potassium one is filtered off, dried, and weighed.

Special Tests.—Special tests are employed when it is simply desired to know if, and in what proportion, a certain substance exists in the clay.

The most simple of these estimations is that of hygroscopic water, or moisture, the amount of which can vary greatly in the same clay, so that sometimes account must be taken of its amount. This test is made by heating a given weight of the powdered clay to 120° C. until two consecutive weighings [made at an interval of an hour between each, during which time the clay has been kept at the temperature mentioned] show no further loss of weight.

It is often very important to know whether a clay contains oxide of iron, and if so in what proportion. This can be ascertained without difficulty by boiling 50 grammes of the finely powdered clay with sulphuric acid diluted with two or three times its volume of water. After having allowed the mixture to remain for twenty-four hours, it is again diluted with water and filtered. The liquid thus obtained is placed in a flask and heated, some pieces of pure zinc being added at the same time. All the iron is reduced to protoxide and it is treated with a solution of permanganate of potash, as already described. Or the presence of iron may be confirmed by adding an excess of ammonia to the clay after it has been treated with sulphuric acid, diluted and filtered as described above. If there is any iron in the clay, the ammonia will form a brown precipitate in the case of iron peroxide, or a darker precipitate which turns brown in contact with the air if the iron is in the form of protoxide. [As alumina is also precipitated as a white material this test cannot be used to estimate the amount of iron present. Some clays require to be fused before solution.]

Lime is another subject which it is important to recognize in clays, especially when it exists in the form of carbonate. This is done very simply by pouring an acid (sulphuric, hydrochloric, nitric, etc.) on to the clay. If it produces an effervescence of carbonic acid gas this is a proof that the clay contains some carbonate, most probably lime, and its proportion can be roughly estimated according to the intensity of the effervescence. [If an accurate knowledge of the amount of lime present is required the clay must be subjected to an ultimate analysis as already described.] For calcareous clays the following process can also be employed: In a light flask are placed 10 grammes of powdered clay, and this is diluted in water and the mixture stirred; into a second flask, which must also be light, are poured about 10 grammes of acid which is diluted with from two to three times its volume of water. The two glasses are then placed on the pans of a balance and weighed. The contents of the second glass are poured into the first, drop by drop, very slowly, so as to avoid a strong effervescence or a considerable heating of the liquid. When the ebullition has ceased the glass is shaken in order to force the bubbles of carbonic acid, which have been able to remain in the clay, to evolve.[1] The two flasks are replaced on the pan, the difference of weight which indicates the proportion of carbonic acid contained in the clay is determined, and the lime contents are deduced from this. Of course if the clay contains volatile organic substances, this process is not applicable.

The proportion of soluble salts contained in a clay can be roughly determined by treating a certain quantity of clay (half to one ounce) for one hour in boiling distilled water. The mixture is poured on a filter, then the filtrate is evaporated to dryness, and the residue weighed. It can be analysed according to the general methods.[2]

Tests for Fineness.—Ordinary clays are formed of extremely small grains of true clay mixed with other grains, very variable in size, depending on the nature and proportion of the other materials entering into the composition of the "clay". A microscope enables the form and often the nature of the coarsest grains to be recognized, but its indications are insufficient.

The separation of the coarser grains according to their size could be effected with a series of sieves, but the finest grains cannot be so separated, and sifting therefore gives incomplete results, and for the finer particles it is replaced by washing. This may be done in two ways. The clay may be placed in suspension in water and stirred strongly, and then left to settle. The coarsest grains sink rapidly, then the medium sized, and finally the finest particles remain for a long time in suspension, and do not settle for several hours, or even for several days. If the process is carried on in a graduated test glass, the number of divisions can be read which correspond to the volume of each size of grain.

This method is very simple, but the results arrived at are inexact, because the particles which are at the bottom of the test glass at the moment of agitation remain mixed with the coarser grains. Moreover, the reading of the divisions is necessarily inaccurate, and it is therefore better to have recourse to the second method, which is more complicated but more precise. It consists in submitting the clay to a continuous current of water, the speed of which can be regulated at will. It will be understood that with a low speed only the finest particles are removed, but with greater speed the medium-sized particles are carried off. Different forms of apparatus have been constructed on this principle. Fig. 1 represents that proposed by Schulz. The clay is placed in a glass into which the water runs from a high reservoir, the speed being regulated to carry off all except the coarsest grains. The particles so removed are brought into a second glass, which has a larger diameter, and where, consequently, the speed of the current diminishes and allows the largest grains brought down to settle. The

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[[1] It is usually necessary to warm the liquid to drive out the dissolved gas.—A. B. S.]

[[2] The objection to this method as published is the difficulty in obtaining a perfectly clear solution. Some clay nearly always passes through a paper filter, but Mellor has shown that an unglazed porcelain crucible is a perfectly satisfactory substitute.—A. B. S.]

same takes place in a third glass, larger than the second, and finally only the finest particles reach the lowest reservoir, where they settle. At the end of the operation the dried residue contained in the different glasses is weighed.

The apparatus shown in Fig. 2, invented by Schoene, gives better results. It consists of a conical tube A D, the height of which is from 23½ to 25½ inches, the diameter at B, 2 inches being reduced to 0·20 inches in the tubes D G and A L. The clay to be tested is first mixed into a slip with water, and the mixture is poured into the tube A D, through the opening A, from which the india-rubber stopper is removed. Water is added until the liquid reaches the mark C. The stopper with the tube A L having been replaced, a stream of water is made to enter the apparatus at G and makes its exit by a small orifice

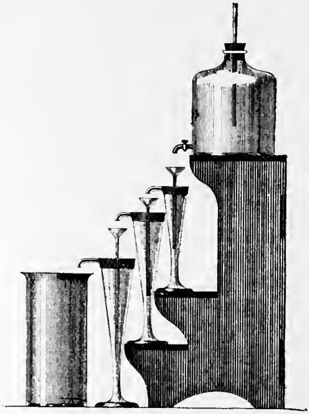

Fig. 1.—Schulz's levigating apparatus.

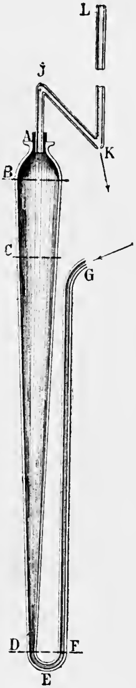

Fig. 2.—Schoene's levigating tube.

K. The speed of this current is measured by the height of the water in the tube K L, to which is given a height of about 59 inches. The entry of the water is regulated by a tap, and it is arranged that the level of the water rises, e.g., to 0·71 inches in K L, the stream of water then taking away the grains of less than ·00039 inches diameter, which are collected in a receiver placed under the orifice K. When the water has become clear the speed is increased, the grains removed are collected in a second receiver, and the operation is thus continued until the greatest speed is reached which the current can obtain by this apparatus, the particles then remaining in the tube being at least ·0156 inches diameter. The deposits in the various vessels are dried and weighed. In order that the orifice K may not be choked up, it is necessary to first sift the diluted clay through a sieve of 100 holes per running inch.

According to Seger the different sizes of grains may be classified as follows:—

Grains of less than ·00039 inch are considered as *clay*.

[This should be confirmed in important cases by an analysis of the material, for though the ultimate composition of these grains is remarkably constant they are not necessarily clay.—A. B. S.]

Grains of ·00039 to ·00098 inch, showing a certain amount of plasticity when held between the fingers, but yielding a mass which disaggregates on drying, are regarded as *silt*.

Grains from ·00098 to ·00156 inch having little or no plasticity, but the different grains of which are not perceptible to the touch, are termed *dust sand*.

Grains from ·00156 to ·0118 inch form *fine sand*.

Grains above ·0118 inch are *coarse sand*.

Tests of the Plasticity.—The plasticity of a clay depends *inter alia* on (see p. 55)—

(1) The plasticity of the hydrosilicate of alumina [true clay] which it contains.

(2) The proportion of this body relatively to other materials.

(3) The nature, the size, and the form of the grains of these materials.

Thus, chemical analysis, the proportion of alumina, the quantity of hygroscopic water, and the result of washing tests can never serve as a true measure of plasticity, and it is necessary to use direct mechanical tests. The most simple of these consists in moulding the clay by hand, and estimating the plasticity by touch. However primitive this may be, it must be confessed that it is nearly always sufficient. To facilitate the comparison of clays among themselves, the following process, by Bischof, can be recommended:—

A quantity of clay is dried at 120° C., and is divided into several parts all having the same weight, e.g. 50 grammes. A fine, dry quartzose sand is added to each part of clay in increasing quantities.

An intimate mixture of the sand and clay is made, water is added to form a body which can easily be shaped by hand, and a series of pellets are fashioned, and left to dry. When the drying is complete these pellets are placed above a piece of white paper, and rubbed between the fingers and thumb. If the proportions of sand have been suitable the pellets which have the least of it remain intact, those which have the most are completely rubbed away, and an intermediary is found which forms the limit, only a small quantity of grains being detached by the rubbing. The proportion of sand which it contains serves as a measure of the plasticity.

In order that the tests may be comparative, the same sand must always be used; that of Fontainebleau is the standard one for tests in France. The quantity of sand which can be mixed varies from 0 to 3 times the weight of clay, according to its plasticity, and each pellet is made by adding $\frac{1}{10}$ more of its weight in sand than the preceding one. If, therefore, a clay has been able to absorb $1\frac{1}{2}$ times its weight of sand, its plasticity will be represented by 1·5.

Bodies must usually be able to absorb from once to twice their weight of sand.

It has been proposed to estimate plasticity by forming test pieces having the form of those used for testing cements, and determining the amount of force required to break them. As clay shrinks it is necessary to measure the reduced section and to divide the weight which has effected the breaking by the surface thus found in order to have the effective resistance per square inch. It must, however, be admitted that although the figures thus obtained are interesting they do not indicate the amount of plasticity.

[Zschokke has obtained better results by multiplying the force thus used for breaking by the percentage of extension. The whole subject of the measurement of plasticity is discussed fully in "British Clays, Shales, and Sands" (now in the Press).—A. B. S.]

Tests of Fusibility.—Tests of fusibility are made with the view to determining the manner in which the clay behaves under the influence of an increasing temperature; its porosity; its shrinkage at different degrees of heat; the temperature at which it begins to vitrify; that of the beginning of its softening. The temperature of true or complete fusion of clays has no practical interest [and the term "fusibility" is therefore commonly used to mean the temperature at which the body loses its shape]. This subject is dealt with in Chapter VIII, on Firing.

Attempts have been made to replace direct tests for the fusibility of clays by calculations deduced from the chemical composition. The molecular ratio of the fluxes to alumina, and of alumina to silica, is inversely proportional to the fusibility. This method, proposed by Bischof, only applies to clays which are highly refractory.[1]

(*b*) *Tests of other Raw Materials.*

Other raw materials are sometimes tested for the purpose of confirming their composition and their purity. The following are a few summarized notes on such tests:—

[[1] Ludwig obtained a much better and wider method of calculation by the use of a graph in which the clays are reduced to a formula with Al_2O_3 as unity, the RO bases being then taken as ordinates and the silica as abscissæ. See "Modern Clay Working".—A. B. S.]

Raw materials analogous to clay are tested by the processes which have just been indicated.

For silicious substances, particularly for sand, a washing test is used. This is much simpler than with clays, and it is usually only necessary to determine the proportion of earthy materials which they can contain. For this purpose it is sufficient to stir a given weight of sand in a test glass full of water, to pour off gently the thick liquid, and to repeat this operation until the water remains clear. The sand remaining is dried, and weighed, the loss of weight indicating the proportion of earthy materials. As the size of the grains of sand plays an important part, it is useful to determine it by means of successive sieves. An examination of the grains with a magnifying glass [or microscope] should also be made, as it will frequently enable the mineralogical nature of the sand to be easily recognized.

When the composition of the sand must be known with accuracy this test is not sufficient, and chemical analysis alone is capable of revealing the traces of fluxes which the silicious materials may contain. As the fluxes may be in the form of felspar, the material should be treated by hydrofluoric acid as already described, but instead of treating the solution by baryta, which precipitates all the bases, it is divided into three parts. In the first the alumina and oxide of iron, are separated by ammonia, lime by oxalic acid, and magnesia by phosphate of soda. In the second the oxide of iron is treated with permanganate of potash; and the third is employed for the determination of alkalies. Sands are sometimes tested as to fusibility.

Alkaline fluxes should be analysed by treating them also by hydrofluoric acid and to determine the alumina, oxide of iron, lime and magnesia according to the usual methods of analysis. The insoluble portion is considered to be a mixture of quartz and clay, which can be separated by washing or analysed by fusion with carbonate of soda or heating with hydrofluoric acid.

The analysis of sulphate of lime (plaster of Paris) should be preceded by a calcination at 200° C., in order to remove all combined water. The calcined material is then treated for twenty-four hours with cold carbonate of ammonia. Sulphate of lime is decomposed into carbonate of lime and into sulphate of ammonia; this latter is separated by filtering, after which the liquid is warmed and treated with chloride of barium, which precipitates the sulphuric acid in the form of sulphate of baryta, in which form it may be weighed. The filtered liquid is treated with sulphuric acid, any barium sulphate precipitated is filtered off, washed and thrown away, and the clear liquid is then neutralized with ammonia and the lime precipitated with ammonium oxalate.[1]

[[1] The foregoing tests are those given by Bourry. It does not follow that they are the ones recommended or used by the translator or reviser.]

CHAPTER IV.

PLASTIC BODIES.

1. PROPERTIES AND COMPOSITION.

CHEMICAL COMPOSITION.—Besides hydrosilicates of alumina, clay and water, which are their essential elements, plastic bodies contain four acids: silica, carbonic acid, more rarely sulphuric and phosphoric acids, and six bases: alumina, iron in different degrees of oxidation, lime, magnesia, potash, and soda, the substances, which are occasionally found in small quantity, may be regarded as accidental impurities in the raw materials. Omitting the water present, the following figures indicate the proportions in which these different substances can enter into the composition of the bodies.

Silica.—Silica is the principal element of nearly all bodies. They generally contain from 55 to 80 per cent of it, but refractory silicious wares may contain as much as 98 per cent. Some refractory aluminous wares on the contrary contain as little as 2 per cent.

Alumina.—The proportion of alumina in bodies varies from 10 to 40 per cent. It falls to less than 1 per cent in silicious refractory bricks, but sometimes reaches more than 70 per cent in aluminous refractory wares.

Iron Oxide.—Iron is generally present in the form of a peroxide [Fe_2O_3], though ferrous silicates are sometimes present, its proportion varying from 0 to 8 per cent, this figure being surpassed in certain stonewares, when it reaches even 20 per cent.

Lime, when present, varies between 0 and 10 per cent, but in some marl bricks, terra-cottas and faiences it can amount to 30 per cent.

Magnesia, which generally accompanies lime, only enters into the composition of bodies in a small proportion, and except in rare cases it does not exceed 2 per cent.

Potash and Soda.—These two bases are generally placed in analysis under the common name of "alkalies". Their proportion varies from 0 to 5 per cent. Exceptionally, as in the case of vitreous porcelain, it can reach 17 per cent.

Carbonic acid is found in bodies in combination with other bases, principally with lime as carbonate. Its proportion can amount to 17 per cent. When the temperature is sufficiently high it disappears completely during the firing.

Phosphoric acid is only introduced into bodies in the form of phosphate of lime (bone) for the manufacture of soft English porcelain, which may contain as much as 35 per cent of it.

Sulphuric acid is generally combined with lime as gypsum. Many clays contain small proportions of it, but it is rarely introduced voluntarily into the body.

The chemical properties of substances which enter into the composition of bodies exert no influence on their preparation, formation and drying, but they play an important part during firing (Chapter VIII.). When studying the composition to be given to a piece of pottery in order that it may fulfil the conditions imposed upon it, one of two independent points of view may be adopted:—

(1) The manufacture in question may be carried on for the purpose of utilizing a given clay, which is most frequently the case for fired bodies. Its physical properties are then first studied, research is made to discover what materials must be added in order that the body may be readily shaped and dried. Firing tests are then made, and from the results obtained it is seen if the composition first adopted needs modification. In such a case, chemical analysis of the clay only indicates *a priori* whether the material can be used for the manufacture proposed.

(2) The manufacture in question may have as its aim the production of a certain class of ware, as porcelain, faience ware, and stoneware, and it is necessary to find out by what means this result can be best obtained.

A series of mixtures is then prepared, based on a given chemical composition, from analogy with similar productions, and by comparison of the composition of substances. From this series trials are made and fired to ascertain if the physical properties are suitable. From the results obtained the raw materials are modified, or the proportions of the mixture, or, if necessary, even the chemical composition and the firing altered and re-altered, until a suitable ware is obtained.

These trials generally take a long time on account of the many qualities the pottery ware must possess, but the use of chemical analysis, unknown to the ancients, enables them to be considerably shortened.

The lengthy calculations, which the investigation of the proportions of a mixture of raw materials necessitates in order to obtain a given composition, can also, often, be simplified by making use of the following graphic method, proposed by Bourgerel:—

At the extremities of a horizontal line 20 cm. long two perpendiculars of 10 cm. are drawn and the latter are marked off in divisions corresponding to the percentage composition of the two materials which it is proposed to mix together. Thus (Fig. 3) in mixing a china

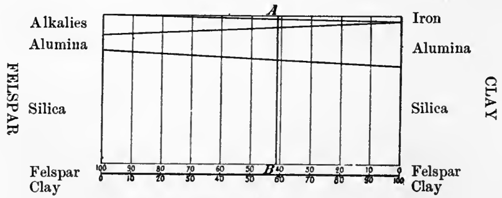

Fig. 3.—Diagram of body mixtures.

clay containing 66 per cent of silica, 30 per cent of alumina, and 4 per cent of oxide of iron, and a felspar containing 76 per cent silica, 10 per cent alumina, and 14 per cent alkalies, the perpendicular on the right is divided into three parts of 66, 30, and 4 mm., and that on the left also into three parts of 76, 10, and 14 mm., and lines are drawn joining each of the points so obtained.

If a graduated metric rule is passed from left to right of A B, the proportions can be measured of the different mixtures which can be obtained with the two substances in question, or if the proportions of one of the materials are prescribed, the proportion of the others can be read.

Forms and Proportions of Water in Bodies.—The water contained in bodies is in the state of (*a*) hygroscopic water, (*b*) water in combination, and (*c*) water of formation.

The water in combination (*combined water*) is that which a body dried at 120° C. still contains, and which only disappears during firing at a higher temperature (400° C.). This water forms an integral part of the true clay (hydrosilicate of alumina) which contains nearly 14 per cent of it. The water combined with hydrate of alumina, halloysite, lenzenite, cimolite, bauxite, talc, magnesite, etc., is also included, but is so small as to be usually neglected, and as a general rule it may be assumed that the combined water in a clay is proportioned to the true clay present, and in commercially pure clays the combined water is proportional to the percentage of alumina. A simple calculation shows that for 100 parts of alumina in the finest particles (true clay) there should be 34·95 per cent, or, in round figures, 35 per cent of water. As the alumina in anhydrous bodies varies from 10 to 40 per cent, a body dried at 120° C. will still contain from 3 to 12 per cent of water in combination.

Hygroscopic water is that which a dried body loses on drying at 120° C. and re-absorbs in contact with moist air. Usually the greater part of this water proceeds from the absorption of the atmospheric moisture by pure clay.

The quantity of water so absorbed depends on the temperature and the hygrometric state of the air; it is therefore variable. In very plastic bodies it can reach 10 per cent, and it may fall to 2 per cent for non-plastic bodies; the ordinary opening substances—quartz, sand, carbonate of lime, etc.—are not hygroscopic. Hydrated silica, oxides of iron, allophane, collyrite, and organic substances can increase the proportion of hygroscopic water, sometimes to as much as 20 per cent.

Water of formation is the water added to the body to give it the plasticity and consistency necessary to the mode of shaping adopted. It evaporates completely when the body is left for a sufficient length of time in a dry atmosphere.

This water of formation enters between the grains of the body, giving to them a certain mobility and enabling some to be displaced by others. It should not only fill the spaces between the particles, but should also cover their surface with a thin, liquid layer. Its action is, therefore, purely mechanical,[1] and its volume for bodies having the same amount of consistency only depends on the size and form of the grains, and not on their chemical composition. It unites with the hygroscopic water, and in all studies of the plasticity the effect of this total quantity of water must be noted.

Texture.—If plastic bodies were composed only of pure clay their texture would be represented by imagining grains of extreme fineness of lamellar form, very close together and entangled one with another, the spaces which separate them being filled with the still smaller molecules of water. The addition of other materials to pure clay has the effect of modifying this view as most other substances occur in much coarser particles than those of clay, being 10, 100, or 1000 times as large. An idea of the texture of a plastic body can be formed by considering grains of varying coarseness, around and between which are much smaller grains of pure clay, the smallest spaces being filled by infinitely small molecules of water. If for the same quantity of clay, the proportion of grains of other materials is constantly increased, a limit is reached where the clay grains are not sufficiently numerous to surround the others, or even to fill the spaces which are left between them. The clay is then no longer capable of cementing the other grains together, and if any plasticity still remains the cohesion of the body is destroyed, and the latter crumbles into dust as soon as the water is evaporated. The limit of proportion of foreign substances which may be added to a clay may be ascertained by adding to a clay increasing proportions of them until the dry body begins to crumble when rubbed lightly between the finger and thumb (see p. 47).

The smaller the grains of non-plastic material the less spaces will there be between them, and more of them can be added to a given quantity of clay. Hydrated silica, alumina, peroxide of iron and mica in impalpable powder yield the finest grains, then come the carbonates of lime and magnesia, and finally felspar, sand and stones. Similarly, the more non-plastic grains there are in a body, the coarser these grains are, the less is the amount of water necessary to give it definite consistency. From this point of view, the quantity of water contained in a body may serve as an indication of the coarseness of the grains of which the body is composed.

In a plastic body there are no "voids" as the spaces between the particles are filled with water, but if a body is in the form of dry powder, that is to say, containing only its hygrometric water, its volume can be diminished by beating it down, and by submitting it to the action of a strong pressure. By these operations the smallest grains are forced into the spaces between the larger, but it is impossible, whatever pressure is exerted, to entirely fill the spaces, about 20 per cent of voids being always left.

The addition of water to bodies obviously diminishes their density; the density of bodies containing from 25 to 30 per cent of water varying from 1·6 to 1·7. If, after formation, this water is allowed to evaporate,

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[[1] Supporters of the theory that the colloids in clay cause its plasticity will not agree with this statement.—A. B. S.]

the dry bodies resulting have an apparent density varying from 1·82 to 1·73.

Thus, a plastic body containing only 5 per cent of hygroscopic water, compressed at a pressure of 2366 lb. per square inch in the form of tiles ½ inch thick, had an apparent density of 1·98. The same clay when prepared in the form of a body and dried had densities of 1·74 and 1·79, according as the body had been coarsely or finely ground. On being placed in suspension in water, left to settle slowly, and afterwards dried, it gave a dry body of 1·82 apparent density. In the first case there was 19·2 per cent of space, 29 and 27 per cent in the second, and 25·7 per cent in the third. As dry bodies always contain air, and by the addition of water this air is not always completely eliminated, some of it may remain in the form of bubbles when the body is made plastic.

Consistency.—The consistency of a body prepared for use depends on the mode of formation to which it is desired to subject it. From this point of view the following distinctions are made in pottery manufacture:—

(1) Dry bodies, which can only be agglomerated under a powerful pressure, and which, even in this state, always preserve a granular appearance.

(2) Stiff bodies, which also need for agglomeration a mechanical pressure, although not so great as for dry bodies; the wares resulting are smooth and offer the same resistance to the pressure of the finger as a piece of leather.

(3) Half stiff (stiff-plastic) bodies, which can be shaped, though with difficulty, by hand, and uniting badly under the simple pressure of the fingers.

(4) Half soft (plastic) bodies, which can be shaped and wielded easily by hand, and preserve the form which has been given them.

(5) Soft bodies which do not lend themselves well to shaping, but stick to the fingers. The objects formed have a tendency to lose their shape under their own weight.

(6) Liquid bodies (slips) which have to be kept in receptacles.

According to this classification, consistency is estimated by touch. Up to the present this method, certainly very rudimentary, has been sufficient for all purposes, and it seems probable that it will be so for some time to come. If, however, for more exact experiments, the need of a more accurate measure is felt, a Vicat's needle, ·04 in. square, weighing from 1·6 to 3·2 ounces, may be allowed to fall from a height of 4 to 8 inches on to the body; the depth to which the needle penetrates serves as a measure of the consistency.

The quantity of water which a body must contain to make it of different degrees of consistency, depends, as has just been stated, on the texture; open bodies require much less than plastic ones. It is difficult, taking into account the considerable variations which can be produced, to indicate even approximate figures. Thus, the following proportions ought to be taken as very rough indications, the smallest number corresponding to very open bodies, and the highest to very plastic ones.

Consistency.	Hygroscopic Water and Water of Formation. Per cent.
Dry body	7 to 18
Stiff body	10 to 20
Half-stiff body	12 to 25
Half-soft body	15 to 30
Soft body	17 to 35
Liquid body	20 to 40 and above.

Plasticity.—The causes of the plasticity of pure clay and the influences which other materials mixed with bodies have on this property, have been mentioned in the preceding chapter. It now remains to examine within what limits it can vary according to the degree of consistency of the body, and the pressure to which it is subjected during formation.

If to a moderately plastic, dry body more and more water is added, the body at first devoid of plasticity to the touch gradually assumes it; it can at first be moulded with difficulty, then more easily, and finally it may be formed with the greatest facility. But if from this moment the proportion of water is still increased, the body begins to adhere to the fingers and it soon becomes impossible to form it into a definite shape.

There exists, therefore, for each body a given proportion of water, at which the shaping by hand is easiest. With less water too considerable an effort must be exercised, with more water the body lacks cohesion and sticks to the fingers. For a moderately plastic body the consistency which corresponds to this proportion of water is that which has been noted under the name of "half-soft body" in the preceding section.

If the same experiment is repeated with a more plastic body, it will be observed that the most favourable proportion of water for moulding by hand corresponds to a stronger consistency, that of a half-stiff body; if it is given the consistency of a half-soft body, it will adhere to the fingers and will allow of no further shaping. Now, as the body at this half-soft consistency does not lend itself well to shaping by hand, it is only possible so to shape it by opening it, that is to say, by diminishing its plasticity.

An excessively open body, on the contrary, only acquires the desired plasticity by having a very soft consistency, which does not allow it to support itself and to preserve the given form. It must be rendered more plastic if it is desired that it should lend itself well to shaping by hand.

If instead of formation being done by hand, it is done by mechanical means, in which the body is subjected to a much stronger pressure, less water must be added to the body, in order to obtain the same plasticity, and it will be expedient to make it of a stronger consistency. Pressure then plays the same part as water, in relation to the plastic qualities of bodies, the one can be partially replaced by the other; in other words, if the amount of pressure used increases the water should diminish, and vice versa. Thus, if a clay has been shaped with the minimum of water which it can have, that is to say containing only the 5·0 per cent of hygroscopic water, the pressure being 1161 lb. per square inch (it would have been impossible to increase it because the clay would have adhered to the mould), yet the same clay in the form of a body containing 22·9 per cent water begins to adhere to an iron mould at a pressure of 29 lb. per square inch, and for a body having 26·4 per cent of water a pressure of 5·64 ounces would be the maximum.

For a more open clay used as a dry body, the pressure would have to be increased in the same way as, in order to shape it by hand, one is led to give it a softer consistency.

The relations which must exist between the plasticity on the one hand, the consistency and the pressure corresponding to the mode of formation adopted on the other, can be summarized as follows:—

(1) Given a body of fixed plasticity, there exists a maximum of pressure and a minimum of consistency between which the body can be formed. If the body is too plastic, this maximum pressure will be less, and, on the other hand, the minimum of consistency will be too great to permit of formation by hand, or by a slight pressure. If the body is too open, the maximum pressure will become considerable and the minimum consistency will yield a body which is too liquid to be shaped.

(2) Given a mode of formation corresponding to a pressure and consistency which are fixed, the plasticity of the body employed can only vary between certain limits. If it is too plastic it will adhere to the mould; if it is too open its grains will not unite among themselves, and it will be impossible to make a compact mass of them.

It is, therefore, of the highest importance that a careful choice should be made of the mode of formation for a body of a given plasticity, or to produce in a given body the plasticity suitable for a given mode of formation. The solution of these problems is often rendered more difficult by the special qualities which the bodies must have in order to give good results in drying and firing.

2. PREPARATION OF RAW MATERIALS.

(a) *Weathering and Crushing.*

The object of breaking up the material is to place the raw materials (rocks or agglomerates) in such a condition that they can be more easily mixed and converted into a plastic body.

The processes of breaking up vary according to the nature of the materials to be treated, thus:—

(1) "Weathering"—applicable only to clays.[1]

(2) Breaking up by heat, sometimes employed for clays and hard rocks.

(3) Mechanical crushing by means of various machines, which may be classified as follows according to their mode of action.

[[1] It is difficult to understand Bourry's reason for this very limited application.—A. B. S.]

Concussion	Stampers	Used for hard materials.
	Centrifugal grinders	Used for dry clays, soft and hard materials.
Concussion and Crushing	Ball Grinders	Used for dry clays, soft and hard materials.
Crushing	Chopping Grinders	Used for hard materials, dry clays.
	Vertical mills	Soft and hard materials.
	Flattening machines	Used for humid material, soft and hard materials.
Cutting	Cutters	Used for humid and dry clays.
	Granulators	Used for humid clays.

Weathering.—Clays always contain at the time of their extraction a certain quantity of water, called "coursing water," which evaporates when the clay remains in a sufficiently dry and warm atmosphere. When this evaporation takes place fairly rapidly it causes cracking and the breaking of the balls of clay. The evaporation at first takes place on the surface of the balls and causes contraction there; the centre of the ball being still moist, cannot shrink. The consequence is that the tensions cause the surface to crack, then gradually all the ball, and the whole finally falls into small fragments. This action is much more energetic when the evaporation is more rapid, and cannot occur if the drying takes place very slowly.

This natural disaggregation, which is a consequence of the plasticity of clays, is employed in a very efficacious manner for the preparation of compact plastic clays, but it represents few advantages for open clays which are naturally friable.

In countries where the nature of the climate allows it, clays are laid out in the air and exposed to the sun in pieces of "fist size". In hot weather a few hours are generally sufficient to cause complete breaking up of the balls. The clay is then collected and placed in sheds ready to be used for the preparation of bodies by dry, pasty, or liquid methods. Where, on the contrary, the climate is frequently moist, the clay is spread in heaps under well-aired sheds, where it slowly breaks up, though less completely than in the preceding case.

When the body must be made into a paste or liquid, if the clay is fairly dry it may be soaked or exposed to the action of the rain. In this case, the surface of the balls imbibes the water and expands, while the centre, being still dry, does not increase in volume. The result is that the balls break up. It is convenient to use heaps of clay not more than three feet thick so that the rain can penetrate them thoroughly. If water under pressure is used, the heaps may be made thicker if holes are bored at short distances from each other, so that the water can penetrate to the centre.

In countries where the climate is severe enough for it to freeze regularly every winter, the clay is dug during the warmer season and exposed in heaps 2 feet 6 inches to 3 feet thick to the action of the cold. The water in the clay is transformed into ice, and the resulting increase of volume breaks up the balls, which become completely shattered at the moment of thawing. This action is rendered more powerful when care has been taken to sprinkle the clay before the frost arrives, so as to saturate it with water.

Thus by making use of solar heat, rain or frost, clays can be broken up in every climate, but it is necessary before adopting a process of "weathering" to know well the average climate of the locality, and the amount of water of formation in the clay.

Clay, especially if plastic, should be "weathered" whenever possible, for this treatment has a considerable influence on the preparation of the bodies, and on the final quality of manufactured ware. Mechanical means of crushing may doubtless replace it partially, but are often more costly to work, and experience proves that with the same stock of tools and the same expenditure of power, 6 cubic feet of body can be prepared with a weathered clay, while only 3 or 4 cubic feet can be obtained with the same clay crushed direct from its original site.

In the earlier days of the potter's art, the storage of the clay in sheds for very long periods, often several years, played a considerable part. The use of mechanical crushing machines for the preparation of bodies has often caused the advantages of weathering to be forgotten: in attempts to accomplish more rapid manufacture grave disappointments have frequently been experienced.

Disaggregation by Heat.—Clays may also be broken up by artificial drying, this method being employed in damp climates, or when waste heat is available.

The artificial drying of clays is not so simple an operation as would be thought at first sight, because the temperature must not exceed 110° C., and in any case must remain at less than 200° C. if the clay is to retain its plasticity. For small outputs the process usually employed consists in placing the clay on iron floors, or on refractory slabs, heated by a system of flues. The thickness of the plates or slabs should be regulated so that the heat transmitted should be uniform at all points on the floor and that the temperature shall not exceed the limit previously noted. The clay is spread in a layer 6 to 9 inches thick and is turned over from time to time in order to hasten the drying and to avoid overheating. A large quantity of heat escapes to the chimney, and the surface occupied by the apparatus is fairly considerable, so that it can only be employed for small outputs.

For larger outputs more economical dryers must be used; dryers with shaft furnaces, into which the clay is introduced in the upper part, and passes out below in a dry state, in a continuous manner, being preferred.

Fig. 4 represents a stove of this kind, invented by Lecaze. The clay balls are placed in an upper chamber, which should be kept filled. From this it falls into the dryer where it circulates round two rows of furnaces, heated by coke or small coal, so as to give it a large quantity of air at a moderate temperature. When the clay is dry, it is taken from the lower part at regular intervals, the material removed causing the descent of the whole of the upper mass. The air, when charged with vapour, makes its exit by a series of openings pierced in the arch supporting the upper chamber and enters two longitudinal flues passing into small chimneys built in the outside walls.

This stove is about 23 feet high, 6 feet 6 inches wide, and respectively 13 feet, 23 feet, or 30 feet long for drying 530, 1060 or 1760 cubic feet of clay in twenty-four hours. A clay containing 13 per cent of water requires 1·9 to 2·2 lb. of coke per cubic foot in order to dry it to such an extent that it does not contain more than 3 to 5 per cent of water.

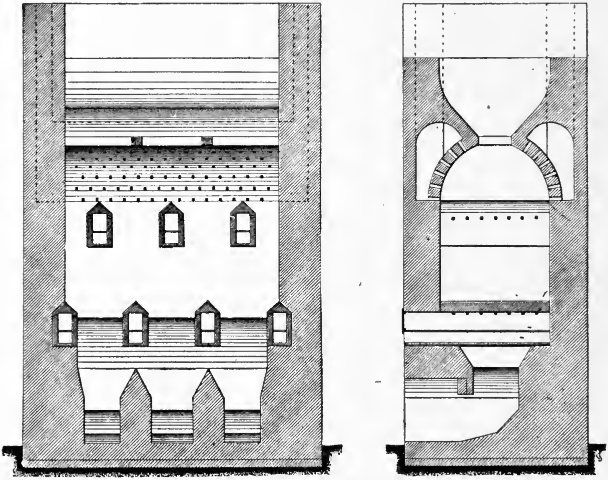

Fig. 4.—Kiln for drying clay.

10 Fig. 5 represents a stove constructed by Smidth & Co., which consists essentially of a shaft into which the clay is introduced by a chute. The balls of clay descend between the exterior wall of the shaft and a central block of masonry, and when dry are removed through lower openings near the base. The heat is supplied by an outside furnace, the heated air passing through a series of apertures pierced in the top of the central pipe, and after being saturated with water by being in contact with the clay, makes its exit by the chimney: this form of stove is used chiefly for large outputs and for very moist, plastic clays.

Heat is also employed to shatter quartz, felspar and flint. These hard rocks are heated to a fairly high temperature, and are then cooled rapidly in water. The expansion and contraction which result from the sudden change in temperature are powerful enough to break it up completely.

Shaft kilns are used, similar to those employed for burning lime; [rotary dryers are even more satisfactory].

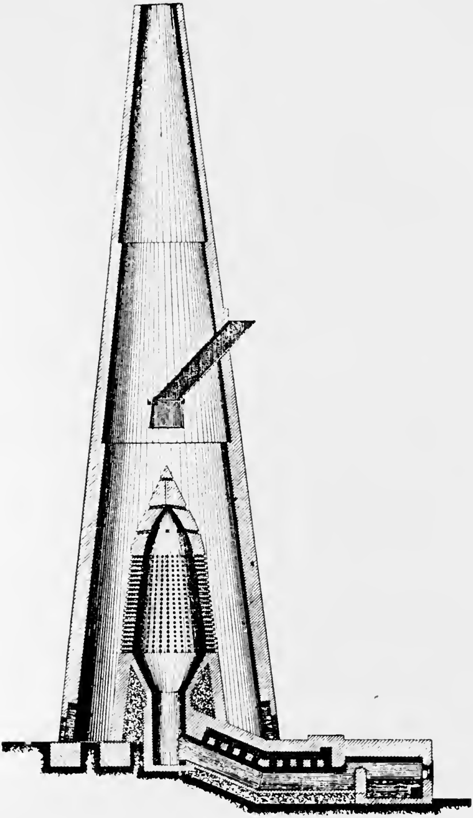

Fig. 5.—Kiln for drying clay.

Fig. 6 represents in section the kind of furnace which is most generally used for flint. It is composed of a truncated hearth, surmounted by a chimney, with a grate below and an opening for the removal of the calcined flint. The height of the kiln is 9 to 12 feet, the diameter of the furnace-mouth 35 to 40 inches, and that of the widest part 55 to 63 inches. Wood is first placed on the grate, and is covered with alternate layers of stone and fuel in equal proportions, so as to completely fill the furnace. Further supplies of stone and fuel are successively introduced in the furnace-mouth in proportion as the mass descends, in consequence of the spaces caused by combustion. As soon as bluish flames are observed on the upper surface of the material, the bars are removed from the grating, the mass falls and forms a sloping heap in the furnace; the space formed at the upper part is filled up with more stone and fuel and the kiln is definitely in work. When the blue flames again appear at the furnace-mouth it is sufficient to draw, by means of hooks, a certain quantity of the calcined substance from the lower part and to fill up the space produced at the upper part by a new charge of stone and fuel.

In the continuous process the proportion of fuel is reduced to about a third part of the volume of the stone to be heated. The fuel which gives the best results is wood-charcoal, but because of its high price it is generally replaced by coke.

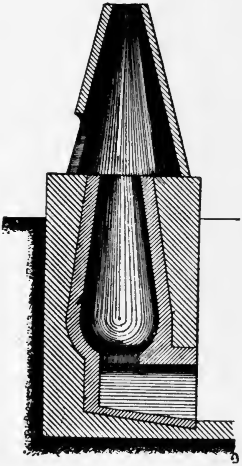

Fig. 6.—Kiln for calcining flint.

The burnt flints taken from the lower part of the kiln are either thrown into water or left to cool in the air. In the first case the breaking up is more complete, but the second process must be used when an impure fuel is employed, and it is necessary to remove by hand the slag which adheres to the flint.

Disaggregation by heat is usually only a preparatory operation which is completed by mechanical concussion, rendered easier by the friability of the calcined stone.

Stampers, which imitate the work of a man with a hammer, were for a long time the only mechanical appliances for crushing employed in pottery manufacture. They have the objection of yielding grains of unequal size, of wearing out rapidly, have a low output, and are very noisy. They are no longer employed except for crushing specially hard materials into small fragments. The construction of a set of stamps is clearly shown in Fig. 7.

For small outputs a single stamper may be used and moved by hand by means of a flying handle.

Centrifugal Grinders rotate at great speed, and the material to be ground is introduced near the centre and projected by the centrifugal force towards the circumference, receiving on its course numerous shocks. These machines may be employed in grinding most raw materials used in ceramics; they can also be used for producing fine powders if the material is sifted on its exit from the grinder or in a separate sifter, though they are not economical when used for very fine grinding. They are not suitable for moist clays, as in this case they have a tendency to choke. They cannot be used to crush materials which must not contain any trace of iron. Their large output and the amount of power needed to drive them limit their use to factories working with a large quantity of raw materials.

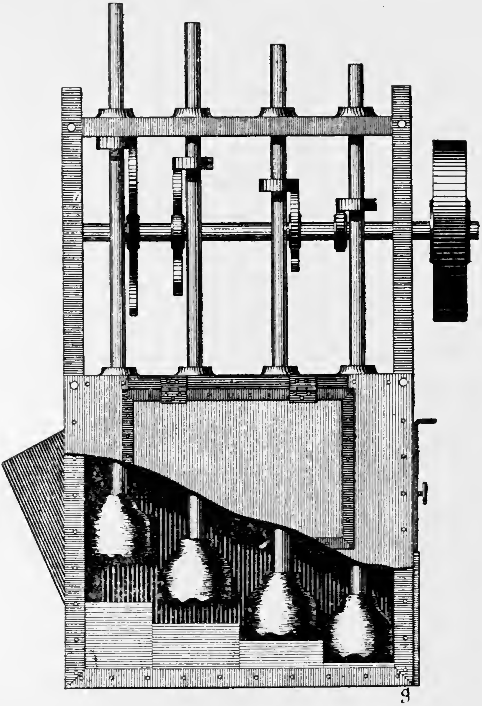

Fig. 7.—Stamp-mill.

Of the many different types of centrifugal grinders the Carr Disintegrator is much used, especially in factories making refractory wares, for the grinding of fired bodies ("grog" or "rough stuff"). It consists (Fig. 8) of two drums, each carrying two circular ranges of steel bars, turning in a contrary direction to each other, the whole being placed in a sheet-iron casing. Each drum is fitted at the extremity of an horizontal shaft worked directly by a pulley. The material to be ground is introduced through a hopper at the centre of the apparatus. There it falls on to the first circle of bars, which strike it, projecting it in one direction until it is struck by the second circle, which turns it in an opposite direction, then by the third turning in the same direction as the first, and then by the fourth rotating in the same direction as the second. The ground material collects at the bottom of the machine, whence it can be removed by a screw, or other suitable arrangement which does not cause clouds of dust. The speed of the machine is regulated according to the degree of fineness of the material desired. Six ranges of bars are often used instead of four.

Several sizes are made, viz. :—

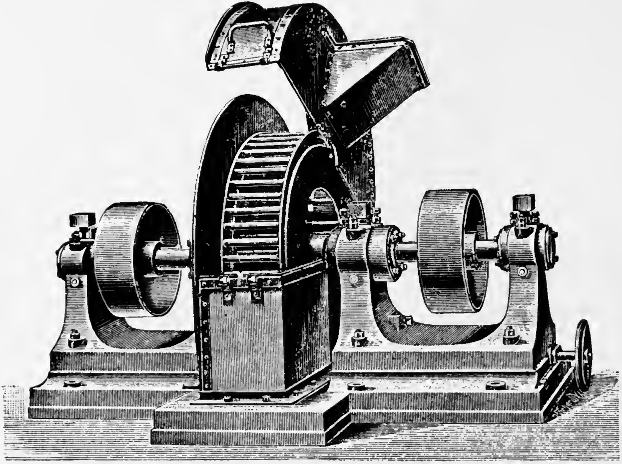

Fig. 8.—Carr's disintegrator.

Diameter of external drum . .	6 ft. 6 in.	5 ft.	3 ft. 3 in.	1 ft. 7 in.
Number of revolutions per minute	300	350	450	600
Output in lb. per hour . .	44,680	26,800	9,000	340
Horse-power used . . .	36	20	4	$1\frac{1}{2}$

Other disintegrators in which rotating arms to which are attached loose "hammers" which beat the material against a grate-like anvil are also popular. With these machines the fineness of the product depends upon the size of the openings in the grate. Replacements are more easily made than in the cage form of disintegrators.

Ball Grinders consist of a case or drum containing balls of different sizes (Fig. 9) and lined with perforated slabs placed like the steps of a staircase, on which the balls roll and fall. The material is introduced at the centre of the drum, and when crushed the pieces, which pass through the holes in the perforated slabs, fall on the exterior ledges which are covered with gauze. Those portions which are too bulky to fall through fall again into the drum in consequence of its rotating movement, and those which are finer are collected in a stationary outside frame. Some ball-mills are provided with slabs, the material remaining in them until it is sufficiently finely ground, when it is taken out and sifted by hand.

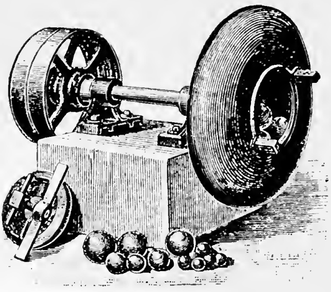

FIG. 9.—Ball-mill (old type).

The sizes ordinarily used are:—

	ft.	ft.	ft.	ft.
Length	12	10	8	3
Diameter	8	8	6	3
Horse-power returned . .	12	8	4	1½

The Carter Mill sometimes used in England and the Cyclone disintegrator of American origin are of this type.

[During recent years the construction of ball-mills has been greatly improved, and they are now used in large quantities, particularly for grinding Portland cement. They constitute one of the best means of obtaining an extremely fine powder.—A. B. S.]

Crushing Machines, or Blake grinders, are used to break hard materials of large dimensions. They are frequently employed as preliminary grinders, for lumps which are too large to be placed directly in other grinders, as they require but little power to drive them. Stone-crushers of this type are not adapted to reducing material to pieces of less than half an inch diameter. They consist (Fig. 10) of a fixed jaw, A, and a movable jaw, B, which can oscillate on a shaft, C; the movement is given by an eccentric, D, mounted on a horizontal shaft, E, provided with two parallel fly-wheels and put in motion by a pulley. This eccentric in its slight vertical displacement causes two cranks, F and F, to rock; the first of these is supported by a prop, G, and the second gives a slight oscillation to the jaw, B, causing any material between the jaws, A and B, to be crushed. The reduced material passes through the opening between the bottom of the jaws which can be adjusted by moving the block, G. The interior surfaces of the jaws, which are the only parts subjected to a rapid wear and tear, are of hard brass, or steel, and are easily replaced.

Stone crushers of this type are very popular in several industries and are manufactured by several firms. They generally run at a speed of 200 to 500 revolutions per minute. These machines are made in several sizes, viz. :—

Upper opening between jaws in inches	24 by 16	20 by 9	16 by 8	12 by 8	8 by 5	8 by 4
Output in cubic feet per hour .	352	212	148	106	70	52
Horse-power employed . . .	14	10	7	5	2	1½

Edge-Runner Mills are frequently used in clay-working, because they can be driven at a low speed, use little power, and wear well.

There are two types of edge-runner mills; in one the axle of the rolls is movable and the slab fixed (stationary pan), in the other the slab is movable and the axle of the rolls fixed (revolving pan).

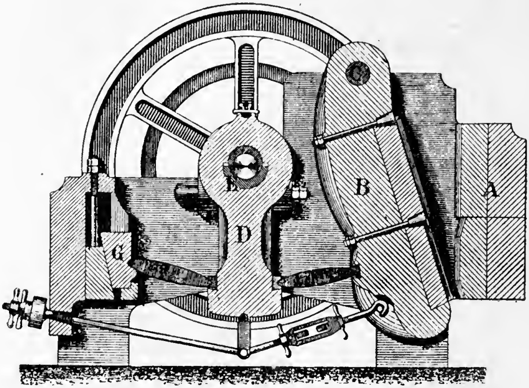

Fig. 10.—Stone-crusher.

The slab or pan may be solid and the ground material is then removed by means of scrapers, or a perforated pan may be used and the crushed material collected beneath it. The weight of the rolls may be altered according to the hardness of the materials to be ground. When it is important that the material should be free from all trace of iron, the rolls as well as the pan are made of hard stone, otherwise they are of chilled iron or mild steel.

Fig. 11 represents an edge-runner mill of the fixed perforated pan type. The rolls are driven by a toothed wheel placed at the top of a vertical shaft, which is connected to the horizontal shaft bearing the rolls in such a manner that they may rise in order to pass over any pieces which are too hard to be ground at the first blow. Scrapers of suitable shape bring the unground materials under the rolls, and prevent lumps of partially ground material accumulating in heaps. The ground material passes through the openings in the pan and is collected on a tray, or removed by an endless screw; the diameter of the pan is usually 9 feet, the weight of the rolls for materials of moderate hardness should be about 1 ton each. The weight of such a machine is about 12 tons, 12 horse-power being needed to drive it. In some machines the driving wheel is fitted below the pan, as shown in Fig. 12.

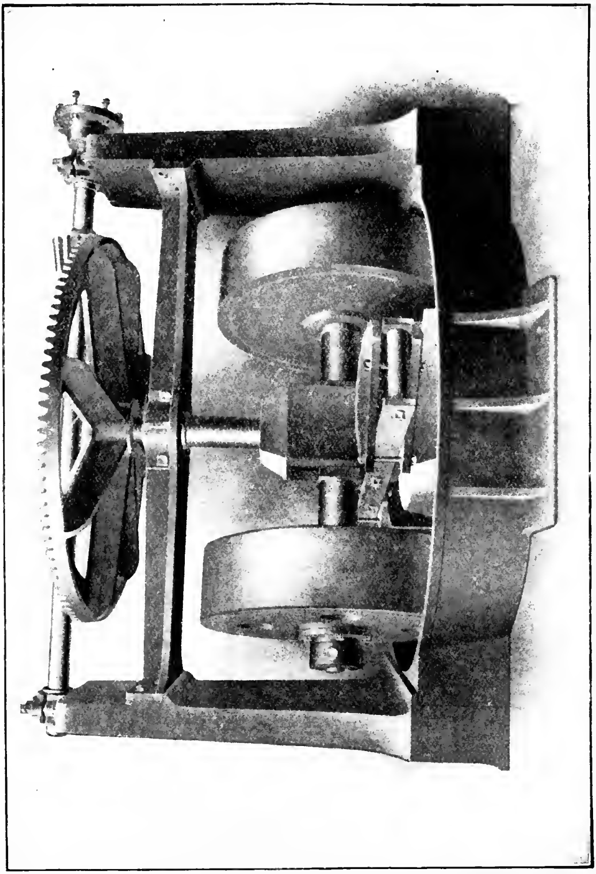

FIG. 11.—Overdriven edge-runner mill.

The two rolls should have their shafts jointed so that they can be raised independently of each other; the scrapers are arranged as in the preceding grinder. Mills with revolving pans are little used in Europe as grinders.[1] They seem to be more in vogue in the United States. Fig. 13 represents a machine of this kind constructed by Thos. C. Fawcett, Ltd.

The pan is usually, but not always, perforated, the rolls rotating independently of any direct drive. They can be displaced vertically by variations in the thickness of the material on the pan; this prevents the machine being stopped by overloading and avoids breakages. Fixed scrapers bring the material under the rolls and keep the pan "clean". The output of this apparatus does not differ from that of a fixed pan mill, and, though slightly more complicated in construction, it works admirably and occasions less dust.

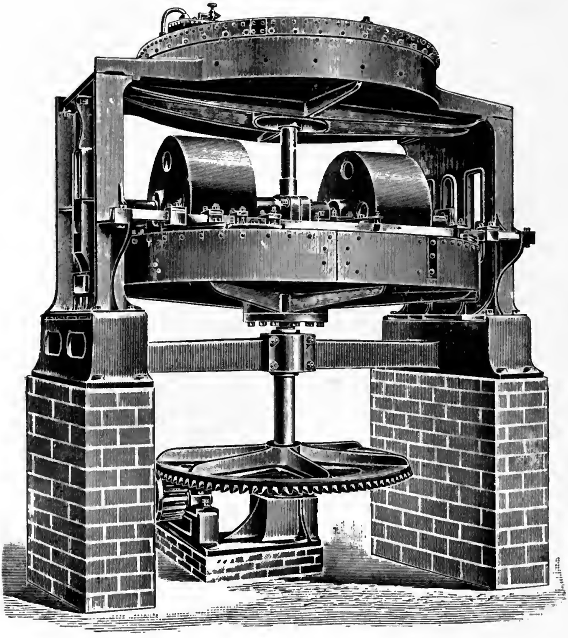

FIG. 12.—Underdriven edge-runner mill.

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[1] Whatever may have been the case when Bourry wrote this statement, it is certainly incorrect in 1910, as edge-runner mills with revolving pans are now in use in large numbers, particularly for grinding shales for brickmaking.—A. B. S.]

Crushing Rolls.—Although rollers are well adapted for grinding hard materials, they are only employed in clay-working to break up lumps of clay when "weathering" is not sufficiently powerful for this purpose. These rolls should be of a sufficiently large diameter to enable them to seize the lumps. Each roll turns at a different speed, so as to add a rubbing action to that of crushing. The distance between the rolls should be capable of easy regulation, and some form of safety appliance should be provided to prevent damage to the machine, in case a piece of exceptional hardness (such as a lump of metal) falls between the rolls. Weighted levers, india-rubber pads, or powerful springs can be used for this purpose. Scrapers are arranged beneath the rolls to clean off any clay which may adhere to them.

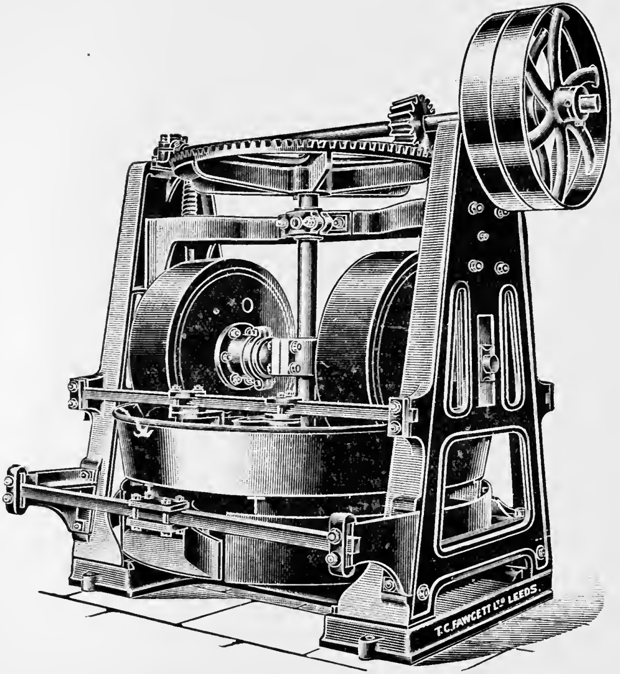

Fig. 13.—Edge-runner mill with revolving pan.

Crushing rolls are often plain, as Fig. 14, which represents a grinder constructed by W. & W. Wills, Ltd., but sometimes they are fluted, or have projecting parts or teeth in order to seize the clay better.

For very difficult and impure clays, it is necessary to use several pairs of successive rolls. The following are particulars of ordinary crushing rolls:—

Diameter of rollers in inches	16	40
Width of rollers	16	28

Output varies from 176 to 362 cubic feet in ten hours for the smaller sizes, and 1400 to 1750 cubic feet for the larger ones.

The driving power required is 2 to 3 horse-power for small rolls and 8 to 10 horse-power for large ones.

Cutters are only employed for clay, or for very friable substances. They are constructed of discs driven at a high speed, knives being attached so as to cut the materials. The chopped material passes out through openings in the discs and between the knives.

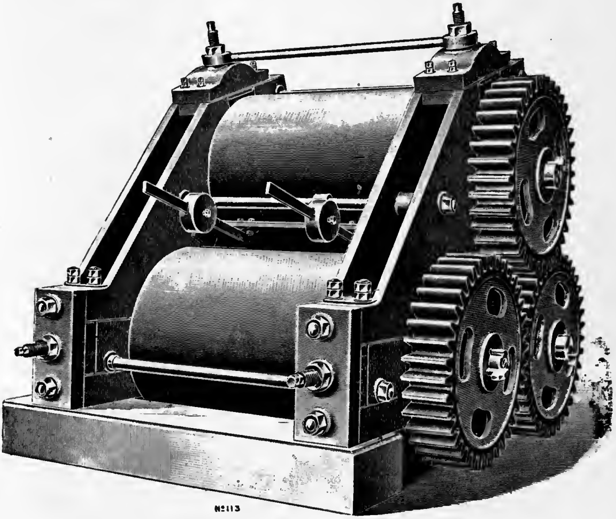

Fig. 14.—Crushing rolls.

When the clay is in the form of large compact and heavy clods, the disc of the cutter is placed vertically, and these clods descend through a chute and lean against the disc, but with smaller pieces of clay it is better to make the disc turn horizontally. The material to be cut then rests with all its weight on the disc, and a cross-beam prevents it from being carried away by a rotary movement.

According to Boulet & Cie., a machine of this kind, having eight knives, a total weight of about 22 cwt., and making 150 revolutions per minute, cuts from 4 to 6 cubic metres of clay per hour, using a force of two horse-power.

Granulators.—The object of granulators is to break slightly plastic or open clays into small pieces; they are much used in America. Fig. 15 represents a granulator, constructed by Chamber Bros. & Co., and consists of an inclined plane, at the bottom of which is a beam provided with knives arranged spirally. The clay, being placed in a tray by the side of the mechanism, is cut and pushed at the same time until it falls in a granulated state over the upper end of the plane. The incline is varied according to the size of the grains which it is desired to obtain. These machines can granulate 3525 to 7050 cubic feet of clay per day.

(*b*) *Purification.*

The Processes of Purifying raw materials used in ceramics are the following:—

(1) *Sorting*, nearly always done by hand, but also by machines, so that the coarse impurities may be removed when they differ sufficiently from the material to be purified in colour, coarseness, or density.

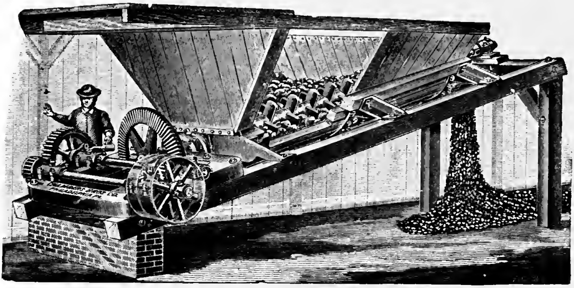

Fig. 15.—Granulator.

(2) *Sifting*, by which the coarsest parts are separated from the finer, as the former remain on the sieve and the latter pass through it.

(3) *Washing*, that is to say, separating by mixing with water, the parts which remain longest in suspension being poured off with the water whilst those which settle more rapidly remain behind. The object of washing clays is to eliminate the materials which settle first; but in the levigation of sands, quartz and felspar, etc., the parts which remain in suspension must be removed, and the residue retained.

(4) *Air-separation* is a process having the same object as washing, but the water is replaced by a strong current of air. This process is seldom used, and is only applicable to fine materials.

(5) *Electrical purifying* in certain cases enables a part of the pyritic iron to be removed from powdered materials.

(6) *Chemical purification* produces by the action of certain substances the elimination of injurious materials or transforms them into inert bodies.

Sorting by hand is much employed for separating the coarse impurities which raw materials can contain. This operation is generally carried out in the place of origin, or in its proximity, often by women and children.

It is usually employed on a large scale for raw materials of value such as kaolin and felspar, but only as a preliminary purification to be followed by washing; for commoner materials, such as ordinary clays, sands, etc., it consists in the elimination of such impurities as stones, pieces of metal, foreign minerals or roots.

Stones and the coarsest hard bodies which some lean clays contain may sometimes be separated mechanically by passing them through conical rolling machines which flatten the clay; the stony impurities, in consequence of the difference of circumference and speed, are displaced and fall over the ends of the rolls.

The efficiency of such purifying rolls depends greatly on the nature of the clay, on the "conicity" of the rolls and their distance apart.

Sifting.—In ceramics three kinds of sifting can be distinguished, viz.:—

(1) The sifting of dry, pulverulent materials, which generally follows grinding and does not really purify but merely separates the grains of different sizes, as when dry clays are sifted in order to remove the coarser particles which they contain. [If the impurities are coarser than the clay a certain amount of purification may be effected by sifting.] This kind of sifting is carried out on screens, riddles, or sieves. It offers no peculiarity worth mentioning.

(2) Sifting of liquid materials, which occurs in the course of purifying by wet grinding, and in the preparation of body slips. [Fine sieves or lawns are used for this purpose.]

(3) Sifting of pasty materials, such as plastic clay. This operation is carried out by compressing the clay to be purified into a box with perforated sides and by forcing it out through orifices of suitable dimensions, the coarser impurities remaining in the interior. Various forms of apparatus have been constructed on this principle and differ only in the nature of the force employed and the mode of transmitting it.

Fig. 16 represents a purifier constructed by Chambrette. It consists of a cylinder, perforated with holes, fitted round a horizontal beam, and of a mechanism for driving the compressing piston. The perforated cylinder being placed vertically, it is filled with clay, then lowered to a horizontal position, and by means of a handle acting by two intermediary gear-wheels the workman forces the piston to penetrate into the cylinder, compelling the clay to make its exit by the holes, while the stones remain in the cylinder. When the piston has reached the end of its course it is brought back again rapidly by working a second handle fixed on one of the arms of the large wheel. The cylinder is again placed in a vertical position and the bottom of it is opened so that the stones which have accumulated in it fall out. With this arrangement a man can purify 140 to 275 cubic feet of clay per day.

Fig. 17 represents a similar purifier constructed by Groke. In this case the compression box is triangular in form and the sieves are parallel sheets mounted on hinged doors. A fly-wheel with levers causes a triangular piston to rise or fall. The operation is carried on in the same manner as in the preceding machine.

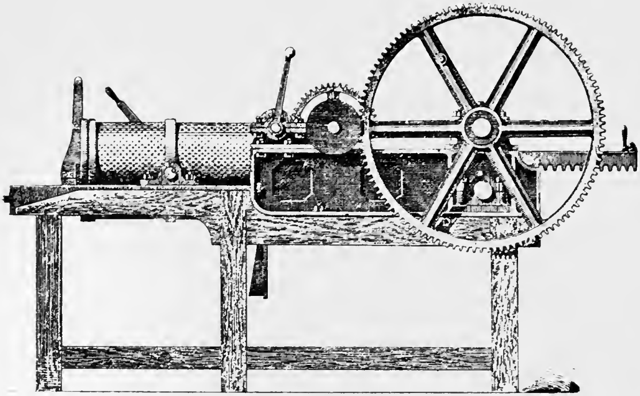

Fig. 16.—Clay separator.

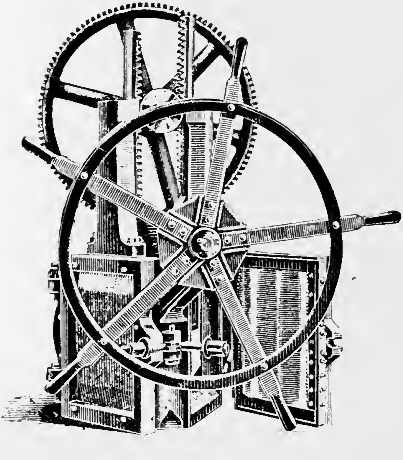

Fig. 17.—Clay separator.

In order to obtain a larger output hydraulic power may be used in a machine consisting of two cylinders perforated with 1500 to 1800 holes, and can be turned round one of the uprights of an hydraulic press, one of them being filled or cleaned whilst the other is under pressure. This machine can purify 560 to 700 cubic feet of clay in ten hours; the total pressure on the piston is about 10 tons.

All the preceding machines act in an intermittent manner, but by using a screw propeller can be made continuous, though in this case only those clays can be purified which are in the form of a fairly soft body.

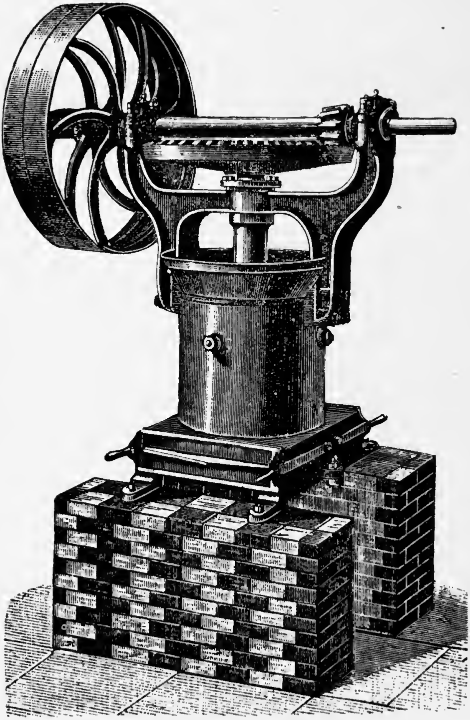

Fig. 18.—Clay separator.

Fig. 18 represents an arrangement of this kind adopted by Brethon, in which the clay loaded at the top of the vertical cylinder is compressed towards the lower by spiral knives, and is compelled to pass through the holes perforated in the bottom of the cylinder. Another knife just above the bottom of the cylinder drives the stones towards the sides, whence they may be removed by gradually opening one of the movable panels from time to time.

Purification can always take place in a continuous manner by using a pair of rolling machines to propel the clay into a box, closed by two movable panels carrying a sieve. From time to time the panels are opened to allow the stones to pass out. A machine of this kind is constructed by the firm of Smidth & Cie. and is known as the Elapidator. Clays which do not occur in a sufficiently soft and plastic body must be prepared by one of the processes mentioned later (see p. 82 *et seq.*).

Washing of Clays.—The object of washing is to separate the coarsest and heaviest particles of clay, which settle rapidly from the finer and lighter ones, which remain longer in suspension in water. Only the coarsest impurities are removed, while those which are frequently in the form of very fine powder, such as sand, carbonate of lime, and oxides of iron, remain at least partially incorporated with the true clay. There is, however, a complete elimination of soluble salts.[1]

Washing is generally employed for china clays, and plastic clays used for the manufacture of porcelain ware, fine stoneware, faience, and terra-cotta. It is too costly for it to be employed for common clays, which are used for the manufacture of architectural terra-cotta and bricks, except in those districts where no sufficiently pure clays are to be found.

The details of the methods of washing vary, for they depend on the nature of the clays, on the degree of purity which it is requisite to obtain, and on the value of the product, but whatever method is employed it necessarily includes three stages:—

(1) Blunging or mixing the clay with water.
(2) Separation of the grit and sand.
(3) Placing the clay in settling tanks.

These different operations will be dealt with in order.

Clay Blungers.—China clays and other open clays are easily blunged in water, and they can be washed as soon as mined. With plastic clays the operation is more difficult, and it is usually necessary to break them up by one of the processes previously described. Natural or artificial drying is the one most employed, and it is the most efficacious.

When small quantities of clay have to be ground, the blunging can be done by hand, by placing a certain quantity of the clay in vats filled with water, and agitating it by means of rakes and paddles moved by one or more workmen. When all the clay is suitably blunged, it is run off into settling tanks through an orifice placed a little above the bottom of the vats in front of which is a grill which retains the grit. The vats are refilled several times, until the deposit of grit has reached the height of the grill; it must then be removed by a shovel and the vat cleaned.

Open clays such as china clays, and when a large quantity of water may be used, can be blunged hydraulically, by being subjected to a jet of water under pressure, which breaks up the clay, carries away the fine parts and leaves the grit behind. For this purpose the clay may be placed in a vat which is refilled from time to time; the

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[[1] This is not strictly correct, as clays absorb salts so that they cannot be washed out.—A. B. S.]

blunged portion flows away in a continuous manner, the operation only being interrupted when it is necessary to remove the grit accumulated in the vat. For the washing of china clays containing stones of large size this hydraulic method is much employed in Cornwall; the rock in its place of origin being attacked directly by powerful jets of water. The stones accumulate at the base, whilst the water which carries away the clay is conducted into large basins.

Besides these special cases, blunging may be effected mechanically, two kinds of mechanical blungers being used; those with a vertical shaft are preferable for open stony clays, and those with a horizontal shaft are more suitable for blunging plastic clays.

Fig. 19 represents a machine of the former kind for medium outputs. The central vertical shaft, carrying two wooden arms, works in a circular vat, the liquid being agitated by a rotary movement. From time to time a quantity of clay and a corresponding volume of water are added. The blunged clay may flow out in a continuous or intermittent stream, by opening one of the wooden stoppers which close the outlets placed in the sides of the vats at different heights. The gritty substances accumulate at the lower part, and may, according to their consistency, be removed by hand from time to time from above, or it may be washed through a lower clearing hole by a stream of water. It frequently happens that when the working of the blunger is stopped for some time, the clay originally in suspension settles and forms with the grit a fairly hard mass, which may break the spikes of the harrows when the mill is started. In this case, the harrows of the blunger should be first turned by hand by means of the levers shown in the illustration until the hard mass is broken up.

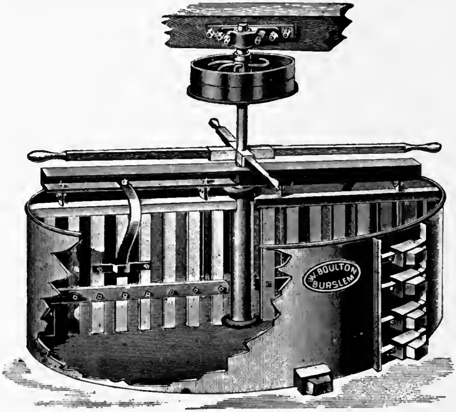

FIG. 19.—Blunger.

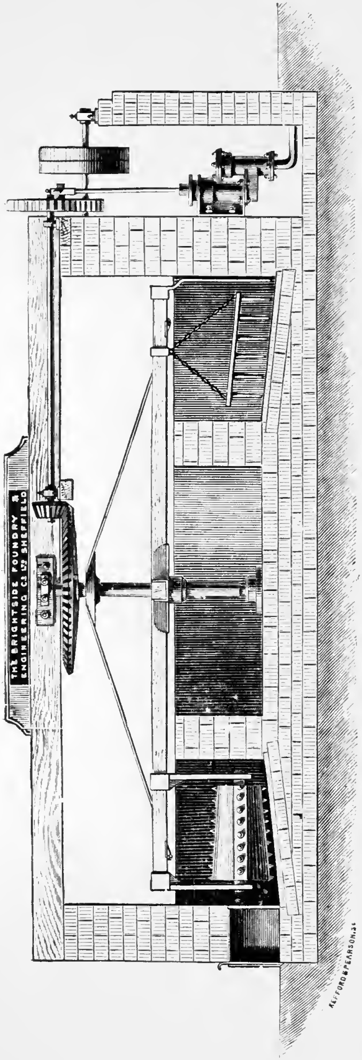

FIG. 20.—Wash-mill.

In England this mill is usually employed for milling Cornish stone and flint.

For large outputs and particularly for clays which are very stony, the wash-mill, shown in Fig. 20, is used. It consists of a circular trough, in which two or three wooden harrows suspended by chains are rotated, the clay and water are introduced at regular intervals, the slip or slurry flowing out continuously through an orifice provided with a grating placed at a short distance above the bottom of the mill and acting as a dam. The grit accumulates at the bottom of the mill, and in proportion as its thickness increases the length of the chains is shortened, thus raising the harrows; this flexible suspension has the further advantage of preventing damage on re-starting the mill. Many attempts have been made to render the working of these blungers absolutely continuous, the grit and stones being removed by elevators or screw conveyors, but the advantage which results therefrom is counteracted by the greater repairs needed. It is better to stop and clean out every ten or fifteen days.

The proportion of water used in these blungers is two or three times the weight of the clay. Their output depends entirely on the tenacity of the latter and on the power used. For medium outputs horse-driven machines may be used, but for larger outputs a mechanical propeller is necessary. In this case, the quantity of clay washed may reach 1760 and even 2550 cubic feet in twenty-four hours.

Blungers with an horizontal shaft are formed of a drum, in which this shaft, provided with knives, rotates. Either the drum may be rotated, the shaft being fixed, or the shaft with the knives revolves inside the fixed drum, or, finally, both may be made to move in opposite directions. The arrangement for the supply of water and clay, as well as the egress of the blunged clay and grit, have roused the ingenuity of constructors. The two following are only given as examples. Fig. 21 represents a blunger with fixed framework in which is a shaft carrying, by means of three sheet-iron discs, six wooden cross-bars, on each of which are placed six blades. The clay is introduced by a lateral hopper which is then closed by a cover to prevent the water being thrown out; the slip is withdrawn through a lower pipe, the clay and sand being carried out by the water, the apparatus only being suitable for clays which are not very stony. The dimensions of these blungers vary from 6½ feet to 22½ feet in width, and from 3 to 10 feet in diameter. The speed of rotation is from 15 to 30 revolutions per minute, 1 to 3 horse-power being required, 175 to 875 cubic feet of clay being washed per day.

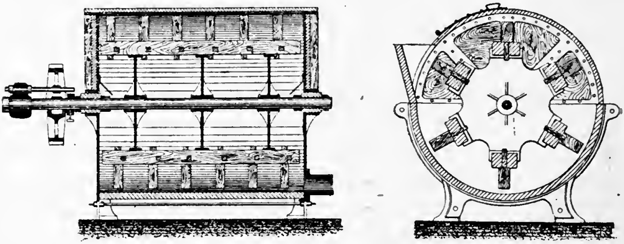
FIG. 21.—Horizontal blunger.

In the Schmelzar blunger, the clay is fed in a continuous manner by a shovel, at the same time as a small quantity of water, into a kind of pug-mill mounted on a horizontal shaft. The clay is there broken up and then passes in the form of a pasty substance into a neighbouring box where it is blunged with a large proportion of water. From there it falls into a sifting framework which allows the clay and blunged sand to pass; the gritty substances are retained and brought to the extremity of the apparatus, where they fall into a hopper. One hundred and eighty to seven hundred and fifty cubic feet of clay may be blunged daily according to the size of the apparatus and the nature of the clay.

Sand Separators.—In all the preceding machines, the stones and grit which the clay contains remain in the blunger, or are there separated from the other parts carried away by the washing water; a sieve at the outlet of the apparatus regulates the maximum size of the grains removed at the same time as the clay. Sometimes this treatment is sufficient, and the liquid going to the settling tanks may be used direct, but more often it is necessary to eliminate most of the sand contained in it.

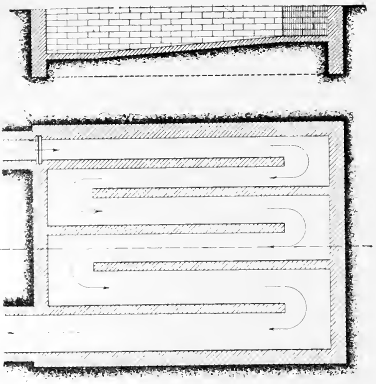

Fig. 22.—Sand separator.

For this purpose it is sufficient to gradually reduce the speed of the liquid according to the degree of purity which it is desired to obtain. For small quantities it is sufficient to allow the liquid from the blunger to flow into a tank, where it is allowed to remain at rest for a length of time according to the degree of purity to be obtained. The surplus liquid is then run off into settling tanks, or "backs".

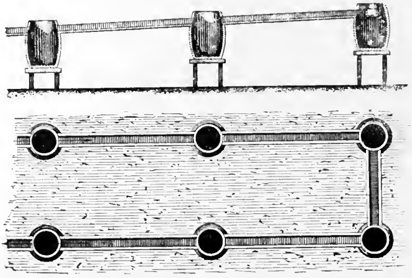

Fig. 23.—Sand separator.

For large outputs, the separation is carried on in a continuous manner, by running the liquid from the blungers into conical stonework channels coated with cement, or wooden trenches. Fig. 22 represents a sand separator of this kind. The sand, which settles at the bottom of the pipes, is removed twice daily with a shovel, or by means of a stream of water.

Fig. 23 shows another type of sand separator in which the slip flows down wooden trenches, leading every 10 or 13 feet into casks, at the bottom of which the sand settles, and should be removed by hand from time to time. The length and slope of these trenches and the number of the casks determine the degree of purity obtainable.

Settling Tanks.—Whatever may be the process of washing, the liquid holding the clay in suspension is finally sent into tanks, where all the solid parts settle. For clays intended for the manufacture of fine wares, several medium-sized settling tanks should be filled successively. For the manufacture of ordinary fired bodies, tanks of large dimensions may be used, in which the deposit is much less homogeneous, the more sandy particles naturally depositing themselves near the point of entry of the liquid.

These tanks are provided with lateral outlets, at different heights to allow the clean water to flow away. A pipe with a movable joint may also be used as shown in Fig. 24. When all the surplus water has been removed, the clayey mass is still too soft to be used; it is necessary to allow it to stiffen by slow evaporation of part of the remaining water, the most tiresome of the operations of washing, for it requires much time and space. Attempts have been made to shorten it by means of filtering tanks, the base of which is formed by a layer of sand in which drain-pipes are placed. This arrangement acts very well for a time but the pipes rapidly clog. Apart from this, a porous floor ought to make such filtering tanks preferable to those with an impermeable floor.

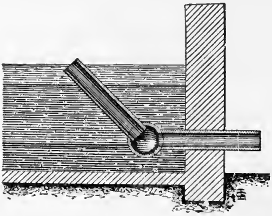

FIG. 24.—Decanting pipe.

The stiffening of small quantities of clay may be hastened by removing it from the tanks and placing it in small heaps to dry in the sun. Filter presses may also be used for the same purpose, and are described in the preparation of bodies by the liquid method (p. 95).

Settling tanks usually have a height of 3 feet 3 inches corresponding to a deposit of clay from 8 to 12 inches in thickness. But it must be remembered that this clay, which is deposited in successive layers, is not homogeneous, the most sandy parts being at the bottom. It is expedient, therefore, to dig it out vertically in order to have a fairly regular composition.

In all plants for washing clays it is necessary to make use of natural variations of level, or to raise the clay to be washed to the highest point, the decanting basins being at the lowest part. If this cannot be done, an elevating apparatus, such as bucket elevators, plunger pumps, etc., must be used. When the sand is in small proportion and very fine, pumps with simple working pistons and spherical valves can be satisfactorily used.

In **Washing Sands** and other non-plastic materials, two objects are in view :—

(1) To remove the earthy impurities.

(2) To separate the coarsest parts in order to obtain a fine homogeneous material.

For the first, clay blungers as described above may be employed. If the materials to be retained are coarse, they remain in the blunger, and are drawn out when the water runs off clear. If, on the contrary, the fine materials are needed they are allowed to flow into settling tanks from which the surplus water is removed later. Stiffening takes place very rapidly, and offers none of the difficulties met with in washing clay.

The same process allows the grading or classification of sand into grains of decreasing sizes.

Air Separation.—By directing a current of air on to pulverized materials they are placed in suspension in the air, as they would be in water. If the speed of the air current is diminished, the coarsest particles settle first, and the finest impalpable powders only fall when the air current is stopped. Separating by air, therefore, acts in the same way as washing, and in certain cases it can economically replace it.

This process is but rarely employed, and chiefly for the purifying of china clays. The latter, in consequence of the notable differences in density which exist between clay and rocky powders, lend themselves best to this method. The china clay is first reduced to a fine powder by pulverizers and placed in a hopper, whence it flows in front of the blast pipe of an air-separator. The air current then enters a pipe of increasing diameter and ends in a rather large chamber. The dimensions are calculated in such a manner that the parts which it is desired to eliminate settle in the pipe, and only the purified china clay enters the chamber. The air leaving this chamber ought to be sifted through canvas or packing, which must be beaten from time to time.

Electrical Purification.—Iron and magnetic oxide of iron may be removed by utilizing their magnetic properties. The material to be purified should be reduced to a powder and suspended in water, so as to give to the parts to be eliminated a sufficient mobility to enable them to be drawn by electro-magnets.

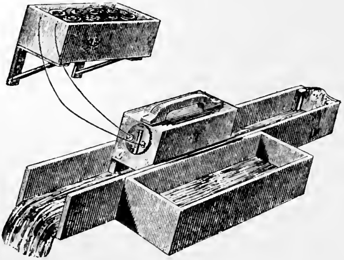

FIG. 25.—Electro-magnet purifier.

When the material is pulverized it is placed in a trough in the midst of which magnets are caused to turn, and they are removed from time to time to clean the iron, etc., particles which adhere. A commoner process makes use of the arrangement shown in Fig. 25, the material to be purified being placed in suspension in water, flows in the form of thin sheets through a trench, above which are placed the electromagnets, traversed by a current coming from an ordinary battery. From time to time the flowing is stopped, the magnets are removed, they are placed in a trough filled with water placed at the side, and the current is interrupted so as to make the ferruginous particles which have adhered fall. This process of purifying is used in certain earthenware and porcelain factories for removing metallic iron from the body.

Chemical Purifying.—It is only in very rare and quite special cases that raw materials used in ceramics can be purified chemically. The mellowing or "laying" of clays appears, however, to rest on a chemical reaction. Salvetat has admitted that under the influence of water charged with organic substances in decomposition the sulphate of lime contained in certain clays can be reduced to sulphide of calcium. This last salt, in contact with the carbonic acid of the air, is decomposed in its turn with an evolution of sulphuretted hydrogen, which is often easy to observe. Moreover, the colouring of the body black, which is sometimes produced in this case, as well as its bleaching when exposed to air, can be explained by the formation of black iron sulphide which on oxidation produces colourless sulphate. Sulphates often produce efflorescence or scum on the surface of terra-cottas and bricks, in consequence of its relative solubility in the water of formation. This scum can be neutralized most efficaciously by adding to the clay some salt of baryta, such as the chloride or carbonate. It then produces a double decomposition :—

$$CaOSO_3 + BaCl_2 = CaCl_2 + BaOSO_3,$$

or

$$CaOSO_3 + BaOCO_2 = CaOCO_2 + BaOSO_3.$$

In the first case, the chloride of calcium produced is easily removed in consequence of its great solubility; in the second, the carbonate of lime is insoluble as well as the sulphate of baryta, and can no longer produce efflorescence. The use of carbonate of baryta is preferable; it is obtainable in the form of a powder containing up to 97 per cent of barium carbonate. It is essential that this powder should be very fine, in order that chemical action may be produced completely without it being necessary to add too great an excess of reagent.

The proportion of barium carbonate to be added is easily calculated when the amount of sulphate in a clay is known, but it is expedient to multiply the quantity theoretically necessary by 1·5 or 2. Witherite is found in different parts, chiefly in the Rhine provinces, where it is sold in a pulverized state, at 100 to 130 francs per ton. [A chemically prepared barium carbonate is in many ways superior to witherite.]

The use of dilute hydrochloric acid is to remove the carbonate of lime contained in bodies by formation of chloride of calcium, which is removed by washing. This process has never been employed on a large scale, as the acid affects the clay. Washing with acidulated water will also eliminate some of the oxide of iron, which becomes soluble unless the iron is in the form of silicate. In this case the silica could only be displaced by a prolonged fusion with soda or potash.

3. Preparation of Bodies.

The raw materials having been broken up and purified, the next stage in the manufacture consists in mixing them in the correct proportions in such a manner as to produce a uniform body having the desired composition and consistency. This preparation of bodies includes three series of operations which may be carried out successively or simultaneously.

(1) The measurement of the raw materials.
(2) The mixing to render the body homogeneous.
(3) Operations to give suitable consistency.

Bodies are prepared by:—

(*a*) Plastic methods, in which the materials are mixed to form bodies of the desired consistency. "Soft body" is distinguished from "stiff body" by its consistency.

(*b*) Dry methods, in which the materials are mixed in the form of dry powder, being moistened later if necessary, in order to obtain the desired consistency.

(*c*) Liquid methods, in which the materials are blunged and mixed with water, and partially dried in order to give the body the necessary consistency.

Plastic methods are usually the least costly; they are preferred in the manufacture of bricks and terra-cotta for buildings, pottery ware made of refractory materials, faience and common stoneware, especially when clays are used which naturally have the desired composition. They do not prove suitable in cases where the proportions of the materials must be accurate within narrow limits, and become laborious if it is desired to obtain perfect uniformity of composition.

Dry methods, on the contrary, lend themselves to an exact apportionment; the materials may be easily mixed and the texture of the body may be coarse or fine at will. They are often employed in the manufacture of refractory goods, some architectural terra-cottas, faience, and common stoneware. The only drawback is that only those materials which are sufficiently dry to be crushed can be used. When a very fine texture and intimate mixture is desired, a liquid method should be used, though it is more costly and more complicated than the others. This last is the method used in the manufacture of porcelain ware, faience and fine stoneware.

(*a*) *Preparation by Plastic Methods.*

In plastic methods there are usually two distinct operations: (*a*) the apportionment of the raw materials and the water, and (*b*) the mixing of the materials. According to the amount of moisture in the raw materials they are treated in one of three ways:—

(1) Raw materials which contain a suitable proportion of moisture

are placed directly in the mixing machine in the desired volumes, as three barrowfuls of plastic clay, one of open clay, and one of sand.

(2) Raw materials which are too dry to make plastic bodies must have water added to them.

An open lean clay, which easily absorbs water, may be placed on the ground, or better, on a board, in heaps 3 feet to 4 feet 6 inches high, formed of horizontal layers of various raw materials, the thickness of each layer corresponding to its proportion in the body, as 15 inches of plastic clay, 5 inches open clay, 5 inches sand, then again 15 inches plastic clay, and so on. During the formation of the heaps they are sprinkled with water from a hose or watering-pot, and the whole is left for at least twenty-four hours and as much longer as possible, so that the moisture may distribute itself evenly throughout the whole mass; the heaps are then cut vertically and the pieces brought to the mixing machine.

Dense clay, which absorbs water with difficulty, is similarly treated, except that the successive layers are placed in pits and water is added until the material is covered. Any excess of water may be removed by opening a bung hole provided in the lower part of the pits. The pits are usually 3 feet 3 inches to 6 feet deep, and have a capacity of 8 to 35 cubic yards; they are dug out of the ground and lined with cement or bricks. The mass should remain sufficiently long in the pits for the clay to be completely broken up and thoroughly soaked. The usual time is twenty-four to seventy-two hours.

(3) Raw materials which are too moist, as in wet weather, when clay is obtained from beneath water, or has been washed, should be mixed with dry powdered clay and then treated as in (1) or (2). Sometimes the dry clay may be replaced by broken products which have been thrown out of shape during the drying.

The **Homogeneization** of the body comprises two operations: *grinding*, by which the lumps of clay, pebbles and stones are crushed; and *pugging*, the object of which is to mix intimately all the substances which compose the body.

These two operations ought not to be considered as quite distinct, for grinding rollers cause a certain amount of mixing and pug-mills break up lumps in the clay. When the body contains neither pebbles nor grit, grinding is unnecessary and pugging may be sufficient, but the latter is an indispensable operation for the obtaining of a body of uniform composition.

Grinding can only be done by mechanically-driven mills, as small rolls worked by hand are not efficacious.

Rolling mills usually consist of two hard cast cylinders, driven by two cog-wheels, the teeth of which are arranged so as to be adjusted for wear and tear. Except for their dimensions they are similar to roller grinders (Figs. 14 and 26). They generally rotate at different speeds so as to break up the clods of clay efficiently, and are provided with scrapers in order to detach those which adhere.

The outputs and power required are shown in the following table:—

Diameter. Inches.	Length. Inches.	Output in Cubic Yards per Hour.	Horse-power.
11	11	1	2 to 2½
15	15	2 to 3	3 to 4
19	19	4 to 5	5 to 6
23	23	7 to 8	8 to 9

When the clods of clay are too large or the stones too numerous they must be passed through two or three pairs of rollers in turn, the upper rollers being set apart, while the lower ones are put as close together as is suitable to obtain the desired degree of fineness of the product. The second and third pairs of rolls rotate more rapidly than the first, in order to allow them to deal with the same quantity of body.

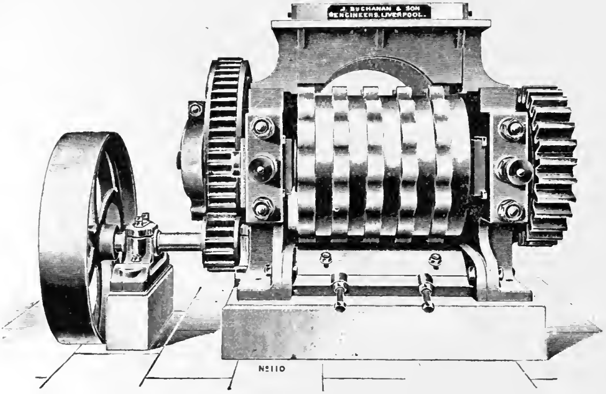

FIG. 26.—Kibbler crushing rolls.

The amount of mixing produced by the rolls may be increased by fluting them, or by making them conical in form, the smaller diameter of one being placed in front of the larger diameter of the other. Scrapers remove any material which may accumulate. For an equal output the power required for these rolls is nearly double that consumed by plain rollers.

Pugging was formerly done by treading the clay with feet on floors, or in shallow pits. This work is still carried on in the same manner in some cases, as in making crucibles for steel melting, or by means of horses or oxen which walk round and round a circular track.

Vertical or horizontal pug-mills are now almost exclusively used.

Vertical pug-mills consist of a cylinder closed at the base, in which a movable shaft carrying knives at different heights rotates. The body is introduced at the top and passes out through a lower opening, the size of which can be regulated at will. Fig. 27 represents a pug-mill of this kind. Sometimes pug-mills are underdriven, but, unless under special circumstances, this arrangement is not to be recommended. For a small output the driving-power can be replaced by manual labour or a horse, in which case the driving shaft is fixed directly on to the shaft of the pug-mill.

The material descends by its own weight, but in order to increase the output the knives should be arranged in spiral lines, so as to compress the clay towards the base. Vertical knives are also provided to divide the mass. At the bottom of the pug-mill a double knife is fitted to drive the pugged body towards the outlet.

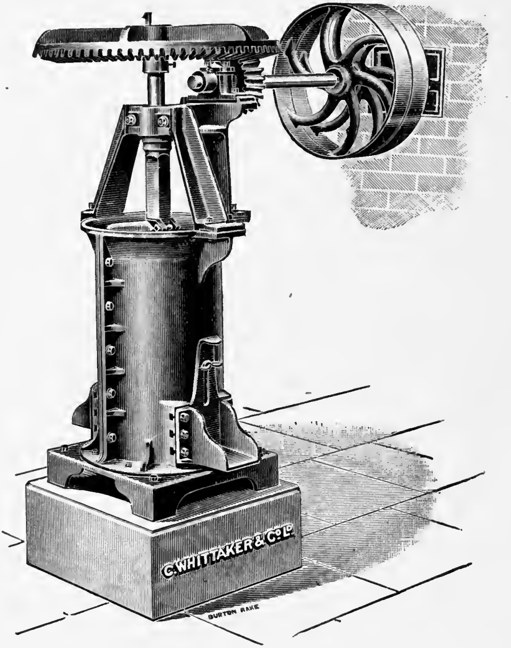

Fig. 27.—Vertical pug-mill.

Pug-mills are constructed with a diameter varying from 20 to 40 inches, and a height from 40 to 80 inches, the shaft making from 8 to 12 revolutions per minute; their output depends entirely on the degree of plasticity and the consistency of the body. For lean clays having a consistency corresponding to that of clay used for hand moulding one horse can pug about $1\frac{1}{4}$ cubic yards per hour. For plastic clay the same result can only be obtained with two or three horses. Pug-mills worked by mechanical power are of the dimension given below :—

Diameter. Inches.	Length. Inches.	Output in Cubic Yards per Hour.	Horse-power.
20	40	0·7 to 1·2	1 to $2\frac{1}{2}$
28	59	1·5 to 2·5	2 to 4
36	78	2·5 to 4·0	3 to 6

When it is desired to obtain stiffer bodies, it is preferable to use horizontal pug-mills (Fig. 28) consisting of a horizontal sheet of cast iron in the centre of which a shaft with knives rotates. The material enters one end and passes out at the other.

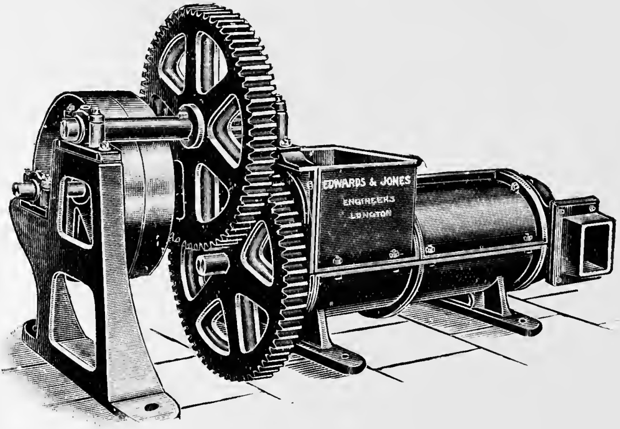

Fig. 28.—Horizontal pug-mill.

The knives (Fig. 29) being of cast iron or with a shank of cast iron and adjusted blades of iron or steel are helicoid in shape, corresponding to $\frac{1}{8}$ to $\frac{1}{2}$ spiral. Usually the width of the knives increases from the inlet of the pug-mill to the outlet. Contrary to what takes place in vertical pug-mills, the body, especially if it is rather plastic, tends to turn with the blades, and to prevent this movement, which would stop nearly all the mixing, some "counter knives" are fixed in the cylinder (Fig. 30).

Horizontal pug-mills are constructed with diameters varying from 16 to 28 inches, lengths from 59 to 98 inches; the speed of rotation being 10 to 15 revolutions per minute. The output is approximately as follows :—

Diameter. Inches.	Length. Inches.	Output in Cubic Yards per Hour.	Horse-power.
17	78	2 to 3	3 to 5
23	78	4 to 6	5 to 8

Horizontal pug-mills can also be constructed with two rotary shafts bearing knives turning in opposite directions, according to the arrangement shown in Figs. 31 and 32. The machine, generally of sheet iron, is open above. The material is fed in at the side of the machine, and passes out by a lower opening at the other end. The shafts are supported at one end by fixed gearing, and at the other by ring bearings. The knives are helicoid in shape, corresponding to $\frac{1}{8}$ or $\frac{1}{10}$ spiral. They work in footsteps of square or octagonal sections in four directions. These pug-mills are constructed with a

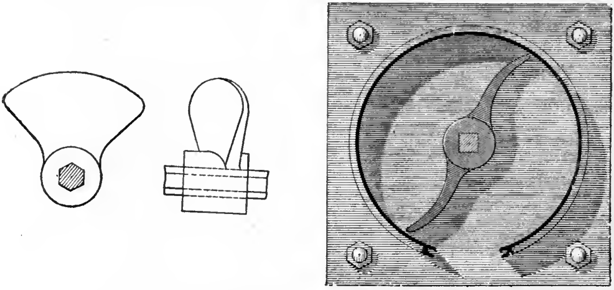

Fig. 29.—Pug-mill knives.

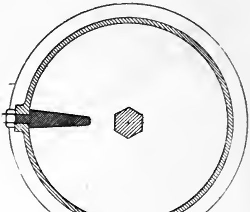

Fig. 30.—Counter knife.

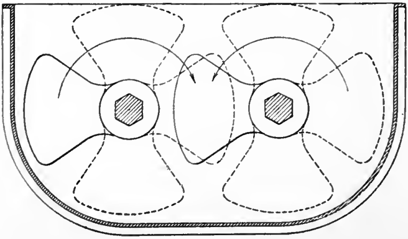

Fig. 31.—Diagram showing blades of double horizontal mixer.

width of 21 to 40 inches, and a length of 118 to 138 inches. The speed of rotation is 12 to 15 revolutions, and the output is 70 to 140 cubic feet per hour, for an expenditure of 3 to 5 horse-power. They are good machines, having less wear and tear than closed horizontal pug-mills with a shaft, but furnish a body of less density.

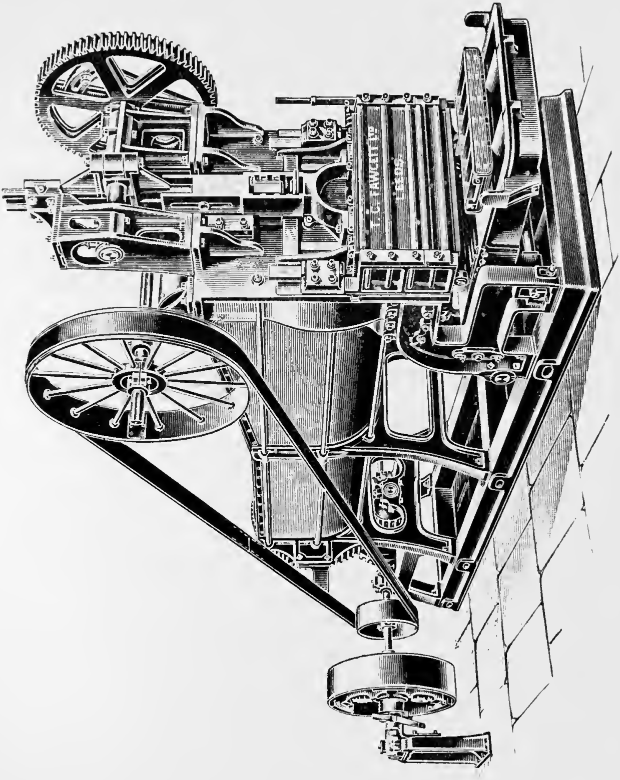

Fig. 32.—Double-shafted mixer.

Whatever may be the type of pug-mill adopted, it is well, before using the pugged body, to let it remain in heaps covered over with damp cloths for at least 24 hours to "sour". Only in the case of the manufacture of very common wares, or when the actual moulding is preceded by rough shaping, can the body be used as soon as it has left the pug-mill.

Rolling and Pugging Combined.—Rolls and pug-mills, such as have just been described, may be placed close to each other, and the material made to pass from one to the other by means of an endless band or by gravity. Another arrangement frequently used consists in placing the roller machines above the pug-mills. Fig. 33 represents a combination of a double pair of rollers with a horizontal pug-mill.

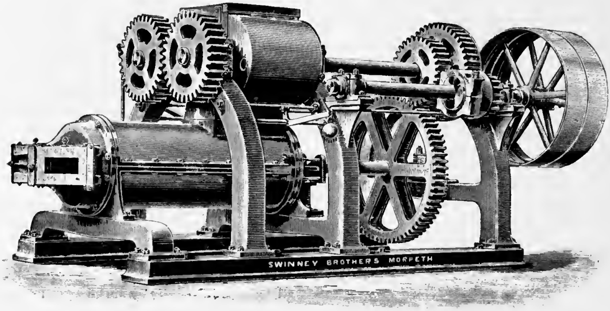

FIG. 33.—Combined rolls and pug-mill.

Preparation of Stiff Body.—The machines just described are most suitable for the manufacture of a soft body, but when a stiffer body is desired some modifications are necessary.

In this latter case, the mixing cannot be effected in pits, which would yield too soft a body, but must be done in heaps, unless the raw materials have, naturally, the required proportion of moisture.

Uniformity is effected by rolling and pugging as in the preparation of soft bodies, but the machines should be more rigid, and a greater driving power is necessary.

The granulating roller machine by Dumont (Fig. 34) is specially suitable for clays containing pebbles, as it supplements the work of the pug-mills when the latter have to mix a very stiff body. It consists of a pair of upright and plain rollers and of a second pair of larger diameter, perforated with a large number of small holes through which the material is forced and falls into the interior. The use of rolls is indispensable in the preparation of stiff bodies, for the great stiffness of the body prevents ordinary pug-mills from being sufficiently efficacious, and vertical pug-mills, of a small height (about 40 inches). are employed as horizontal pug-mills require too much power.

In the preparation of very stiff bodies it is not desirable to allow the pastes to remain standing after they leave the pug-mill before their formation. Moreover, the chief object of using machinery is to work on the clays as they are found *in situ*, and without weathering, and to obtain marketable wares as speedily as possible.

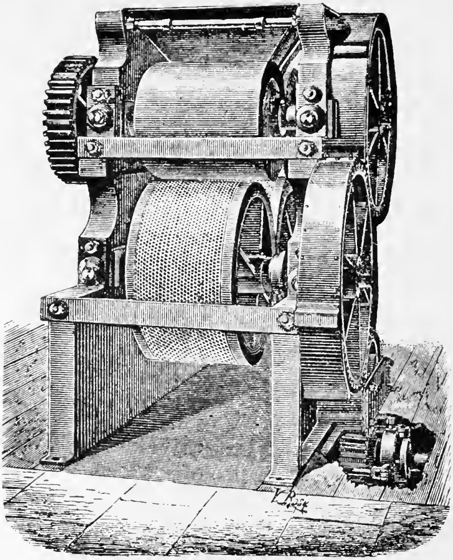
FIG. 34.—Granulating rolls.

When stiff plastic materials are to be mixed in definite proportions the use of an "Automat" feeder (Fig. 35) is advantageous.

(*b*) *Preparation by Dry Methods.*

In preparation by dry methods there are three distinct operations: (*a*) Pulverization of raw materials; (*b*) apportionment; and (*c*) combination of water with the body.

The clays are first dried, then ground and sifted. The grinding is performed by means of centrifugal grinders, ball grinders, crushing rolls or edge-runner mills, similar to those described, but arranged so as to obtain a product of greater fineness. The ground material is sifted, the residue being returned to the mill to be still further crushed again into the pulverizer.

The great drawback to all dry process machines is the production of a thick dust, which flies about and is injurious to the workers. The mills should, therefore, be enclosed and ample means employed for ventilation.

Non-plastic materials which enter into the composition of bodies, are similarly ground by stamping machines, centrifugal grinders, stone-breakers, rollers or edge-runner mills, the crushed material being sifted to keep out coarse material.

Very small quantities of materials may be moistened on the floor or on a board. After having added the necessary amount of water, the body is kneaded, left standing for a day or two, and then kneaded again. For larger quantities this primitive process has now been replaced by pugging, all the pug-mills described being suitable. It is usually sufficient to fix a pipe for the supply of the water, and to regulate the flow by a tap. The open horizontal pug-mill is, in this case, specially useful as the water-tap may be replaced by a pipe laid parallel to the shaft, pierced with a fairly large number of orifices, by means of which the water can be distributed more uniformly over the clay.

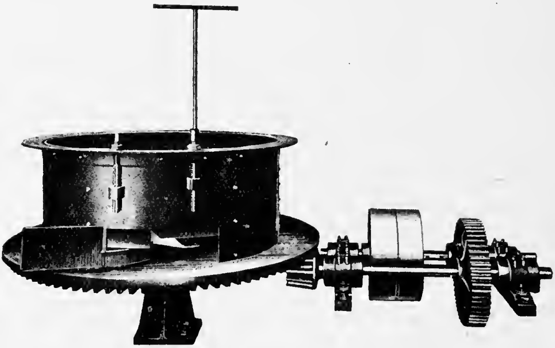

Fig. 35.—Raupach's "Automat" feeder.

Sometimes warm water or even steam is used, but it is then necessary to proceed at once with the shaping, as the body dries rapidly. In all other cases the body which has been pugged should remain for several days, covered with damp cloths to prevent it from drying superficially.

This allows the grains of clay to become more completely combined with the water than they could have done during their rather short passage through the pug-mill. The result is an increased plasticity of the body, which often facilitates the work of formation.

(c) *Preparation by Liquid Methods.*

The preparation of liquid bodies is done by one of two methods, which are distinguished by the physical condition of the materials. The first comprises four operations: (*a*) The measuring out of the raw materials in the dry state; (*b*) blunging and mixing in water; (*c*) sifting; (*d*) hardening.

The second method also consists of four operations: (*e*) Blunging of raw materials in water; (*f*) measuring and mixing in liquid state; (*g*) sifting; (*h*) hardening.

The two last operations of sifting and hardening are performed in the same manner in both methods. It is often necessary to add to these a fifth operation, the pugging and kneading of the body.

The dry measurement of the materials is made by volume, great care being required as bodies of fine faience and porcelain do not allow much variation in composition.

Blunging the clay is performed in mills similar to those used for washing clay, but as only crushed or washed clays are used there is no fear of the inconvenience resulting from stones or coarse sand. The blunger shown in Fig. 19 is that most generally used, but that shown in Fig. 21 is also employed.

The blunging is not done in a continuous manner, but fixed quantities of clay and water are introduced, and when the mixture is homogeneous it is run into a tank or "ark".

Non-plastic materials, as quartz, felspar, etc., must be ground before blunging. They are then placed with a suitable quantity of water into special blungers. For a long time horizontal roller mills, similar to those used for grinding corn, were used for this purpose, the grindstones, from 40 to 60 inches in diameter, being arranged in belfry fashion with four pairs of grindstones, but levigating mills (Fig. 36) are often used, and consist of a circular vat 4 to 6 feet wide, the bottom of which is paved with hard stones and a vertical shaft provided with four horizontal arms which in rotation impart their motion to blocks of stone. An iron ring prevents these blocks from rubbing against the walls of the vat. The chief advantage of such grinding mills is to save the wear and tear on other types.

The Alsing Cylinder seems destined to replace the grinding mills just mentioned. It consists (Fig. 37) of an iron or steel drum, lined with stoneware, into which particles of flint are incorporated to prevent its becoming polished and partially filled with pebbles, being in fact a type of "Ball Mill" (q.v.). A definite quantity of water and of material is fed into the mill, which is rotated until the grinding and mixing are complete. The door closing the cylinder is then replaced by a sieve which allows the blunged substance to be run into a tank whilst the pebbles are kept back. Alsing Cylinders are constructed for loads from 335 to 3350 lb. of ground flint; the amount of power required varying from two to twelve horse-power.

Mixing in Liquid State.—In order to mix together two or more substances which have been blunged in water, it is essential that the liquid bodies should have approximately the same consistency, so that they may have no tendency to separate from each other. It is also necessary to keep them in a continual state of agitation, in order to avoid their settling.

In order to know the proportions suitable for mixing several liquids to form good bodies, it is necessary to know the weight of dry materials which they contain for a given consistency. This weight is easily obtained by drying a given volume of the body, e.g. one pint, at 120° C. and by weighing the dry residue thus obtained.

A simple calculation of proportions enables one to determine in what ratio, by volume, the bodies should be mixed to obtain the desired composition. To avoid constant repetitions of this calculation, bodies are usually all manufactured of a standard consistency.- This consistency may be

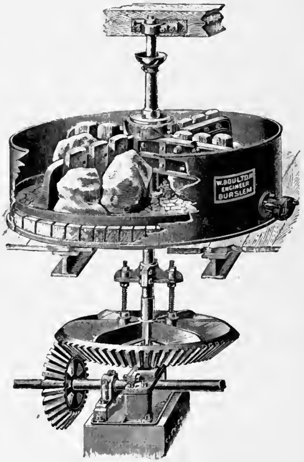

Fig. 36.—Grinding mill for flint, etc.

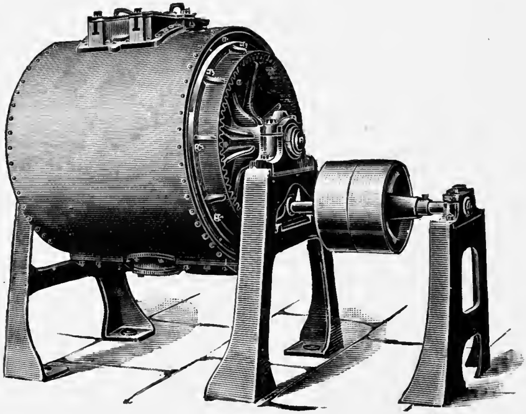

Fig. 37.—Alsing cylinder.

measured in different ways. Hydrometers may be employed, but are not sufficiently exact, and it is better to weigh a given volume of the body. For this purpose a vessel of known capacity, say 1 pint, is used. It is balanced on a pair of scales with shot or other convenient material, and after being filled with the liquid it is replaced on the scales, where it is weighed. If heavier than the standard, the body is too thick, and a little water must be added to it; if the vessel is too light, there is too much water in the liquid, and it must be allowed to settle for a short time in order that some of the water may be poured off, or some body of greater consistency may be added. This operation of adding water or body is repeated until the body has the desired consistency. With a little practice the variations are very slight and are corrected at the first attempt.

The different bodies having been thus made into slips of definite densities, definite volumes may be measured out and mixed together in a large tank.

[Sometimes these slips are kept in a series of tanks all the same size, and it is then sufficient to draw out the slips until it has sunk to a definite level. The measurement is effected by a stick, the marks on which are one inch apart and are termed "wet inches".]

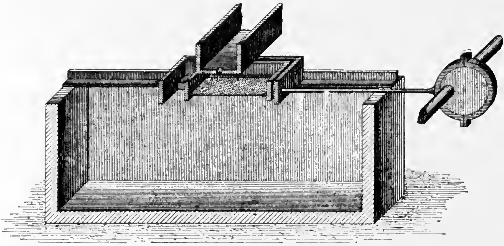

Fig. 38.—Lawn or sieve for slip.

A single receptacle can also be employed which is provided with index marks. The first body is poured into this vessel until the first mark is reached, then the second body until the second mark is reached, and so on.

In any case the mixture is easily effected by hand or in a blunger.

Sifting separates from the body any coarse grains which have escaped the sieves used in blunging and grinding.

The consistency of the body, and the tendency of the grains of sand, surrounded by clay, to remain in the holes of the sieves make sifting tedious, and the riddles are therefore shaken and struck constantly. A small quantity may be sifted by hand, but in factories an arrangement shown in Fig. 38 is generally used. Above the vessel intended to receive the filtered body two slides are placed, between which is moved a frame to which is communicated a reciprocating motion by means of an eccentric wheel. The sieve rests on two longitudinal slides inside this frame, and is slightly narrower and shorter than the frame, so as to slide easily.

The sieves are made of silk, or, better, of bronze wire.

The body to be sifted is brought to the sieve by a trough. From time to time the supply of body is stopped, the sieve is removed, overturned, and struck to cause the residue to fall out into another vessel. One sifting is not usually sufficient; the body being passed through two or three sieves, each finer than the others. For large quantities, sieves are arranged side by side in the same frame. Sometimes these sieves are replaced by a revolving horizontal framework of six or eight sides covered with a cloth which allows the body to pass through it but not coarser particles. The slip is fed in at one end and the coarse particles pass out by the other. The framework is revolved mechanically.

Stiffening or Hardening.—The filtered body is too fluid to be made into shape, and unless the articles are to be made by slip casting (Chapter V.) some water must be removed from it. This operation is called stiffening and may be effected by exposure to the air in settling tanks, though this process is not practicable for the preparation of pottery bodies by liquid means, as it is much better to work rapidly and not to occupy so much ground space as when clay is washed for brickmaking.

The slip may be partially dried by spreading it on floors heated by fires or by waste heat. In these floors, plates of cast iron cover a series of stonework channels placed between the fire and chimney, and arranged so as to present a large surface for utilizing the heat in the best possible manner. The layer of body is from 12 inches to 14 inches thick, and it must be stirred constantly during the drying in order to prevent the lower parts drying completely. When sufficiently stiffened the material is made into "balls" and placed in cellars for several weeks, in order that the remaining moisture may be distributed uniformly throughout the entire mass.

Slips may also be stiffened by absorbing the water from them by porous terra-cotta or plaster vessels. Terra-cotta vessels are rendered as porous as possible by adding to their body sawdust, or any other organic substances which burn out in the kiln. After being filled with the body they are placed on shelves exposed to the wind in order to hasten evaporation. Plaster vessels are able to absorb a still larger quantity of water. When they are saturated, they are scraped clean and then placed in stoves to be dried before again being used.

The chief appliance employed in stiffening slips is a "filter press" in which the liquid body is pumped into bags made of strong cloth, which retains the solid matter and lets the matter pass through.

The first presses used had the arrangement shown in Fig. 39. A series of wooden frames (from 6 to 30) are pressed one against the other by means of iron bars. Cloths with their ends folded, to form bags, are placed between the frames. At the top, a pipe brings the liquid body under pressure into the interior of each bag. The water passes through the cloth, into the side grooves of the frames, and escapes through a series of lower apertures. As soon as the bags are filled with stiff body, the bars are loosened, the frames are removed, and the cakes of body are taken out of the cloths.

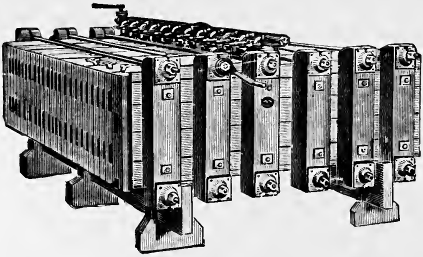

Fig. 39.—Filter press.

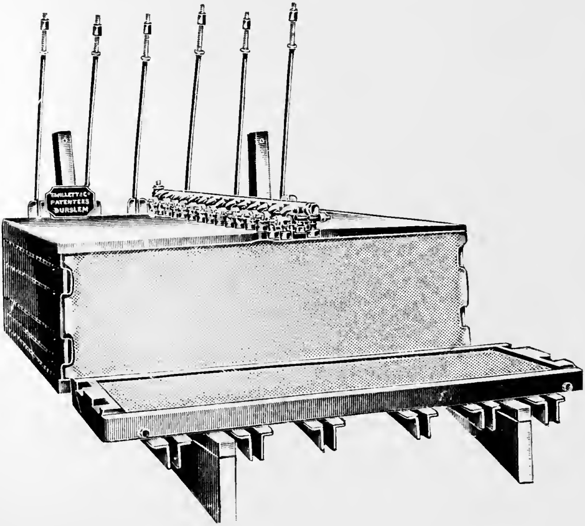

Fig. 40.—Willett's filter press.

The mode of construction now preferred is that presented in Fig. 41, in which the cloths are pressed between a solid disc and a frame.

The body enters through a central aperture, the cloth being pierced at its centre and fixed against the disc by means of a filleted tube.

Figs. 42 and 43 show a more powerful press, much used in France and Germany, but in England the one represented in Fig. 43, having circular disc sliding on the frame, is commonly used.[1] The pressing is done by means of a screw which has its point of support in the structure. For very large presses this screw may be replaced by an hydraulic piston. The usual sizes of filter presses are:—

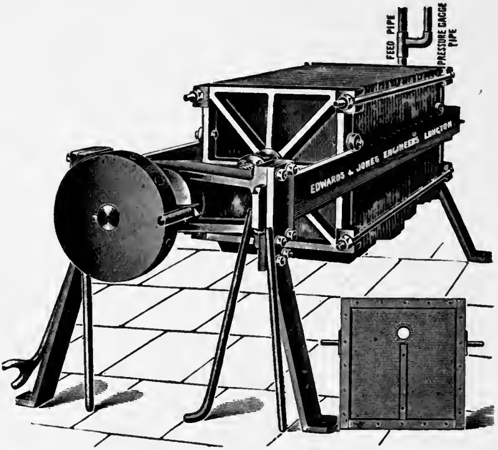

Fig. 41.—Edwards & Jones' filter press.

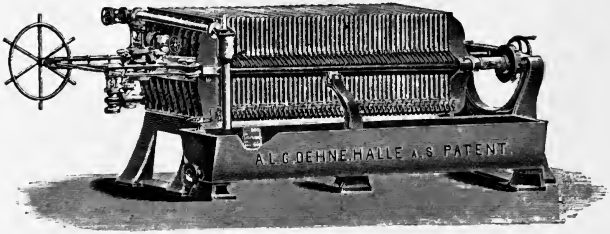

Fig. 42.—Dehne's filter press.

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[1] [This statement is not strictly correct in 1910.]

Dimensions of Frames. Inches.	No. of Frames.	Volume of Body Hardened. Pints.
24 × 24	6 to 24	61 to 225
32 × 32	18 to 30	308 to 572
40 × 40	24 to 40	792 to 1320

It must be observed that the more plastic the body the more difficult its stiffening by means of filter presses becomes, and it is almost impossible to stiffen a body of pure, plastic clay. Each pressing takes two to four hours. After several operations the cloths must be washed, by letting a current of water circulate in the press, the ordinary taps for the exit of the water being closed.

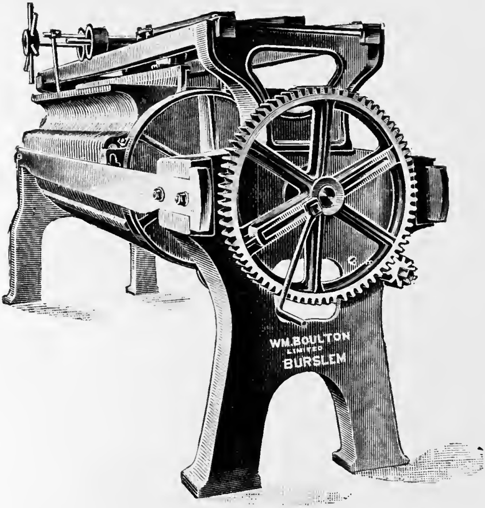


Fig. 43.—Boulton's filter press.

The cloths should be preserved by soaking them occasionally in weak carbolic acid solution. Membrane pumps are used to compress the slips in the press. They consist of a "plunger piston" of simple design which does not act directly on the body, but through the medium of an india-rubber membrane, rising and falling at each stroke of the piston in a case. The slip is drawn in through a ball-valve when the membrane rises, and is compressed through a similar valve when the membrane descends. A side opening in the pump (provided with a safety valve) allows the desired quantity of water to be introduced, and serves as an intermediary between the piston and the membrane. For small outputs these membrane pumps are worked by hand, for medium outputs they are worked by an eccentric wheel mounted on the transmission shaft, but when it is desired to work several filter presses at the same time, a single pump, arranged horizontally, and driven by a pulley, is to be preferred. The cakes which form the filter presses have generally a semi-stiff consistency, and in works which manufacture and sell body exclusively they are often dried by arranging them on shelves in well-aerated rooms, heated by hot air.

Fig. 44.—Vertical pug-mill for press cakes.

Pugging and Wedging or Slapping.—The filter press cakes in the natural state, or after drying, must be pugged so that the material may be made uniform. For this purpose the different pug-mills previously described may be used, but the vertical pug-mill shown in Fig. 44 is frequently preferred. In this, the body is powerfully compressed in consequence of the horizontal position of the orifice or exit.

Air-bubbles, which occasion inconveniences in the formation of fine and thin wares, must be removed from the pugged mass by "wedging" or "slapping" by hand, though for large outputs this long and laborious work is replaced by machines, consisting of a revolving pan, in which fluted cylinders move, or of a fixed pan and movable cylinders. These pans have a diameter of 3 to 6 feet, that of the cylinder being 16 inches to 24 inches.[1]

[[1] "Wedging" consists in cutting the paste into small pieces with wires, and throwing them forcibly on to each other ("slapping"). The paste so formed is kneaded into a uniform mass, the operations of cutting and kneading being repeated as often as is deemed necessary.—A. B. S.]

CHAPTER V.

FORMATION.

By the term "formation" is meant the whole of the operations to which plastic bodies are subjected in order to give them the shape of the articles to be manufactured. According to this shape, the formation is accomplished in one or several operations. It should be preceded by "wedging" and followed by "slapping," words which sufficiently designate the kind of operation to which they apply.

The method of formation which at first sight appears the simplest is that which is done exclusively by hand, with only the assistance of a few simple tools. This process is now only used for the making of original models: a few words will be said about it when dealing with the decoration of pottery ware.

Formation for manufacturing purposes can be done by three processes—throwing, jollying, and moulding.

Throwing is based on the use of the wheel. It can only therefore be used for the making of round objects. The body should be stiff for the article not to lose its shape under its own weight, yet it should be soft enough to yield easily to the pressure of the hand. Articles are sometimes made in a single operation; others are first shaped, then "turned" on a lathe when the body is stiffened.

In *jollying*, the body is pressed out by means of a profile, having the outline or the article to be made. The body used is usually semi-soft, but sometimes the jollying is done with a semi-stiff or stiff body.

Moulding is done in moulds, the interiors of which correspond to the solid parts of the articles to be made. Articles of any shape which can be readily removed from the mould can be made in this way.

In moulding by hand the body, having a soft or semi-soft consistency, is placed by hand into the mould and pressed to shape.

In moulding by jigger, employed for round or oval articles, the semi-soft body receives the desired form partly by moulding and partly by jiggering, a "jigger" being similar in principle to a jolly.

In moulding by press, the body is compressed in the interior of the mould, and can be semi-soft, semi-stiff, stiff or dry according to the pressure exercised.

In moulding by casting, the liquid body is compressed in a mould of absorbent material such as plaster.

Making by press, when done in soft or stiff body, is always preceded by a shaping by one of the three processes. On the other hand, moulding by press in dry body and moulding by casting only require a single operation.

Whatever process may be employed the making is often followed by a finishing or "fettling" of the surface.

(*a*) *Throwing.*

Potter's Wheels are of two kinds: potter's wheels which are put in motion by the thrower or by an assistant, and mechanical wheels which are worked by an engine.

The potter's wheel consists (Fig. 45) of a vertical spindle, the lower end of which rests on a footstep fixed in the ground, and which is secured at its upper part by a collar fastened to a table. This spindle is surmounted by a small stand called the wheel-head, holding the piece to be made, and carries at its lower end a heavy solid fly-wheel which the workman sets in motion with his feet. The thrower sits on a small inclined board placed near to the level of the table, and can rest his feet, when the wheel has the desired speed, on another inclined board. The speed can at any moment be augmented or diminished either by giving a fresh impetus, or by allowing the foot to rub on the fly-wheel. The preceding arrangement is employed in French and English potteries. In Germany, a similar wheel is used, but the upper part of the wheel is held by a piece of wood under the seat of the thrower, who is thus astraddle. Moreover, the fly-wheel is smaller but thicker, and the workman rests his feet on two pieces of wood at the side. When large pieces have to be thrown, an assistant drives the wheel by means of a handle. Figs. 46 and 47 represent arrangements of this kind. A certain amount of skill is necessary to enable the assistant to regulate properly the speed of the wheel to the requirements of the thrower.

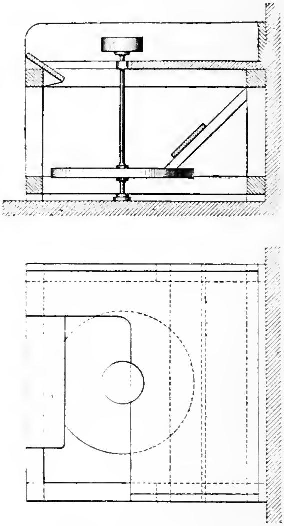


Fig. 45.—Potter's wheel.

Mechanical Wheels.—For large outputs hand-driven wheels are replaced by those mechanically driven, the shaping of the articles being always done by hand.

When small objects of simple shapes are to be made, wheels of invariable speed may be used. In this case a simple belt drive is used as represented in Fig. 48. The wheel is started by a workman placing his foot on the pedal, it being brought to a standstill automatically when he ceases to touch the pedal.

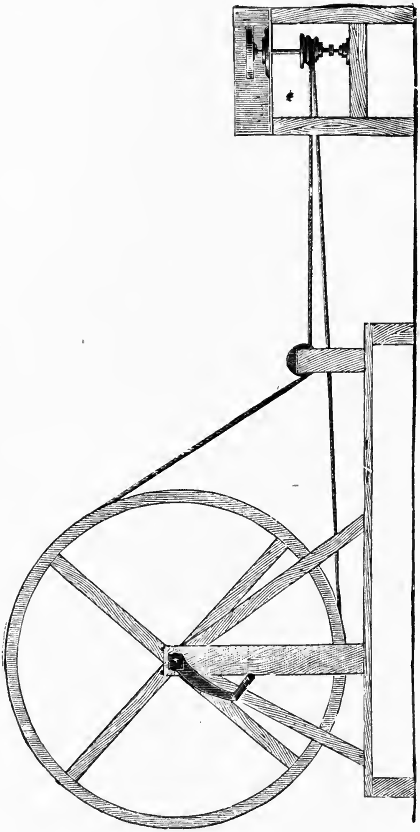


Fig. 46.—Potter's string wheel.

Fig. 49 shows an inverse arrangement, the wheel being started when the pedal is depressed.

It is possible to vary the speed of the wheel either by altering the diameter of the pulleys or by inserting intermediary conical drums, but these are no longer sufficient when in consequence of the dimensions of the body to be thrown, or of other difficulties, it is necessary that the thrower should be able to modify the speed at any moment as he does on the potter's wheel. In such cases, the wheel may be driven by a pinion, whose point of contact with a motive disc can be displaced from the centre to the circumference of this disc as shown in Fig. 50. A counterpoise brings the pinion towards the centre and reduces the speed, while the thrower, by pressing a pedal, makes it descend and increases the speed to suit its requirements.

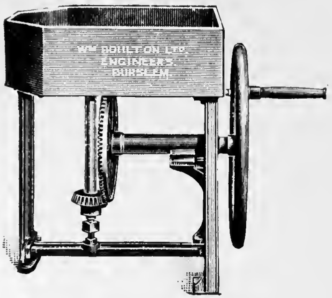


Fig. 47.—Potter's cog-wheel.

When the throwing requires very little power it is preferable to make use of the very simple arrangement shown in Fig. 51; the driving pulley being mounted on the spindle and carrying a conical space into which a conical piece fitting on the spindle can penetrate, and be raised and lowered by means of a pedal. When the thrower does not press the latter the two cones fit together and the wheel revolves

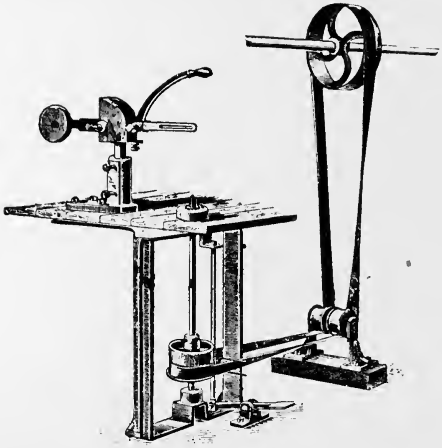


Fig. 48.—Power-driven wheel (jigger).

at its maximum speed. If he presses the pedal lightly, the contact is less perfect, it produces a certain sliding and the speed is slackened. If, finally, he presses more heavily, the contact ceases and the wheel stops.

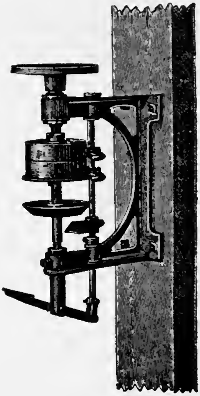


FIG. 49.—Power-driven wheel.

The cone drum-wheel constructed by Boulton (Fig. 52) solves the question in the most complete manner, but is of a rather complicated design. On the spindle of the wheel is a cone which can be set in motion by another cone placed in a contrary position, having a slightly arched surface, and displaced at the same time as a frame, the ends of which are caught in two slides, an upper and a lower, fixed in the structure. This second cone has a continuous and rotatory movement caused by a thick rope passing on a grooved pulley on the spindle. A pedal is fixed to the frame, and its counterpoise tends constantly to bring the mechanism into the position shown in the figure, in which the two cones are not in contact, the wheel being consequently at rest. If the thrower presses on the pedal, he causes the frame to turn slightly and pushes it against an elastic spring contained in an horizontal cylinder fixed to the back of the structure. Under the influence of this spring the frame is pushed forward and the small circumference of the driving cone comes into contact with the largest circumference of the cone fitted on the spindle of the wheel, to which it communicates the least speed of which the apparatus is capable. If the thrower increases the pressure on the pedal, the oscillating movement of the frame continues and the increasing circumferences of the driving cone come successively into contact with the decreasing circumferences of the other cone, so that the speed increases until it reaches a maximum. The thrower can thus, by regulating the pressure on the pedal, and without great effort, vary the speed at will. For wheels of large dimensions a check, mounted on the spindle of the wheel, stops the movement when the pedal is left to itself.

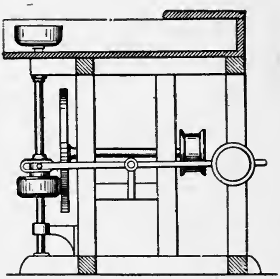


FIG. 50.—Power-driven potter's wheel.

Mechanical wheels are usually arranged near each other so as to be driven by the same rope.

Processes of Throwing.—The thrower takes a quantity of body, proportionate to the size of the object to be made, and places it on the wheel-head. He then sets the wheel in motion, and after having wetted his fingers he presses the mass and forces it to rise and fall several times, then with the thumb on one part and the fingers on the other he makes it gradually assume the desired form. This operation, which at first sight appears very easy, requires much practice to press the mass uniformly, and to prevent knuckle marks, a defect which is known as "twisting". He must know how to regulate the speed of the wheel to the ascending or descending movement which he gives to the body with his hands, and must by suitable sprinklings prevent the body from drying unequally in contact with the fingers. The thrower places a model of the object to be made on the table in front of him. For the principal measurements he uses an instrument called

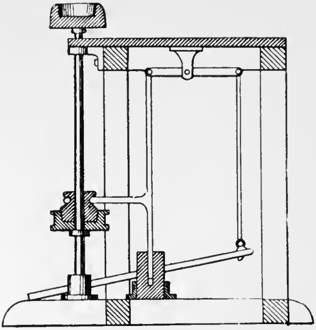


FIG. 51.—Power-driven potter's wheel.

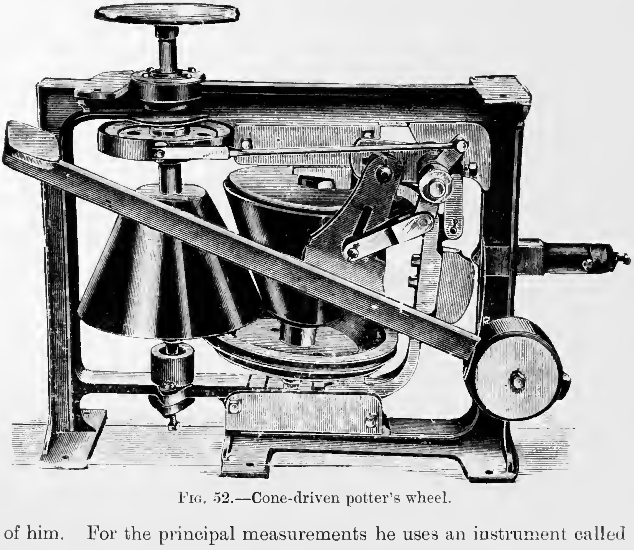


FIG. 52.—Cone-driven potter's wheel.

a gauging rod, consisting of a vertical rod fixed on a stand and holding horizontal rods (Fig. 53), which gives at the same time the height and the distance from the side of the wheel head. When the object is finished the thrower detaches it by passing an iron wire between it and the top of the wheel, and then places it on a board to be taken to the drying room. When the object is too heavy to be thus removed without risk of throwing it out of shape, this board is fixed on the wheel head previous to the throwing being commenced.

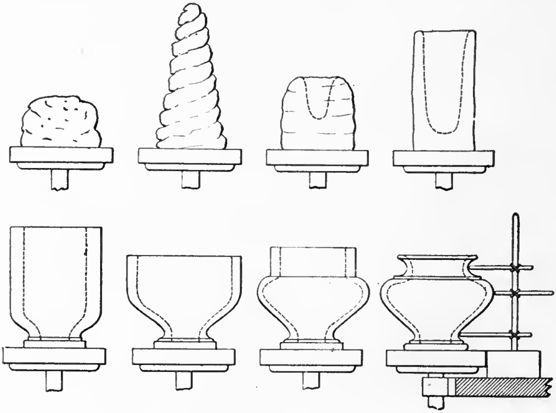


Fig. 53.—Stages in process of throwing a vase.

Fig. 53 shows the various stages in the throwing of a vase and Fig. 54 that of a flat cover. The making of difficult pieces requires a very plastic body, such as those generally used in the manufacture of terra-cotta, stoneware, or faience ware. When the bodies are open, as porcelain, the most complicated pieces must be made in several parts which are afterwards fastened together. Fig. 55 represents the moulding of a decanter in three pieces. The parts to be joined are levelled in order to increase the surface of the joint. Usually the thrower makes several pieces of each kind, then, when the body is a little

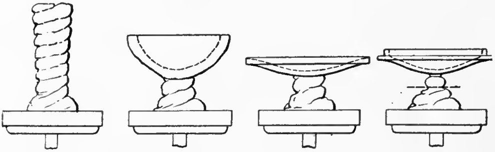


Fig. 54.—Stages in throwing a flat cover.

stiffened, he brings the parts together, after laving the joint with a sponge, and presses them firmly into contact. In certain cases the process called "throwing by cord" may be used, as represented in Fig. 56. Round a vertical rod a cord is rolled with varying thicknesses according to the shape of the interior of the article. Then the body is applied to the cord, the exterior outline is given on the lathe, and after leaving the body to harden a little, the cord is unwound and comes off entirely, leaving a space corresponding to the place it occupied.

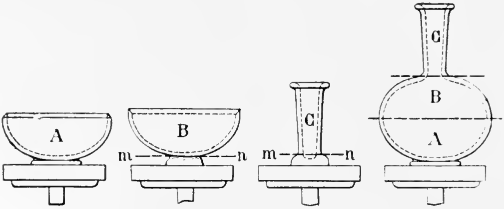


Fig. 55.—Stages in throwing a decanter.

When it is desired to obtain pieces having a more rigid form, a "profile" (that is to say, a plaque in which the outline to be made is cut out) is used. This profile is made by means of mechanism gradually to approach the piece thrown on the lathe; it removes the superfluous body and produces an object having the exact form of the profile. Fig. 57 represents a profile used for making the baluster, of which the "cord throwing" is shown in Fig. 56.

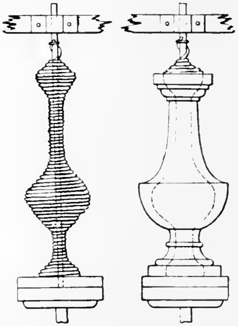


Fig. 56.—"Cord throwing."

Fig. 57.—Profile.

It must be observed that a complete "profile" of this kind can only be used when the piece to be thrown is supported internally as in Fig. 56, because the body is too soft to resist the lateral pressure of the "profile". Throwers use small tools of metal, wood, slate, or horn to give more precision to the moulding, to sink certain contours, or to sharpen the edges.

The throwing is generally completed by smoothing the surfaces with a small sponge, lightly applied, and by polishing them with a steel or horn blade.

Oval or square bodies can also be thrown, though this process is no longer used except for fancy articles, pieces being manufactured with much greater precision by means of moulds.

Turning is employed—

(1) For giving a very exact form to objects made of a plastic body.

(2) For making objects in a lean body which must be made thick because of its feeble cohesion.

Before it is fit for turning, the body must be sufficiently hard not to lose its form, but yet soft enough to allow the finger-nail to make an impression, the pieces waiting to be turned being kept in a cellar or other place having a constant humidity.

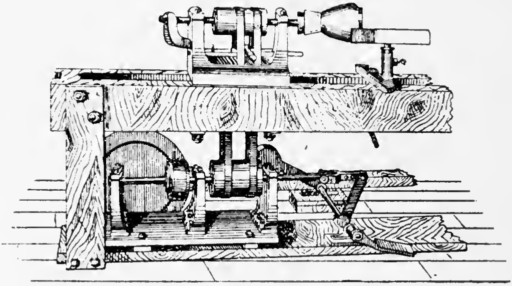


Fig. 58.—Horizontal lathe.

Both vertical lathes and horizontal lathes are used in turning, potter's or mechanical wheels being used for the former (see p. 102). A shank is made by throwing a mass of stiff clay on the wheel and by turning it to a shape capable of fixing the object to the wheel. The plasticity of the body is sufficient to hold the piece tightly to the shank after they have been lightly pressed together. Short props, which are moved according to the height at which it is desired to work, serve as a support to the hand of the turner.

Horizontal lathes are similar to those used for turning wood or metal as shown in Fig. 58. The tools used are small blades of steel, of various shapes fixed to a wooden handle. Compasses or calipers are used to measure the diameter or thickness of the object. Turning is an easier operation than throwing and can be quickly learnt by any thrower. The body must be cut, not scraped, and when it becomes too dry and apt to break it should be damped with a small sponge. The piece is finished by polishing it with a steel or horn blade.

When turning porcelain or other dry bodies, a dust is produced which is very disagreeable and injurious to the health of the workers. The latter should then be provided with masks, or, better, an exhausting fan should be arranged to carry off this dust.

(*b*) *Expression.*

Expression is employed for making objects of a symmetrical shape, about one axis, as pipes, bricks, and tiles.

The machines used consist of three essential parts :—

(1) The *die* or aperture through which the body is forced.

(2) The *propeller* or mechanical part, for compressing the body.

(3) The *cutting apparatus* in which the article is cut to the desired length after coming out of the die.

When the objects to be expressed have a simple section, as a brick, the dies are formed of a slab of metal or hard wood, in which is bored an aperture having the form of the object to be obtained. The opening must be rather larger at the side where the body enters, and it is wise to slightly round the angles, and to smooth the interior of the die.

Figs. 59 and 60 show two dies, one for expressing a 2-inch cylinder of clay and the other a square brick with rounded edges. The wider opening is $\frac{1}{10}$ to $\frac{1}{5}$ of the thickness of the die larger than the other. A similar arrangement is also used when the objects to be expressed are hollow, but a piece called a bell is placed in the aperture and upheld by means of a rod and an iron bridge. This bell is shaped like the section of the hollow space in the articles to be made.

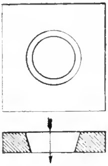


FIG. 59.—Cylinder die.

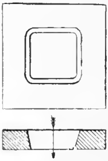


FIG. 60.—Square die.

Fig. 61 shows a die of this kind used for making pipes. The iron bridge must be placed so far from the aperture of the die (6 inches to 12 inches) that the body divided by it may be joined again under the

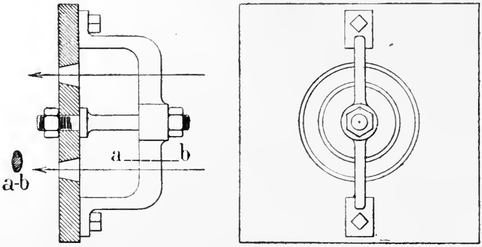


FIG. 61.—Pipe die.

influence of the pressure of the propeller and of the compression which it experiences by its expression through the die. In order to divide the body as little as possible, the bridge has a section indicated by the sketch *a*—*b* (Fig. 61).

When the object to be made must have several spaces, a corresponding number of bells are used, held by one or more bridges. Fig. 62 represents the arrangement employed for the expression of bricks with six holes.

The construction of dies is a more delicate matter when solid objects are to be expressed of more than two-inch diameter. The body admitted into the die by a uniform pressure, produces friction along the walls which consequently retards its movement. Owing to the cohesion of the clay, this resistance is transmitted to the whole of the mass, where the orifice is not too large, but beyond a certain limit the body, instead of advancing uniformly, travels more quickly at the centre than at the sides, and especially at the corners. When the difference in speed is not too great, differences of density result, and cause the ware to lose its shape during drying and firing. If the fault is great a roughness at the corners is produced, as shown in Fig. 63. These are sometimes called "dragon's" teeth. This defect may be remedied by increasing the resistance at the central parts, and by reducing it as much as possible at the angles, by the use of "cheeks" of cast iron (Fig. 64) or phosphor bronze attached to the outside of the die. They have the greatest length at the centre of the upright parts, and disappear at the angle.

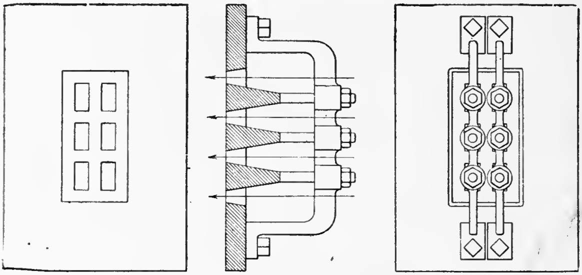


Fig. 62.—Hollow block die.

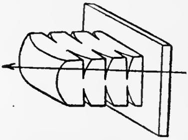
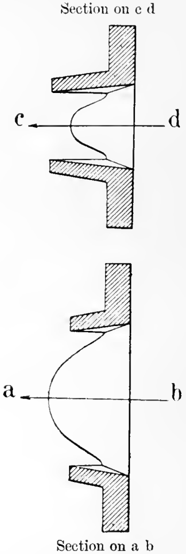


Fig. 63.—Clay issuing from faulty die.

Dragon's teeth may also be prevented by lubricating the die with water contained in a vessel above the die, and communicating with it by means of a pipe and a tap. The chief difficulty consists in making the water flow uniformly over all the surface without the openings for the entry of the water being stopped up by the clay. A type which is now most employed is shown in Fig. 65.

In an exterior conical box are placed several wood frames forming a series of circular pipes communicating with each other and with the tap through which the water enters. On the frames, plates of zinc are placed above each other, so that the water can flow between them in a very thin layer.

The construction of dies for large articles is often difficult, because their different proportions depend on the plasticity and consistency of the body used, but it is nevertheless very desirable that ceramists should use the forms best suited to their requirements and not rely entirely on the builders of the machines.


Section on c d

Section on a b

Fig. 64.—Sections of mouthpiece.

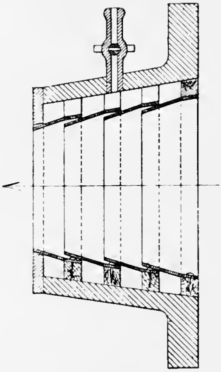


Fig. 65.—Water-lubricated mouthpiece.

Propeller presses are of five forms :—

1. Piston propellers or plungers. 2. Blade propellers. 3. Single-screw propellers or auger machines. 4. Twin-screw propellers; and 5. Cylindrical propellers.

Fig. 66 shows the principle of the *plunger-press* or "stupid" (bounded on one side by a die and on another by a piston), in which the body to be expressed is introduced through an opening so as to fill the box completely when it is closed by means of a cover. The piston is then set in motion in the direction indicated by the arrow, thus forcing the body out through the die. When the piston has reached the end of its course it is brought back and the operation of filling is repeated. The working is therefore intermittent.

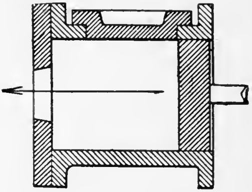


FIG. 66.—Section of "Stupid".

The movement of the piston can take place horizontally as in Fig. 67, or vertically as in Fig. 68. The piston may be moved by hand or by steam power, either by a pulley or by placing a steam cylinder on the top of the one containing the body.

Blade propellers are pug-mills similar to those shown in Figs. 27 to 30, the die being fitted to the exit end of the mill, and the blades nearest to the die serving as propellers. The body is thrown into the top of the mill and, when pugged, passes out at the bottom at intervals corresponding to the passage of each blade behind the die.

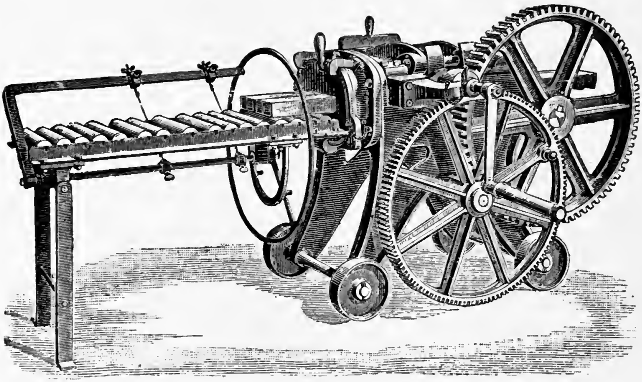


FIG. 67.—"Stupid" for small pipes and blocks.

Single-screw propellers or auger machines are frequently used, and consist (Fig. 69) of a cylinder closed at one end and the other is provided with a die with an internal screw or worm. The material enters through an opening at the back and is progressively compressed towards the front and forced out by the screw. The diameter of the cylinder, the speed of the screw and the size of the die must be accurately adjusted to suit the clay, as the material will not be properly compressed if the die is too large. If, on the contrary, the die is too small, the clay cannot pass out properly; the screw will choke, and will eventually draw the mass round with itself without propelling it forward. The pressure on the section *ab* (Fig. 69) is not constant, as each turn of the screw brings a fresh quantity of body which is pressed most at its extremity. At any point of the section *ab* the pressure is therefore greatest when nearest to the end *c* of the screw and least when *c* is furthest from *a* or *b*. To avoid the irregular expulsion which would result if they were close together a certain distance is left between the end of the screw and the die so that the pressure may become uniform.

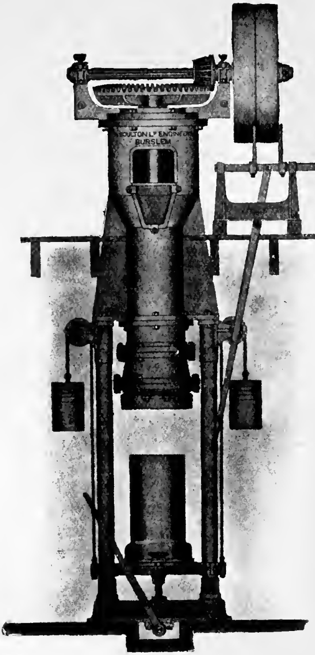


Fig. 68.—Vertical plunger machine for large pipes.

This distance must be sufficient but not so great as materially to increase the resistance. As the clay remains motionless in the corners *d*,*d*, and only advances in the form of a cone, the friction produced between the part not in motion and the propelled body is very great and may stop the machine if the cone is too long.

This difficulty can be greatly decreased by making the screw at the end of the cylinder conical as shown in Fig. 70. This makes the

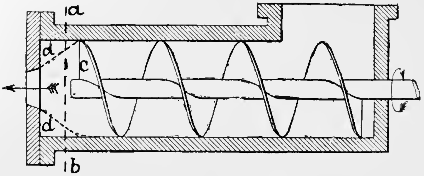


Fig. 69.—Propeller or auger machine.

pressure much less variable, and consequently allows the screw to approach perceptibly nearer to the die.

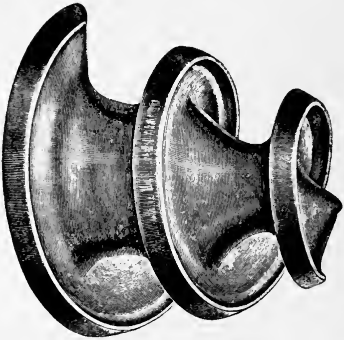


Fig. 70.—Worm propeller.

Screw propellers are frequently combined with horizontal pug-mills (Figs. 28 to 33), the same machine being used for both pugging and shaping. For this purpose, half the shaft is provided with "blades" and sometimes with *counterblades* (Figs. 29 and 30), the other half being in the form of a screw or worm in several pieces, or a conical helix. Screw propellers are seldom moved by hand, and steam power is usually employed. They are frequently used for making both solid and hollow bricks, pipes, and for the production of many objects which are afterwards more accurately shaped by pressing. Unfortunately, they require a considerable power to drive them and articles made by them often have a helicoid structure.

Twin-screw propellers are similar but have parallel screws, turning in a contrary direction to each other and compressing the material through a single die, the object being simultaneously to pug and shape the body. But the very slight pugging thus obtained by means of the tangent worms must not be confused with the much more efficacious action of the pug-mill with two shafts previously described (Fig. 31), the blades of which intersect each other. A twin-screw propeller has the further disadvantage of producing two parallel currents of paste and the compression of the die does not always weld them together.

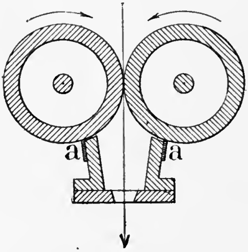


Fig. 71.—Vertical die and expression rolls.

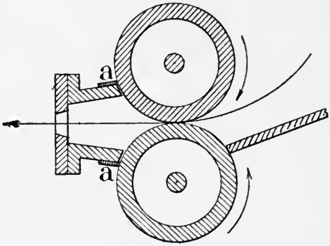


Fig. 72.—Horizontal die and expression rolls.

Figs. 71, 72, 73 and 74 represent in vertical section, and Fig. 83

in horizontal section, various arrangements of *roller propellers* or "*expression rolls*," which consist of two or three rollers and a die through which the body issues. These machines are power-driven, are simple

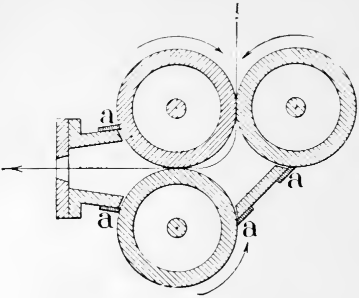


FIG. 73.—Compound expression rolls.

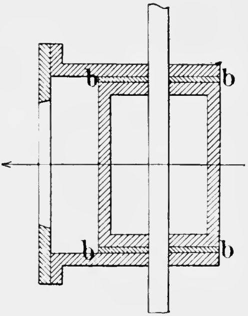


FIG. 74.—Plan of Fig. 72.

in construction, yield pastes of more uniform texture than screw propellers and absorb less power. The joints between the die and the rolls are made by inlaid sheets *a*, *a*, *b*, *b*, fixed by bolts, and kept in contact with the rolls as they wear. In spite of these precautions it is difficult to obtain tight joints; leakages of clay absorb power and make the machine dirty, and this is the chief, if not the only difficulty experienced in using this type of shaping machine.

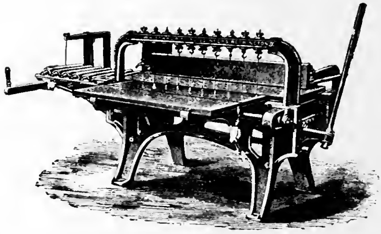


FIG. 75.—Cutting table.

Cutting Machines.—The body on passing out of the die has the desired section, but must be cut to the desired length. It is received on a "table" provided with rollers of metal or wood covered with oil, felt or plaster. If the propulsion of the clay is intermittent or is stopped at the time of cutting, an apparatus with fixed cutter (Fig. 75) may be used. The cutter consists of a "table" and a frame, on which are stretched steel wires passing through the table, their distance apart being equal to the length of the articles to be made. When the band of clay is still, a workman seizes this frame, which turns on two pivots and draws it towards him, thus forcing the wires to pass through the body, and dividing the latter into pieces which are removed by hand. The cutting frame is then replaced in its original position.

When the propulsion is continuous, a table with a movable cutter must be used. This (Fig. 76) consists of a fixed table and a second mounted on four wheels, which runs on two rails. The band of clay is received on the first table and passes on the wagon which is placed close to it. The clay tends to push the wagon with it, but the workman keeps it fast until the clay has reached the end of it. He then allows it to advance with the same speed as the clay, and cuts the latter by drawing down the frame carrying the steel wires. The articles are then removed and the man pushes the wagon back to its original position.

When the propulsion is effected vertically, as in Fig. 71, the body is received on a balanced table which descends until the clay band reaches the desired length. The machine is then stopped and the clay is cut by a steel wire stretched in a horizontal frame. The cut piece is removed and the table returns to its original position under the influence of a counter-weight.

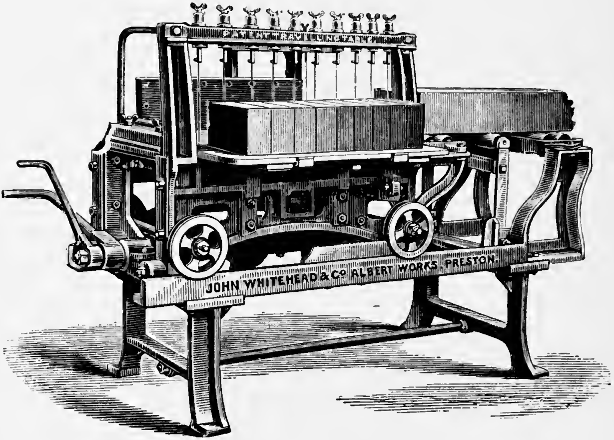


Fig. 76.—Movable cutting table.

(*c*) *Moulding by Hand.*

Wooden Moulds.—When the articles to be moulded by hand are similar to bricks or slabs in shape, wooden moulds are used in which the body is compressed. These moulds may be in one or in more pieces, according to the shape of the article.

The simplest case is the moulding of ordinary bricks in a wooden frame (Fig. 77) the shape of the brick to be moulded. The moulder places this frame on a wooden table, then takes a quantity of body, throws it violently into the mould, compresses it with his hands so as to fill the corners, and smooths the upper surface with a piece of wood called a strike. The mould is raised and turned first on its side and then emptied on to a board or pallet. As the body used must be very soft, the mould and the surface of the table are damped or sanded to prevent adhesion. For the moulding of bricks, metallic hinged moulds are also used, but this special process of making is described in Chapter X.

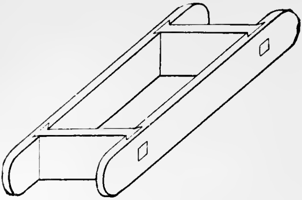


Fig. 77.—Wooden brick-mould.

Bricks of all shapes and sizes, tiles, plaques, etc., may be moulded in this way, but the body should have the desired degree of plasticity, not be too soft, and should fill the mould well, particularly the lower corners.

Articles with intricate grooved parts, or which require too complicated moulds, are made roughly to shape, and, when sufficiently hardened, they are finished with manual tools.

Clays of hard or semi-hard consistency are suitable for carving by means of tools.

Plaster Moulds.—When the objects to be made are not irregular in form or are ornamented, plaster moulds either in one or more pieces are used. Plaster is, in fact, the only material which can be utilized, as it does not adhere to the soft clay body. Formerly, biscuit moulds were used, but they have been abandoned as they make manufacture more difficult and more laborious.

The plaster used must be good superfine plaster of Paris and must be kept in a dry place. The mould is made from a model representing exactly the object to be made, but slightly larger to allow for the shrinking of the body (see Chapter VI.). If the object has "undercut" parts which would prevent it leaving the moulds, it would be necessary that these be first stopped up with plastic body or wax, and removed after moulding.

Models made of plaster must be greased or oiled before being cast, a solution of soap and olive oil being often used for this purpose. To prevent the plaster model from absorbing too large a quantity of the fat, it may be first coated with a solution of resin in alcohol. Clay models do not require any preparation, but the dampness of the plaster spoils them, and they can only be used for a single casting.

Unless the article is of a simple form the mould must be made in several pieces. This division is made by cutting away the plaster, or by placing sheets of pasteboard or metal at the joints and making one part of the mould at once. In order to join again the pieces of a mould, their exterior surfaces are dressed, and a casing of plaster is run all round.

The first mould obtained by casting from the model is only used for moulding when a small quantity of pieces are to be made. Usually it is called the "master mould" and is only employed to cast other models in plaster, from which, in their turn, working moulds are cast. Plaster moulds wear rapidly, in consequence of the constant dampness they absorb from the body, and because of the mechanical weakness of plaster. The plaster may be made stronger by mixing some alum with it.

The making of moulds needs special care, because it is essential that the plaster should always have the same consistency, so that its absorbing power may be always the same. If of two moulds made from the same model, one has been made with thick plaster and the other with thin plaster, the latter will be more absorbent, it will dry the body more quickly, and will give denser wares having less shrinkage. This defect will be more serious if the mould be of such large dimensions that it has to be made in several pieces, unless the precaution is taken of each time adding the same proportion of water to the plaster.

The thicker the plaster mould the more water it can absorb, and it is well to proportion this thickness to that of the wares. If the latter have narrow parts beside thicker parts it is necessary to take this into consideration or some would dry before others, causing warping and even cracks, or certain parts of the mould may be moistened before use to make them less absorbing.

It is also desirable in deciding the form to be given to moulds, to take into consideration the shrinkage of the body, as this must always be allowed to take place freely.

When the shape of the object would be opposed to allowing this condition to be fulfilled, the mould must be made in several pieces, so as to be able to remove, after the making, those which would impede the shrinkage.

If a mould were too absorbent in consequence of the great porosity of the plaster or its too great thickness, it would produce the same difficulties as a too rapid drying. The remedy would consist in diminishing the thickness or in mixing the plaster more strongly, or, finally, in moistening it sufficiently. In pressing by hand in plaster moulds the workman throws pieces of body into the mould, pressing them with his hand, or with a sponge if the body sticks to his fingers. A rough sheet of body of uniform thickness, called a "batt," is often made by placing a mass of body on a prepared and moist table, and beating it out to the size of the "batt" desired. Two rules or straight edges, the thickness of which determines that of the "batt," are arranged a suitable distance apart and the body is beaten between them. The surface is smoothed with a roller of damp wood run on these rules. This "batt" is lifted by hand and applied to the mould, but with complex moulds it is preferable to cut pieces corresponding to various parts, and to beat them by hand against the moulds. For lean bodies, a cloth, or preferably, a damp skin, is spread on the table and used to convey the "batt" to the mould, without the risk of breaking it. Sometimes the "batt" is replaced by a piece of clay made on the wheel, which is placed in the mould. This thrown piece is called a "cover," and it is applied to the mould either with a sponge or by hand.

Fig. 78 represents a panel moulded in one piece by applying a suitable sized "batt" to the mould, and by forcing it by the hand or with a sponge to take the form of the mould. When the mould is properly filled the excess of clay is cut off with a wire, the surface smoothed, if desired, and the mould with its contents is set aside to dry in the mould; then when the clay is ready to be detached, in consequence of its shrinkage, the mould is turned upside down, and the moulded piece is received on a board, where it remains until quite dry.

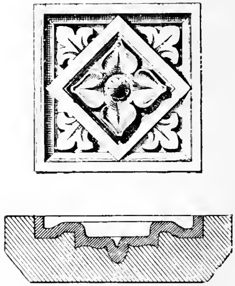


FIG. 78.—Panel and mould.

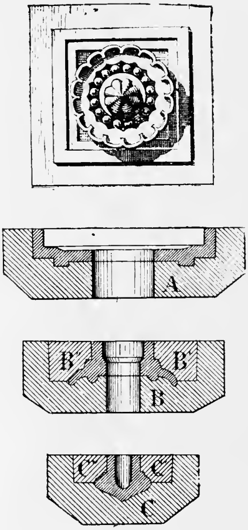


FIG. 79.—Moulding a panel.

Fig. 79 represents the moulding of a panel of more complex form, and made in three pieces. The first is made in the mould A, as in the preceding case; the part of the "batt" which is found above the central aperture being removed with a knife. The rosette is moulded in a case mould, B, in which are two pieces, B′ and B″, the batt being replaced by a cylindrical or conical mass of body which is forced into the mould; the two ends are then joined, and the interior circular part is smoothed by hand. The mould is emptied as before, by turning it, raising the case mould, B, and by drawing aside the two parts, B′

and B″. The central piece is moulded in the same way, also in a mould in three pieces, C, C′ and C″. The three parts of the panel are joined when the body is sufficiently hardened, but sometimes they are fired separately and joined together afterwards with cement.

A piece which is to be visible on every side, e.g. Fig. 80, is moulded in two or more parts which are afterwards joined. The grooved pedestal is first made, then each half of the body of the chimera in separate moulds. A section on the line *mn* shows the arrangement of the mould, which consists of a case, A, in which is placed a series of pieces, *a*, *b*, *c*, *d*, etc., distributed in such a way as to allow of emptying. The halves of the chimera are then moulded as indicated, and when sufficiently dry they are joined first to each other and then to the pedestal. It is preferable to mould the tail by itself and afterwards join it. When the articles are of very large dimensions, they are made in several pieces which are fired separately and afterwards joined together with cement.

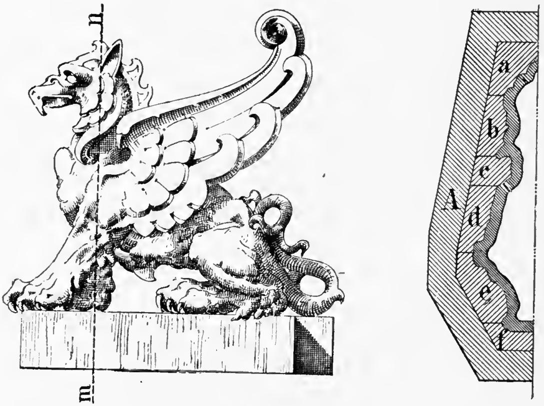


Fig. 80.—Model and mould.

Each model should be studied separately in order to determine the most suitable form of mould and the position of the joint so as to allow of emptying and yet not cut delicate parts, such as the face in a statuette. It is necessary also to take into consideration the shrinkage during the drying, and the durability of the pottery in the kiln and in use.

The making of moulds is generally entrusted to special men. Moulding, however simple it may be, requires a certain amount of technical skill for the uniform distribution of the body, without which certain parts may be more compressed than others, and these would fall apart during the drying and the firing. The moulds themselves after having been used should be dried, so as to remove the water which they have absorbed. This drying is much easier than that of bodies. It is done either by aeration or in the same drying rooms which are used for the bodies. But it often becomes difficult unless a drying stove is employed. According to the shape of the moulds and the degree of consistency of the body during the making, the moulds must be dried after each moulding, or as is most frequently the case it is only proceeded with after two or three fillings.

(*d*) *Moulding on a Jolley.*

In moulding on a jolley—applicable to round or oval articles—the part of the piece which must be produced with the greatest amount of care (the interior or exterior as the case may be) is made on a mould placed on a jolley, while the other is made with a profile. This kind of moulding is thus done by means of three tools, the jolley, the mould, and the profile.

Jolleys consist of a vertical shaft, similar to a potter's wheel, but, as a smaller force is exerted, the disc can be lighter and of less diameter. It is not necessary to modify the speed, and for articles of small dimensions (cups, flower-pots) it is sufficient to have a jolley of constant speed provided with a brake well within reach of the turner.

The heads of jolleys which receive the moulds must be placed and removed very rapidly. For this purpose they have at the top a truncated space corresponding to a similar projection on the mould. A simple pressure fixes and centres the latter (Fig. 81). The head may be of plaster or wood. The edge of the truncated space is often strengthened by a lead ring.

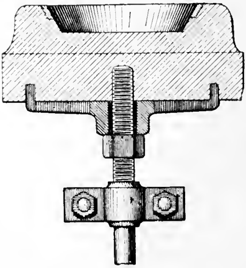


Fig. 81.—Jolley head.

Oval pieces can also be made on jolleys by using, for example, the arrangement shown in Fig. 82, in which the jolley spindle ends in a metallic piece, in which slides a kind of rule, carrying at its centre the head and at its two ends some T's, the horizontal branches of which slide along an eccentric disc, fixed by means of iron pins on the table of the jolley. This eccentric imparts to the head a reciprocating movement which in combination with the rotation of the jolley causes it to describe a kind of oval, the form of which is determined by the amount of eccentricity.

The moulds are made of plaster and in one piece for all flat objects (dishes, plates) as well as for those wide at the top (cups), but it is necessary to make them in two or three parts for articles with narrow apertures. In all cases they are terminated at the lower part by a truncated cone which fits into the head.

Profiles are rather thick sheets of steel or strongly fired body (faience or porcelain body) cut so as to remove the excess of material and to press the body against the mould.

The profile is fixed to a support, called a *jigger* (Fig. 83), fastened on the table of the jolley and capable of turning round a horizontal axis, or the profile is fixed to an upright, which allows it to descend in contact with the body, then makes it turn by means of a handle fixed on the vertical beam, as shown in Fig. 84.

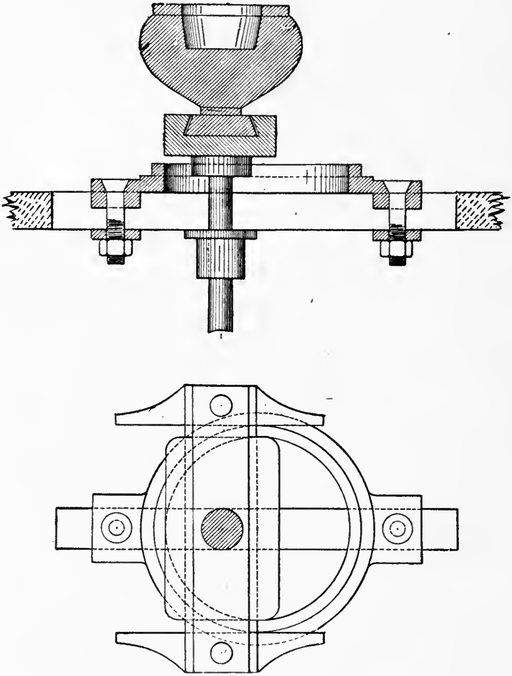


Fig. 82.—Oval jolley head.

In moulding bodies for common pottery-ware of suitable shape (porringers, flower-pots, etc.) in a single operation, the workman places in the mould a piece of body, sets the lathe in motion and gradually introduces the profile. This compresses the body towards the mould and finally leaves between it and the mould a layer of body which has exactly the section of the piece of pottery desired. For pieces requiring care (plates, dishes, etc.) and a compact body free from bubbles, it is preferable to make the "batts" on the jigger, the head being replaced by a disc (Fig. 85) on which is placed a piece of body which is pressed into the form of "batt" by means of a profile mounted on one arm. When the body is very open (porcelain) it is preferable to use a wooden ring covered with a stretched skin, mounted on the head. The helicoid profile descends vertically and the "batt" obtained is removed with the ring.

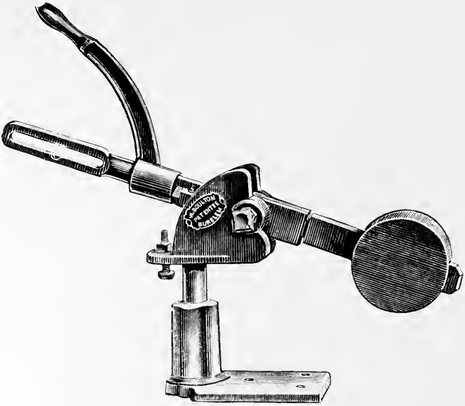


FIG. 83.—Jigger.

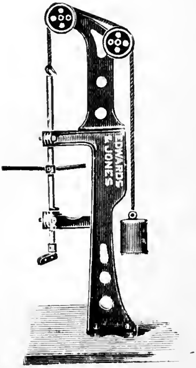


FIG. 84.—Upright jolley.

Plates and similar articles are made outside the mould (Fig. 86), the "batt" being placed on or in the mould, the jolley being set in motion and the body pressed close to the mould. The profile is then drawn down until the article is of the correct shape; Fig. 87 shows the moulding of a deep piece of pottery in a similar manner. The profile must be so placed that it leans to the centre of the piece so as to drive the excess of body towards the circumference. When the pieces of pottery have a convex shape this process is no longer applicable, and Fig. 88 shows a better arrangement. The profile is fixed at the end of a prop slightly eccentric to the axis of the jigger. When the profile is in the position AA′ it can enter the piece of ware, it is then made to take the position BB′ which puts it into contact with the body. To allow of emptying the mould must be in two parts. Very open bodies (porcelain) do not readily assume the form of the mould. The use of the profile also demands a certain plasticity of body unless the piece is given a thickness considerably greater than is necessary in the finished ware,

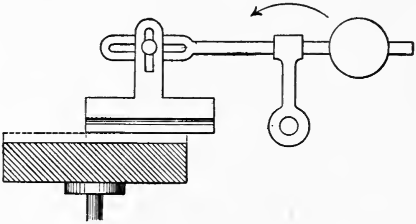


FIG. 85.—Batt-making.

and when dry is taken out and turned (p. 109). The turning then constitutes the chief operation in the making, and must not be confused with the operation of finishing, which is dealt with later.

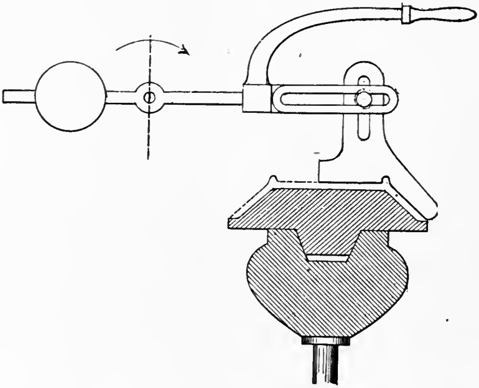


FIG. 86.—Jiggering.

(e) *Mechanical Moulding by Compression.*

The machine used in this process consists of two essential parts—the mould and the press.

The moulds, in spite of their diversity of shape, may be divided into two classes—squeezing moulds and compressing moulds.

Squeezing moulds consist of two parts, between which the mass of body is squeezed, and forced to take the desired form. The excess of body escapes between the two parts of the mould.

This mode of making permits the use of bodies of almost any degree of consistency, provided that the article made does not lose its shape on being taken out of the mould. When soft body is used, a plaster mould is preferable, or a metal mould covered with plaster in those parts in contact with the body, plaster being the only material which allows of an easy delivery. Where the body is stiff, plaster would not resist the pressure which must be applied, and metallic moulds, which must generally be lubricated in order to prevent sticking, are used.

Fig. 89 represents the pressing of a tile in soft body by this process in metallic moulds lined with plaster. When the two parts of the mould rest on each other, the space corresponds exactly to the form of the tile. A "batt" or cake of body, about the same size as the tile, but slightly larger, is laid between the moulds. The excess of body escapes at *m*. The moulds are emptied by turning the lower mould upside down.

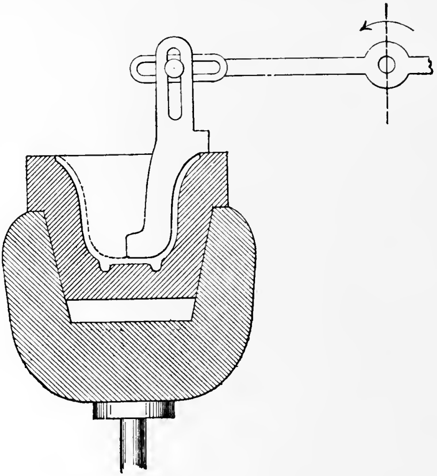


Fig. 87.—Making by jolley.

For moulding a flower-pot in a medium body, the metal mould consists of three parts—a mould, a core, and a movable bottom plate. A piece of clay paste of suitable size and consistency is placed in the mould, and by hand or mechanical power is pressed into shape by the core. The latter is then raised, and by raising the bottom plate delivery is effected.

The force necessary for such moulding is that expended by the friction of the body sliding on itself and on the walls of the mould. This force depends on the consistency, on the quantity of body in excess, and on the form of the mould. In order to avoid deformation in delivery the body must not be too soft, but it is not desirable to make the body too stiff or too plastic as this wastes power and gives a laminated structure, in which the different thin plates are insufficiently joined. If some air remains imprisoned in the deep parts and becomes compressed, preventing the body from penetrating the mould completely, this difficulty is lessened by giving two or even three successive pressures, moving the dies a little each time to allow the compressed air to escape. Air-holes may be pierced in the mould, but unless a very uniform body is used the latter have a tendency to become stopped up. [Helical air-grooves are much more satisfactory, particularly if the mould is rotated rapidly.—A. B. S.]

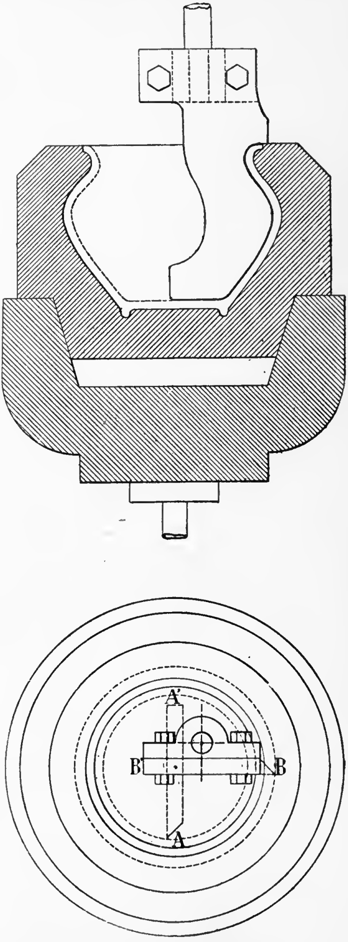


Fig. 88.—Making by jolley.

Compressing Moulds consist of a box in which the body is placed, and compressed by a plunger entering and fitting the mould exactly. This pressing is done with a hard or dry body, the moulds being always of metal. The mould is sometimes in several pieces in order to allow of delivery.

Fig. 90 represents the principal arrangements of this mode of making. The "batt" in a hard body, or the measured quantity of dry body, is placed in the mould formed by the parts B and C, then the plunger A is made to descend. When the pressure is sufficient, this latter is raised, then the delivery is carried on by raising the bottom plate C. In some machines the mandrel, A, and the bottom, C, approach each other simultaneously in order to increase the pressure.

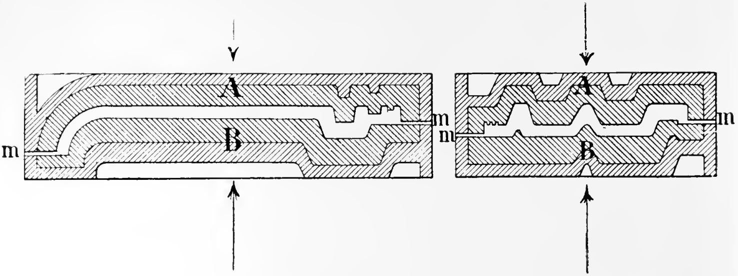


Fig. 89.—Hand pressing or moulding.

In articles of slight thickness, tiles for example, the arrangement shown in Fig. 91 is often preferred, delivery being effected by removing part B from the mould. The power needed to drive a suitable machine has, in this case, first to force the body to fill the mould and afterwards to compress it to the desired degree.

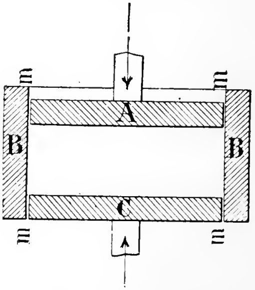


Fig. 90.—Die-box of press.

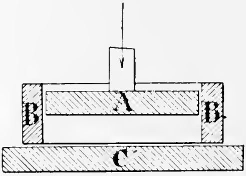


Fig. 91.—Die-box for encaustic press.

In making by compressing moulds there may be two objects :—

(1) To give an exact form to a soft plastic mass, after having allowed the body to harden and the greater part of the shrinkage to take place. (2) To make articles with a dry body in a single operation. Only the shape of the ware can be improved, and not the quality of the ware, for the compression causes cracks in the body which are only imperfectly rejoined in consequence of their lack of plasticity.

In the second case, there must be a more powerful compression as the body is drier. But as pressure can never impart to the molecules of clay the cohesion which they acquire by their mixture with a sufficient quantity of water, and as the air between the grains of the dry body cannot entirely make its exit by the joints of the mould or by the air holes which are arranged in it, dry moulding does not produce so strong an article before firing as does a plastic body. Fig. 90 shows that the force of compression begins by acting on the upper parts of the body and spreads nearer and nearer to the lower. The air contained in the latter cannot traverse the upper layer, as this has already been rendered dense by compression; it is therefore imprisoned in the form of flat bubbles, which separate the lower layers of body and prevent adhesion. This serious defect can only be minimized by repeated pressings and allowing the imprisoned air to escape between each, but with very thick wares this remedy is often insufficient.

Moulding with a dry body does not take into consideration the essential physical properties of the clay, and would never be used if it were not that the simplification of the preparation of the bodies and the suppression of the drying considerably reduces the cost of manufacture. This is usually done at the expense of the quality of the ware, though suitable for some bricks and tiles.

Presses are of numerous patterns and a complete description would require a special treatise. Only those interesting from a ceramic point of view are therefore given here. Presses can act either by shock (stamping) or by pressure (squeezing). In presses by shock the movement is perforce intermittent, the mandrel or one of the parts of the mould continuing its movement until all the active force has been destroyed by the work of resistance. With squeezing moulds, the stoppage is produced when the two parts of the mould come in contact, the blow being mitigated by the presence of the body. With compression moulds the body alone determines the stoppage of the plunger, and it is therefore very important to have the same quantity of body in the press each time it is used or the articles will vary in thickness. Presses by shock must be employed when the power of the motor is not sufficient to give the desired pressure, or with presses worked by manual labour (Figs. 92 and 93). In the first, the workman presses a lever which forces the base of the mould-forming mandrels to rise and compress the body against the sides of the moulds. The top of the mould is shown open in the position which it occupies when being filled with body; at the time of pressure it is brought down and held by a hook. In the screw press (Fig. 93) the moulder turns a screw by the aid of a fly-wheel, provided with handles. The screw carries the upper part of a mould, the second half of which can slide backwards and forwards so as to allow it to be turned upside down or is fitted with a rising bottom plate to deliver the finished article. The fly-wheel of the screw may be driven mechanically by means of two discs (Fig. 94), one causing the screw to rise by friction and the other to fall, each disc being brought in turn in contact with the fly-wheel.

Shock presses can be constructed by making use of other mechanical

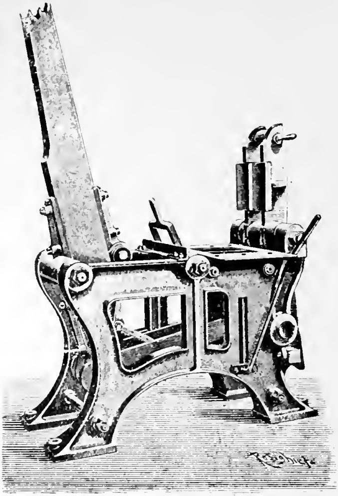


FIG. 92.—Lever press.

arrangements such as stamping mills worked by cams, eccentric wheels worked by a fly-wheel, etc.

In squeezing presses, the power is exerted during the compression. This can be calculated and the pressure exerted proportioned to the square inch of surface of the mould; the motion may be either intermittent or continuous.

The typical press with intermittent action is the hydraulic press, the working of which is so well known as to render a description unnecessary. They are only used for tile making. Presses with continuous action are driven by cogs or eccentric wheels, which give two or more increasing pressures.

When very small articles have to be made these presses may be worked by hand (Fig. 95), but generally they are power-driven (Fig. 96). In the latter, the upper part of the mould receives an alternative up and down motion from an eccentric wheel. There are five lower moulds arranged on a framework which turns intermittently so as to allow a fresh cake of body to be placed at one side of the press and the finished tiles to be delivered at the other. The revolving frame is automatically locked during the application of the pressure. Fig. 97 represents a brick press with eccentric wheels, and two twin plungers, while four pairs of moulds are ar-

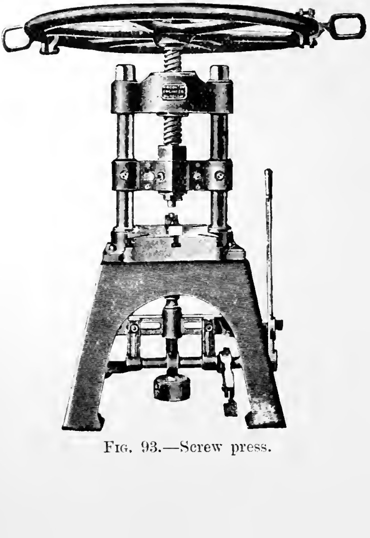


FIG. 93.—Screw press.

ranged on a turn-table moving a quarter of the circumference between each pressure. The delivery is effected by raising the lower

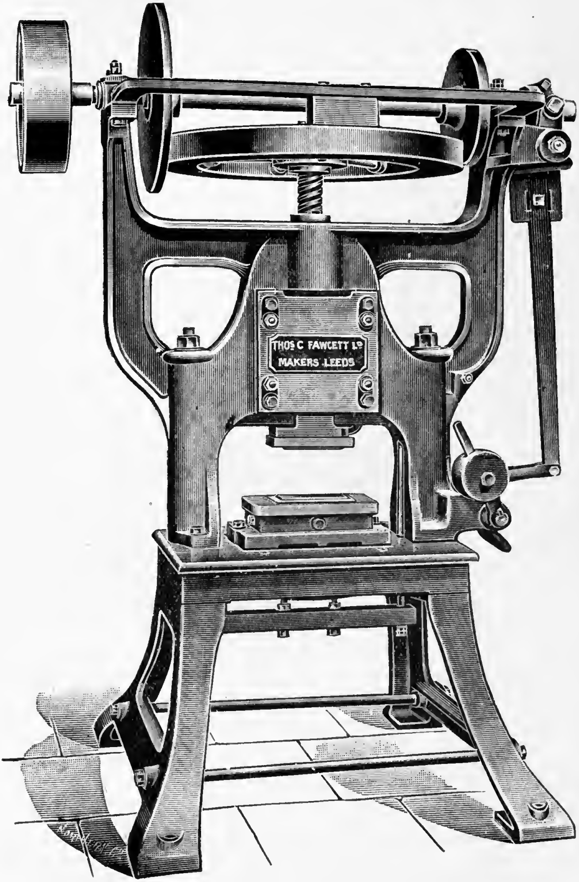


Fig. 94.—Power-driven screw press.

part of the moulds automatically. A description of some other machines on the same principle are described in Chapter X.

(f) Moulding by Slip Casting.

If a dry plaster mould is filled with a liquid body (slip) and the liquid is removed at the end of some minutes, the inside of the mould will be covered with a layer of the body, a part of the water having been absorbed by the plaster. By leaving this body in the mould until it has become hard it can be delivered, and an article obtained reproducing exactly the form of the mould, and of any desired thickness.

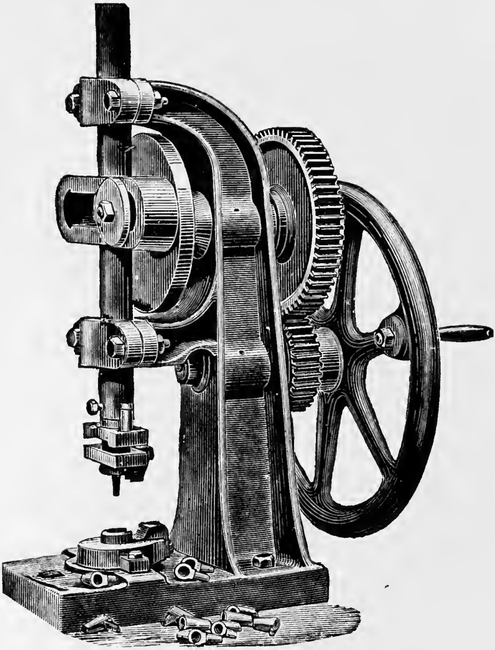


FIG. 95.—Press for small articles.

The body should not be very plastic, or the absorbing action of the plaster would be hindered, as, with a plastic body, the layer nearest the mould forms an impermeable coating. Hence this process of making can only be employed for certain porcelain bodies or for others having china clay or other lean clays as a base. The body should be extremely fine and very carefully prepared. It is expedient to pass it through a very fine sieve before use so as to separate all air-bubbles. The moulds are similar to those used for moulding by hand, and according to the form of the object to be reproduced, are in one or more pieces, and are placed so that the opening through which the body slip will be poured is at the top. The excess of body slip may be removed either through the same orifice, or (which is better for strong bodies) through a lower one, which is closed by a plug during the fill. The length of time the mould remains filled with slip depends on the plasticity of the body, and on the absorbing power of the plaster, i.e. on the thickness of the walls of the mould (two to four inches) and on its dryness. It is usually necessary to dry the mould

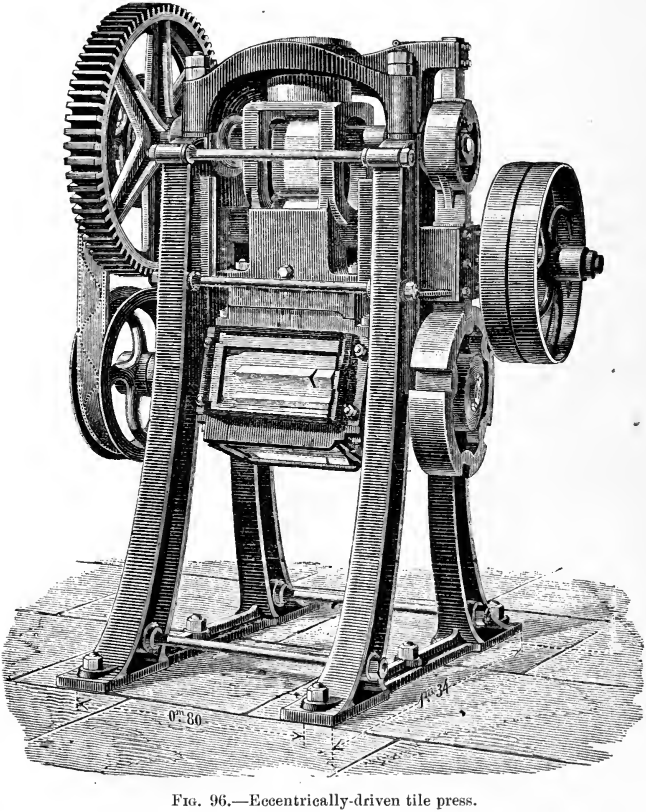


Fig. 96.—Eccentrically-driven tile press.

after each filling. With thick-walled articles the "pouring" should be done in three or four times, allowing the body to harden a little between each operation. When the moulds have complicated designs or are difficult to work, it is well to paint them with the body slip by means of a brush before casting to prevent the air-bubbles adhering to the plaster. If the plaster absorbs too rapidly, which would cause breaking in the pieces, the inside of the mould should be painted with a very thin layer of an emulsion of hard soap in olive oil.

The absorption of the plaster can be hastened by placing the mould in a hermetically sealed box, in which a vacuum is made by means of an air-pump or by closing the interior of the mould, and connecting it with a reservoir of air under pressure.

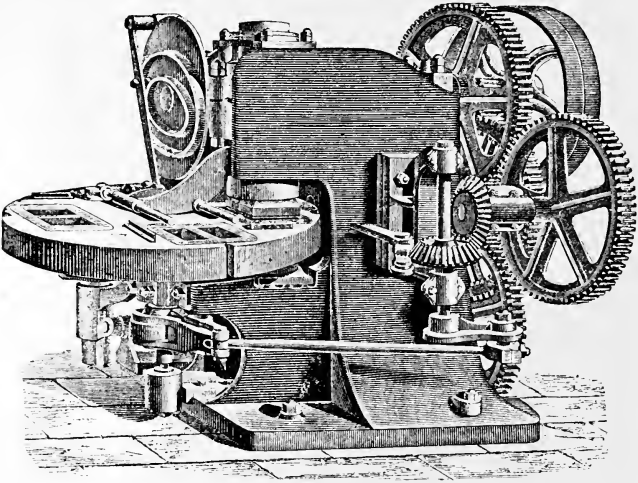


FIG. 97.—Brick press with rotary table.

Moulding by casting greatly simplifies the preparation of bodies and allows the making of very difficult pieces—impossible to obtain by other processes. Unfortunately, it only applies to certain bodies and necessitates a very large number of moulds, which rapidly wear away.

(*g*) *Finishing.*

Finishing consists of a series of manual operations, which vary according to the form of the object made, but always have two aims:—

(1) To correct the imperfections of making. (2) To unite the different portions of an article when these have been made separately.

The imperfections of making occur chiefly at the seams of the moulds, and in certain parts which had to be left solid, but which it is necessary to scoop out. The finishing is generally done by means of hand tools. When the articles have been thrown, the finishing is generally done on the lathe, the body being first allowed to harden and then turned.

When a large number of pieces is made simultaneously, certain precautions must be taken so that their drying takes place conveniently. When necessary, the latter is arrested by keeping the objects in a damp place.

The manual operations of finishing may be thus distinguished :—

Scraping, which consists in removing the marks of the seams of the moulds, and other excess material.

Carving (*undercutting*), in which those (unnecessary) parts are removed which have been left solid in order to facilitate delivery.

Grooving and *perforating*, the aim of which is to make hollows or holes, which it would be too complicated or impossible to obtain directly in the moulding.

Repairing, or correcting by means of a small quantity of body, the defects, such as bubbles, cavities and cracks, which have arisen during the moulding.

Sticking or reuniting the thick parts of an article; an example of this has been given when dealing with throwing (Fig. 55). It must be done when the body is sufficiently plastic and yet has sufficient resistance to retain its shape under a certain amount of pressure. The parts to be reunited are cut bevel-edged, as in Fig. 98. If the sticking must be done at a corner, a little of the body in the form of a small cylinder is added at the re-entering part. The parts to be united are first moistened, then one hand is placed inside, the other outside, and pressure is exerted, the workman endeavouring with his fingers to mix intimately the bodies of both parts. When the shape of the article does not allow of the hand being introduced on one side, it is replaced by a damp sponge fixed to the end of a stick. The sticking being finished, the part is smoothed with a sponge, and finally with scraper.

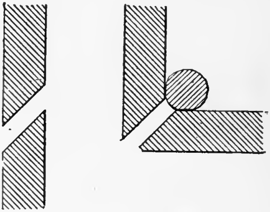


Fig. 98.—"Sticking."

Slipping is employed for bodies which are but slightly plastic, and for fine objects, handles, spouts, feet or stands, ornaments, etc., which have been made by themselves and which would lose their shape by sticking. The body must in this case be more consistent. The parts to be united having been made and so adjusted that the surfaces to be slipped correspond exactly one with the other, these are rendered slightly rough by means of a small comb, are covered with a thick liquid slip, and are pressed strongly one against the other. At the end of a short time, pressure may be released and the excess of body removed by means of a brush. Fig. 99 shows the surfaces of slipping (mm.) of a vessel with a handle and a spout. It is a simple operation, but in order that it may be successful, the objects to be joined, as well as the liquid body, must have the desired consistency. Experience enables the most favourable conditions to be determined.

The operations of slipping are known under the name of *handling* when they are applied to handles, spouts or stands, and by that of *sticking*, *sprigging* or *figuring* when used for fixing ornamentation.

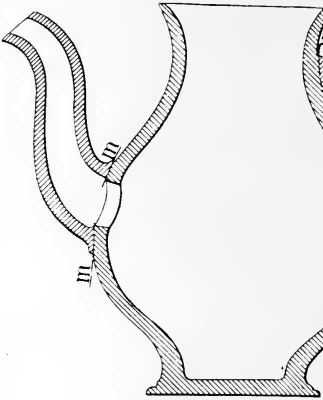


FIG. 99.—"Handling."

(*h*) *Slipping or Engobing.*

Slipping consists in covering a body with a layer of another body known by the name of a slip in order to (1) modify the colouring and the appearance of the first body; (2) give to the article the properties suitable for enabling it to be covered with a given glaze; (3) obtain decorative effects by the use of bodies, or engobes of various colours. The means employed for this purpose will be mentioned in the chapter relating to the decoration of pottery ware.

Considered merely in the light of fulfilling the first two aims, slipping or engobing is a very simple operation. The only difficulty consists in finding a slip which fulfils the required conditions and having the same shrinkage in drying and in firing as the body on which it is placed. The correct composition can only be ascertained by trial, a likely body being used as the foundation, and with this is mixed a plastic material, such as white clay, or a non-plastic material, such as fine sand, until the trial pieces obtained are without defects. If the body has more shrinkage than the slip the latter cracks, leaving in its place the bare body. If the contrary defect is produced the slip becomes detached and breaks off in scales.

When a slip of the desired composition is obtained it is blunged to form a liquid body (see p. 74).

The body made must, on its part, be hard enough to be manipulated without danger of its losing its shape, but it must not be too dry to absorb the water of the slip, which would consequently become dry and yet would not adhere.

The application of the slip or engobe may be made—

(1) By dipping the object in a vessel containing the liquid slip, either by immersing it entirely or by only dipping those parts which it is desired to cover.

(2) By sprinkling the object with the slip, the excess of which falls into a vessel placed below, a process employed when it is only desired to cover the exterior.

(3) By filling the object with the liquid, and by emptying it shortly afterwards: a method utilized for covering the inside of vessels.

(4) By applying the slip with a brush.

It sometimes happens that the slip is more refractory than the body, and adheres badly after firing. This fault can be remedied by the addition of a certain proportion (from 1 to 10 per cent) of alkalies, which considerably increases the fusibility and the adhesion.

In certain cases it is necessary to give to the slip a greater thickness than that which it is possible to obtain by the means just indicated, as in the case of paving tiles which are liable to wear thin, and would leave the body with its natural colouring, or when the pieces of pottery have projecting parts, for which it is desired to preserve a precise form.

It is then necessary to have recourse to a process known as "incrustation," which consists in moulding simultaneously two bodies forming two layers placed above each other, the thinner, placed on the *apparent facing*, constituting the slip, and the thicker, inside, serving to give to the piece of pottery the thickness necessary for its solidity, representing the body proper. According to the process of making employed, *incrustation* can be done in different ways.

In hand moulding, the layer of slip is placed in the mould in such a way that it fills all the parts to be in relief, the body then is added, and forced to adhere to the slip by judicious beating and pressure.

In pressing, a rough outline is first made by means of two layers of body placed parallel above each other; or when the making is done with dry body, a certain quantity of powdered engobe is placed in the mould, and the filling is completed with powdered body. In both cases the pressure determines the adhesion of the body and its slip.

Further notes on coloured slips relating to decoration are given in Chapter IX.

CHAPTER VI.

DRYING.

1. Drying of Bodies.

Theory of Drying.—By the term "drying" is understood the operation by which the water of formation is removed from bodies so as to harden them sufficiently to enable them to be carried to the oven and placed therein, and to make the firing more rapid and less risky. When the articles are made of dry body, the drying may sometimes be avoided and the ware placed in the oven immediately the bodies are made.

In the drying of any "body," the surfaces first lose a certain proportion of water. A further supply of water is then carried to the surface by the interior layers which are nearest to them, this transference being continued till the centre of the mass is reached. There is thus produced a capillary flow of water from the centre towards the surfaces, the speed of which depends on the texture of the body. It continues at the same speed so long as the drying action is not transmitted to the centre of the ware, but then the speed diminishes, but does not cease for some time, viz. until the body is uniformly dry.

The elimination of the water takes place (theoretically) in two periods: in the first its speed is constant and proportionate to the duration of the drying; in the second it diminishes progressively until it ceases entirely. So long as there remains in the body a sufficient quantity of water to allow the grains to become displaced, the latter collect together, filling up the spaces occasioned by the departure of the water which separated them. The result is a reduction in volume equal to the volume of water removed. When there is no longer sufficient water to allow the grains to move, a further elimination of the water produces, in the interior of the body, spaces equal to the volume of water which has been removed.

This second phase of the drying continues until the whole water of formation has been eliminated. If the drying has taken place equally throughout the whole mass, these two phases would be clearly distinct, but this condition being impossible to fulfil, the edges and the surfaces being necessarily dry before the centre, the drying is in reality subdivided into three phases:—

(1) In which the body shrinks in volume proportionally to the water eliminated. (2) In which spaces begin to form at the same time that the body continues to contract. (3) In which the shrink-

age ceases, the spaces which are produced being proportional to the water eliminated.

The following table gives an example of experiments on a plastic clay made by hand in the form of cylinders of 1·57 inches diameter and 7·87 inches long, the consistency being that of an ordinary (half-soft) body:—

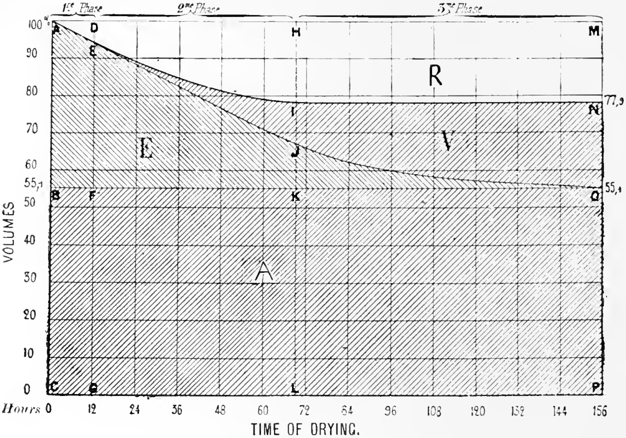
Duration in Hours.	Weight of		Lineal Shrinkage (Measured).	Volume of			Total Volume.
	Clay.	Water.		Clay.	Water.	Spaces.	
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	
2	75	25·0	2·1	55·1	44·9	—	100·0
12	75	21·5	3·7	55·1	38·7	—	93·8
24	75	18·0	5·1	55·1	32·4	1·8	89·3
36	75	14·5	6·5	55·1	26·1	3·3	84·5
48	75	11·2	7·6	55·1	20·2	6·4	81·7
60	75	8·0	8·0	55·1	14·4	9·4	78·9
72	75	5·6	8·0	55·1	10·1	12·7	77·9
84	75	3·8	8·0	55·1	6·8	16·0	77·9
96	75	2·5	8·0	55·1	4·5	18·3	77·9
108	75	1·7	8·0	55·1	3·1	19·7	77·9
120	75	1·1	8·0	55·1	2·0	20·8	77·9
132	75	0·7	8·0	55·1	1·3	21·5	77·9
144	75	0·3	8·0	55·1	0·5	22·3	77·9
156	75	—	8·0	55·1	—	22·8	77·9

In this case the trial piece, which has by weight 75 per cent of clay and 25 per cent of water, and by volume 55·1 per cent of clay and 44·9 per cent of water, has experienced in a drying lasting 156 hours a lineal shrinkage of 8 per cent, its volume being reduced to 77·9, consisting of 55·2 per cent of clay and 22·8 per cent of spaces.

These figures can be represented graphically (Fig. 101) by dividing an horizontal line proportionately to the number of hours, by drawing perpendiculars for each dozen hours, on which are marked the volumes of clay, water, spaces, shrinkage, and connecting the points just determined by continuous lines. In the first stage of the drying, for about twelve hours, the initial volume of the trial piece, represented by AC (of which AB stands for the water and BC for the clay) is reduced to EG, of which EF stands for water, the shrinkage DE being equal to the volume of water eliminated. In the second stage from the sixty-ninth hour the volume is reduced from EG to IL, the water passes from EF to JK, and the spaces, at first nothing, become equal to IJ. Finally, in the third stage, from the sixty-ninth hour to the one hundred and fifty-sixth hour, the volume no longer varies, IL being equal to NP, and spaces are formed in the place of the water, which latter is eliminated more and more slowly.

The preceding table, as well as the graphic representation (Fig. 101), only refer to a single plastic clay, moulded by hand in the form of cylinders, dried slowly and regularly, and the figures will vary with other clays.

Influence of the Nature of the Body.—The following table shows the results of a large number of trials made with various clays, by measuring the duration of the drying and the shrinkage of the clay. Clays were divided into four classes: china clays (average of seven different tests), plastic clays (six tests), clays moderately plastic (fifteen tests), and open clays (nine tests). They were made into cylinders, the body being of ordinary (half-soft) consistency; diameter 1·57 inches, length 7·87 inches, which were dried simultaneously.



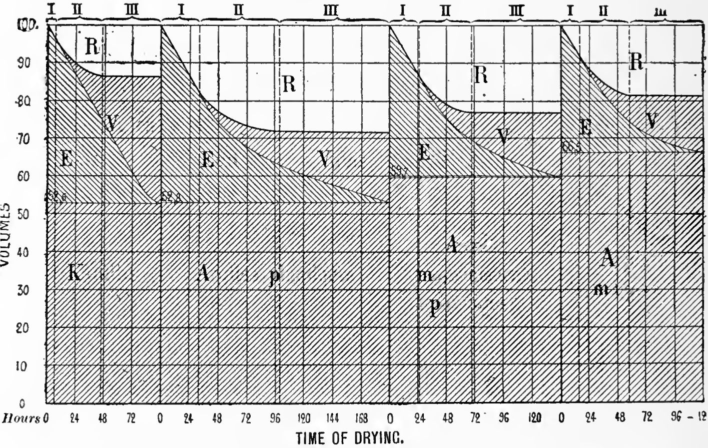
R = Shrinkage. E = Water. V = Pores. A = Clay.

FIG. 101.—Drying chart.

		Duration of Drying.	Weight of			Volume of the			Total Volume.	Proportion of Spaces.
			Clay.	Water.	General Shrinkage.	Clay.	Water.	Spaces.		
China Clays	Plastic Body .	—	72·7	27·3	—	52·6	47·4	—	100·0	—
	Dry Body .	93	72·7	—	4·75	52·6	—	33·8	86·4	39·0
Plastic	Plastic Body .	—	72·9	27·1	—	52·8	47·2	—	100·0	—
	Dry Body .	180	72·9	—	10·50	52·8	—	18·8	71·6	26·3
Non-plastic	Plastic Body .	—	78·4	21·6	—	59·7	40·3	—	100·0	—
	Dry Body .	144	78·4	—	8·30	54·7	—	17·3	77·0	22·5
Open	Plastic Body .	—	83·2	16·8	—	66·5	33·5	—	100·0	—
	Dry Body .	120	83·2	—	6·80	66·5	—	14·5	81·0	17·9

These experiments show the differences which exist from a ceramic point of view between china clays and plastic clays. The proportion of water of formation is the same, but the china clays dry more rapidly, shrink less, and have in consequence a much larger proportion of spaces. The more plastic clays show no differences, except those which result from the variable proportion of the water of formation. The preceding results being averages, certain clays can differ from them considerably, but in these cases an examination of their composition will reveal the cause of their divergencies. The preceding figures are represented graphically by Fig. 102.

The greater the amount of water in a body, the longer is the time taken in drying, the greater the shrinkage, and the greater the amount of spaces. It is well to remember that the proportion of the water of formation only depends on the texture of the body, that is to say, on the fineness of its grains. As the grains of true clay (hydrosilicate of alumina) are by far the smallest, these necessitate the most water; then come those of carbonate of lime, next silica (sand, quartz, flint, etc., finely ground), and finally, those of coarse-grained silica. Thus, given equality of plasticity, a pure clay opened with limestone will absorb considerably more water of formation than the same clay opened with silica.



R = Shrinkage. V = Pores. E = Water. K = Kaolins. A p = Plastic clays. A m p = Highly plastic clays. A m = Lean clays.

Fig. 102.—Drying chart.

Influence of Consistency on Drying.—By modifying the consistency of a particular body the duration of drying, the shrinkage, and the proportion of spaces will vary at the same time. The firmer the body the more rapid the drying, the greater the shrinkage and the fewer the spaces, but there is no fixed ratio between these different quantities.

For example, if it is desired to use a moderately plastic clay body, containing 5 per cent of hygrometric water, to make cylinders having a volume after drying of 100, it will be necessary to give to these cylinders when in the moist state a volume of—

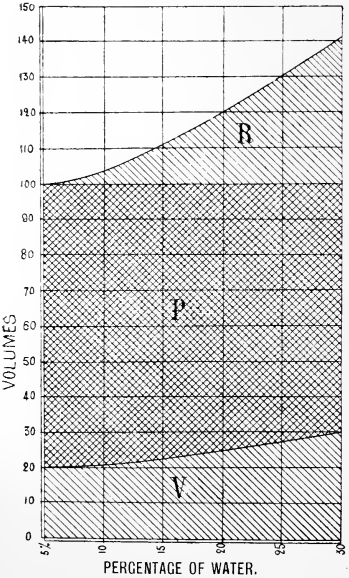
100	for	5	per cent of water.
104	,,	10	,, ,, ,,
111	,,	15	,, ,, ,,
120	,,	20	,, ,, ,,
130	,,	25	,, ,, ,,
141	,,	30	,, ,, ,,

That is to say, the shrinkage in volume will be—

0	per cent	for	5	per cent of water, or a lineal shrinkage of about	0	per cent.
4	,,	,,	10	,, ,, ,, ,, ,,	1	,,
11	,,	,,	15	,, ,, ,, ,, ,,	4	,,
20	,,	,,	20	,, ,, ,, ,, ,,	7	,,
30	,,	,,	25	,, ,, ,, ,, ,,	10	,,
41	,,	,,	30	,, ,, ,, ,, ,,	14	,,

In Fig. 103 these figures have been represented in graphic form, but it must be understood that they depend on the nature of the body, on the method of formation, on the shape of the object, and, to a certain extent, on the rapidity of the drying, and must not be considered absolute, but only as in keeping with the general law which they represent.

The duration of the drying is influenced by the proportion of the water of formation. By making identical trial-pieces with bodies containing more or less water, by drying them together slowly, and by weighing them at regular intervals, it can be proved that about three-quarters of the water is evaporated during a time which is perceptibly proportional to the water content, but that from this moment the drying becomes slower in proportion as the body becomes more consistent. Fig. 104 represents graphically the



R = Shrinkage. P = Clay. V = Pores.

Fig. 103.—Chart showing influence of consistency on shrinkage and pores.

influence of consistency on the drying of the body previously mentioned.

Theoretically, the different methods of formation have no other influence on the drying than that which results from the variations in the consistency of bodies. Exception must, however, be made for certain defects of making which are due to inequality of pressure. These are fairly frequent in moulding by hand and in throwing, when the workman does not exercise a very regular pressure with his hands, and in pressing they may be due to a defect in the mould. In all cases the parts most pressed dry slowest and the inequality in the shrinkage causes deformation of the ware.

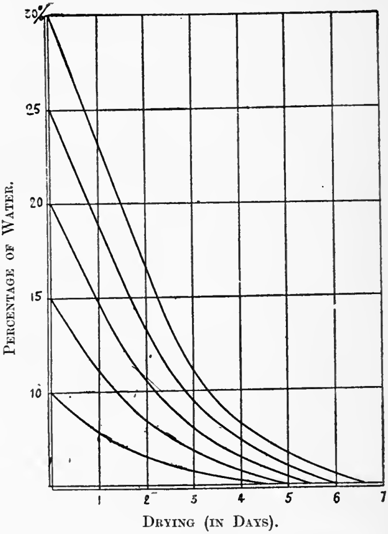


Fig. 104.—Influence of consistency on drying.

Influence on the Shape of the Articles.—As evaporation takes place chiefly at the surfaces, the speed of drying will be proportionate to the size of the surfaces with reference to the volume. Thus a solid brick of $9 \times 4\frac{1}{4} \times 2\frac{1}{2}$ inches has a surface of 143 square inches and a volume of 96 cubic inches, while a hollow brick of the same dimensions having 6 holes and sides $\frac{1}{2}$ inch in thickness will have a surface of 292 inches and a volume of 39 cubic inches. The proportion of the volume to the surface is, in the first case, 1 to 1·48, and in the second 1 to 7·5. The drying will, therefore, be five times as rapid in the case of the hollow brick as in that of the solid one.

The general principle can be enunciated that the time of drying is proportional to the thickness, or to the ratio of the surface to the volume for all wares having a uniform but relatively slight thickness, such as hollow bricks, quarries, tiles and thin pieces of pottery ware; but not for very thick articles, as the capillary movement of the water becomes slower and slower as the thickness increases and it is difficult to remove the last traces of water.

When the body is homogeneous the shrinkage should take place uniformly in all directions, all dimensions diminishing in the same proportion if it is not impeded by the shape of the article. The thin parts, corners and edges dry more rapidly, their shrinkages being hindered by the resistance of the thicker parts, which are still moist. Then when the latter dry they are in their turn restrained in their shrinkage by the thin parts which are already rigid. The result is warping and tension which often cause ruptures.

It is well to observe the following rules in the making of articles of clay:—

(1) Avoid too thick parts by hollowing out where possible, so that every article may have a uniform thickness. If it is impossible to fulfil this condition, an abrupt passage from one thickness to another should be avoided.

(2) Avoid unsymmetrical shapes or parts which project much. In some cases it is better to make the article in two or more pieces.

(3) Avoid objects of too large dimensions, especially when one portion is larger than the other. It is better, as in the previous case, to make them in several pieces.

Even when applying these rules to large pieces or those of complicated shapes, the shrinkage is seldom absolutely uniform, and it is usually necessary, when the measurements of the models must be accurate, to alter the second piece so as to correct any irregularities observed in the first one and to use the second as the model.

Influence of the Rapidity of the Drying.—When the drying takes place slowly and regularly, the inequality between the moisture at the edges, the surfaces, and the narrow parts and that of the interior or thicker parts remains rather slight, so that the variations in shrinkage do not have troublesome consequences. But when the drying is very rapid the antagonism between the parts already dry and those which are still moist can become sufficiently great to distort or even to break the ware.

The rapidity with which the drying can take place depends on the shape of the article and on the texture of its body. With reference to the shape, see page 143; as to the body, it must be neither so plastic as to cause distortion nor too open, or the lack of cohesion will cause ruptures.

Articles having narrow parts which dry too rapidly must be partially covered with damp cloths. They may be roughly shaped and more accurately finished when the drying is sufficiently advanced for no further shrinkage to take place.

Theoretically, the speed of drying being great in the first period, is reduced progressively in the second, and becomes obliterated in the third, so that it must usually be restrained at the beginning of the operation, but from the time when the body, having lost its plasticity, has no further shrinkage, the drying can without risk be forced to take place more rapidly. In practice the critical moment is easily recognized by the change of colour in the body, which becomes lighter. The shrinkage is slightly less when the drying is rapid than when it is slow. Thus, two pieces of identical shape and made of the same body, one dried in twenty-four hours, has a shrinkage of (say) 7·75 per cent, and the other, the drying of which occupied fifteen days, has (say) 8·50 per cent shrinkage.

2. Processes of Drying.

In order to dry a body it must be placed in a relatively dry atmosphere which can provide it with a certain quantity of heat, and which can be renewed so that the water converted into vapour can be removed. It is possible to determine, independently of the process of drying employed, the volume V of air and the heat C necessary to evaporate 1 kilogramme of water contained in a body having *n* per cent of water of formation.

Let θ be the surrounding temperature; T, temperature of air entering into the dryer; t, temperature of air going out of the dryer; p, weight of water vapour in grammes contained in one cubic metre of air entering; P, weight of water vapour in grammes contained in one cubic metre of air departing; a, co-efficient of expansion of gas = 0·00366; 1·3 kilo = weight of a cubic metre of air at 0 degrees; 0·237 = specific heat of the air; 0·200 = specific heat of the body.

The volume of air necessary to evaporate 1 kilogramme of water is—

$$V = \frac{1000}{P - p\dfrac{1 + aT}{1 + at}}, \qquad (a)$$

And

$$\frac{0{\cdot}308\ V\ (T - t)}{1 + at} = 606{\cdot}5 - 0{\cdot}695t + 0{\cdot}2n\,(t - \theta) \qquad (b)$$

On the other hand, if it is granted that the air going out is saturated with moisture, t and P are connected by a function given in suitable tables, indicating the tension of the water vapour in the air at the different temperatures; p can be considered as a known quantity, that is, at the maximum, the weight of water vapour contained in one cubic metre of air at θ°. There are, therefore, three unknowns: V, T, and t, connected by two equations, (*a*) and (*b*), which, in leaving the problem indeterminate (= unsolved), allows the choice of the most suitable values for T and t.

The quantity of heat, C, expended, equal to the number of calories necessary to raise the temperature of the volume of air from θ to T, is therefore—

$$C = \frac{308\ (T - \theta)}{P\,(1 + at) - p(1 + aT)} \qquad (c)$$

These formulæ are not very easy of application; it is better to reserve them for more complete studies, and in practice to take the following table as a base:—

Temperature.	Maximum Tension of Water Vapour.	Maximum Weight of Vapour contained in 1 cbm. of Air.	Heat Absorbed by 1 cbm. of Dry Air, the Temperature of which is raised by 1°.	Heat Absorbed by the Volatilization of 1 kg. of Water.	Water Evaporated by 1 cbm. of Dry Air, the Temperature of which is lowered by 1°.
Degrees.	Mm. of Mercury.	Grammes. P.	Calories. C.	Calories.	Grammes. E.
0	4·5	4·8	—	607·0	—
5	6·5	6·7	0·303	608·5	0·498
10	9·1	9·3	0·297	610·0	0·487
15	12·7	12·7	0·292	611·5	0·477
20	17·4	17·1	0·287	613·0	0·468
25	23·6	22·8	0·282	614·5	0·459
30	31·6	30·1	0·278	616·0	0·451
40	55·0	50·9	0·269	619·0	0·434
50	92·0	82·3	0·261	622·0	0·418
60	148·5	129·1	0·253	625·0	0·404
70	232·6	195·3	0·245	628·0	0·391
80	353·9	290·2	0·238	631·0	0·378
90	527·0	412·7	0·231	634·0	0·365
100	760·0	589·5	0·226	637·0	0·355

The volume V is easily found by the formula

$$(1) \qquad V = \frac{1000}{E(T - t)}$$

in which E is the weight, in grammes, of the water evaporated by 1 cubic metre of air at an average temperature $\frac{T + t}{2}$. It must be observed that p + E(T − t), that is to say, the weight of water removed by 1 cubic metre, must be lower than, or at most equal to, the value of P corresponding to the temperature t, so that

$$(2) \qquad E(T - t) \leqq P - p.$$

The heat, C, furnished by 1 cubic metre of air, the temperature of which is raised by 1°, is given by

$$C = V(T - \theta)c$$

in which c is the value corresponding to the temperature $\frac{T + \theta}{2}$ or

$$(3) \qquad C = \frac{1000\,(T - \theta)c}{E(T - t)}$$

In order to apply these formulæ to an existing dryer, it is necessary to measure the temperatures θ, T and t, and the contents of water vapour P and p. But these determinations do not give any information on the variations which can be produced in the interior of the dryer. For the latter, a small apparatus, shown in Fig. 105, called an evaporimeter, may be used. It consists of a glass tube graduated in centimetres, closed at the top by a ring, by which it can be suspended, and the lower end can be closed by a sheet of blotting paper, having a given surface and held by means of a small spring. The tube is filled with water, closed with the blotting-paper, and hung up in the dryer. At the end of a certain time the volume of the water evaporated is read off on the graduation, which has no signification of absolute value but which, by comparison with the figures given by other similar tubes, is proportional to the intensity of the drying in the part of the dryer in which it has been placed.

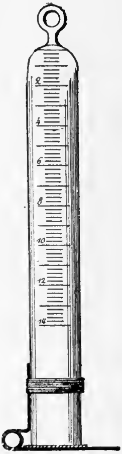


FIG. 105.—Evaporimeter.

Aeration is the term used to designate the drying of bodies in the open air [or in open sheds in which no artificial heat is used]. The heat necessary for the evaporation is furnished by the atmosphere; the renewal of the air is caused by the action of the wind and by the difference of weight between the exterior air and the denser air in the dryer.

In aeration there can be no drying when the atmosphere is saturated with water vapour, which is frequently the case in time of rain or fog. In order that the drying may be brisk, the temperature and the velocity of the wind must not be too low. A dry, fresh wind is better than a greater heat with less displacement of the air.

It is well, in the construction of aeration dryers, to avoid low-sheltered places, and to choose well-aired ground. The drying is twice as rapid at a height of 3 feet as on the ground itself, and trebly so at a height of 6 feet 6 inches, so that elevated dryers are advantageous. It is also necessary to avoid crowding or the placing of one dryer too near to the others. They should be arranged in such a way that the wind may easily pass through them, should present their largest surface in the direction of the most frequent dry winds, and must be well drained. The ware must be protected from the rain even when it is driven sideways by the wind. Too brisk a circulation of air must be avoided, and movable screens, which diminish the force of the too violent winds and prevent the rays of the sun from striking directly on the ware, should be used.

Except for the manufacture of certain common bricks, which are simply piled on top of each other, the ware is generally arranged on isolated wooden stages (Fig. 106) or grouped together in the same structure (Fig. 107). The pieces of ware are sometimes placed direct on these shelves, but usually each of them is supported by a plank or wooden frame, the form and dimensions of which depend on those of the articles.

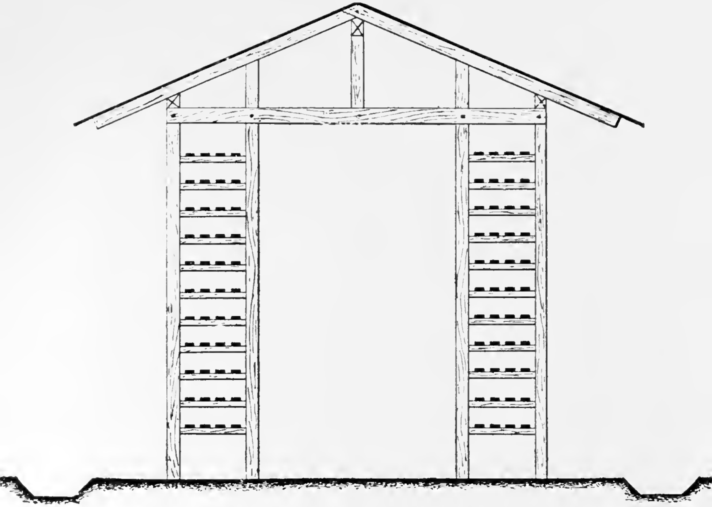


Fig. 106.—Shed-dryer.

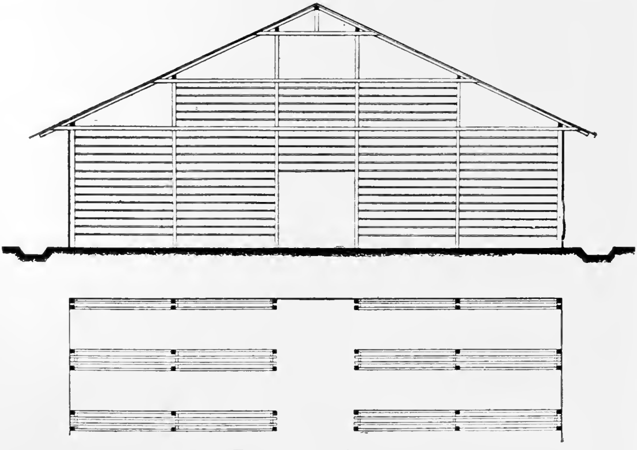


Fig. 107.—Shed-dryer.

In Western Europe, aeration can only take place during five to eight months of the year, and drying almost ceases during the cold and wet months. If the exterior temperature falls to 2° C. or 3° C. below zero, the water contained in the ware freezes, and the increase in its volume (as ice) breaks the body, which falls to pieces or cracks at the time of thaw. This destructive action of the frost is not produced on bodies which contain no water of formation.

The volume of air theoretically necessary to evaporate by aeration one kilogramme (2·20 lb.) of water is—

$$V = \frac{E\ (\theta - t)}{1000}$$

with condition 2 (page 146), $E\ (\theta - t) \overline{<} P - p$.

In damp climates the water vapour contained in the air averages $\frac{2}{3}$ of the maximum weight which it can contain. It is reduced to the half in dry climates. The average temperature during the seasons in which aeration is possible varies from 8° C. to 25° C. All these figures have reference to European meteorological conditions.

For an outside temperature of 10° C.,

$$V = \frac{1000}{0{\cdot}490 \times \frac{10}{5}} = \text{about 1000 cb.m.; or 62 cb. yds. per lb.;}$$

and for a temperature of 25°,

$$V = \frac{1000}{0{\cdot}460 \times \frac{25}{5}} = \text{about 430 cb.m.; or 27 cb. yds. per lb.}$$

These figures may appear large, but it must be noted that a scarcely perceptible wind of 6 feet 6 inches a second is sufficient to send through an aperture of one square inch a volume of 6 cubic yards per hour.

In spite of its many inconveniences, aeration is much used for the drying of heavy wares containing a large quantity of water, such as bricks, the product of filter presses, etc., because, beyond the expenses of installation, the only cost is for the necessary manual work of moving the ware and placing it on the shelves.

Heating.—The heat expended in evaporating one kilogramme (2·20 lb.) of water is given in formula 3 (p. 146), namely—

$$C = \frac{1000\ (T - \theta)\ c}{E\ (T - t)}$$

If the outside temperature $\theta = 0$, this relation is reduced to

$$C = \frac{1000\ (Tc)}{E\ (T - t)}$$

This heat is least when E (T − t) is greatest, that is to say, when this product is equal to P − p (formula 2). In other words, the heat expended for the evaporation is least when the air goes out saturated with water vapour.

Temperature of the Air entering into the Dryer.	Minimum Temperature of the Air going out from the Dryer.	Number of Calories Expended to Evaporate 1 kg. of Water (2·20 lb.).
Degrees C.	Degrees C.	
20	11	1360
40	18	1120
60	24	1030
80	28	960
100	31	930

The figures in the above table are the minimum, and must be increased from 50 to 100 per cent, according to the installation, in order to show the real expenditure in calories. They show that it is desirable to heat the air entering into a dryer as much as possible on condition that it always goes out saturated with water vapour.

It is seldom that a dryer can be heated directly with the gases proceeding from a fire, as they are too hot, and leave deposits of carbon and other substances, and occasion condensation of sulphurous vapours, which are always injurious, on the ware.

The air may be heated in two ways: either the heat is produced in the interior of the dryer, or the air which enters it has been previously heated. In both cases it is sought to utilize as much as possible of the heat which has been lost from the stoves or from the waste steam of non-condensing engines.

Ventilation is often produced by simple aeration, the heated air entering and departing from the dryers by openings more or less regulated, or sometimes simply by fissures in the partitions and in the roofing. This system is only permissible when there is a large amount of waste heat available or the drying is done in buildings. In modern plants it is usual to employ a special process of ventilation, e.g. flues or fans.

In *flues* the air must pass out at a higher temperature than that of the atmosphere. Its velocity is given by the following formula:—

$$v = \frac{\sqrt{2gaH\ (t - \theta)\ (1 - a)}}{1 + at}$$

in which $g = 9{\cdot}8088$; $a = 0{\cdot}00366$; H is the height of the chimney; t, the temperature of the air at the exit end of the flue; θ, that of the outside air; a, the relation of the resistance opposed to the current of air by all the obstacles which it meets on its way to the base of the chimney.

[The factor (1 - a) is to allow for the difference between the calculated and actual velocity; i.e. the losses due to friction and turns in the flues.]

If the flues are not long, if the resistance is slight and the section S large enough, a good ventilation can be obtained with chimneys from 25 feet to 50 feet high, for differences of temperatures $(t - \theta)$ of only 3° to 4° C. As the temperature t is never very high, dryer chimneys are often made of wood covered with tar.

Fans must be used when a current of air meets with a great resistance in its course. Their disadvantage is the necessity of motive power, but they have the advantage of ensuring a powerful draught which can be regulated at will, independent of the temperature, so that they are increasingly used. They are all based on the same principle, though the shape of the fans varies according to the makers. Fig. 108 shows the arrangement generally adopted. A pulley drives the shaft carrying the fan which is supported by special bearings. The structure is placed in any position, vertical, horizontal or inclined, against a circular aperture in the wall. The diameter of the hole is equal to that of the fan. The latter draws in the air and forces it through the aperture, hence the term "induced draught".

FIG. 108.—Fan.

The following are the usual sizes:—

Diameter. Inches.	Number of Revolutions.	Volume of Air moved per Minute. Cubic Feet.	Horse-power required.
14	1200	3,533	½
22	1000	7,067	¾
27	850	14,134	1
33	750	21,201	1½
38	700	28,268	2
44	600	35,335	3

The fans most used are from 22 inches to 38 inches diameter; the draught varies from ·04 inch to ·50 inch of water, according to the velocity. The systems most known are those of Blackman, Scott, [Davison, Sutcliffe, Sturtevant, and Matthews & Yates].

The fans are usually driven by cords or belts, but sometimes it is found advantageous to employ a small electric motor or a separate engine.

Heated and Ventilated Dryers.—Artificial dryers may be divided into three classes:—

(1) Dryers heated and not ventilated.

(2) Dryers with fixed shelves heated and ventilated.

(3) Dryers with movable platforms heated and ventilated.

In heated and not ventilated dryers waste heat is used, or other means of heating are employed, but there is no proper ventilation, the renewing of the air being accidental (by aeration). The temperature is never very high. Dryers of this type are often placed in or near the moulding shed. The ware is placed, as in the case of aeration, on fixed shelves.

The arrangements adopted vary according to the source of the heat utilized, the process of manufacture and local circumstances. They can, however, be divided into three groups:—

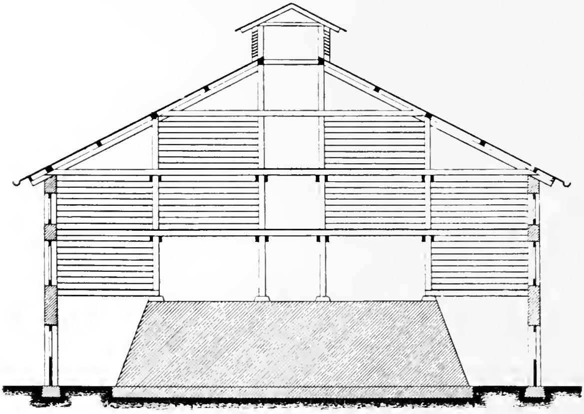


Fig. 109.—Dryer above kiln.

(*a*) *Dryers placed by the side of or above the kilns utilizing their waste heat* (Fig. 109) are much used in brickworks, tile factories, drainpipe factories, etc.

The drying is effected economically, but it is often irregular and is greatly influenced by outside atmospheric conditions.

The kiln is placed in the centre of the structure, of which the upper part is occupied by the dryer. The aeration takes place by means of windows and of the lantern roof. The heat from the kiln is sufficient to raise the temperature inside the structure and to shelter the ware from frost.

(*b*) *Dryers heated by circulation of hot air, hot water or steam* are frequently used in potteries, faience factories, porcelain works, etc., where waste heat from the kilns is unsuitable. The shelves are generally placed in the making sheds and the flues are near the floor. Aeration takes place equally by the windows or by special openings. The heating varies according to the outside temperature.

This arrangement enables the makers of the ware to supervise the drying, but it is not economical, and compels the men to remain in a warm, damp atmosphere to the injury of their health.

(*c*) *Dryers heated by flues placed below the floor, the place being used for making or being exclusively reserved for drying.*—This arrangement is seen chiefly in manufactories of refractory ware where the size of the pieces is too large to allow them to be moved when in a damp condition. The heating is effected by underground pipes connecting the kilns with the chimney; or special fireplaces are employed, the combustion products circulating in the zigzag flues under the floor before reaching the chimney. These flues are covered with terra-cotta slabs or plates of sheet-iron, the thickness of which diminishes in proportion to the distance from the fireplace. [Instead of hot gases, steam may be used with advantage.]

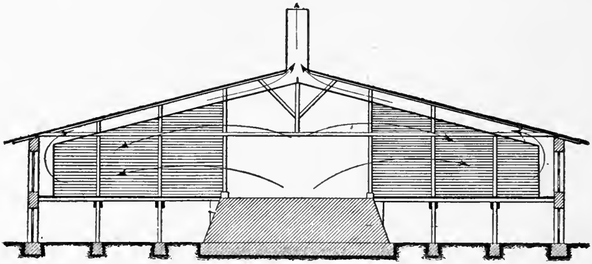


FIG. 110.—Dryer above and around kiln.

In heated and ventilated dryers with fixed shelves the air is renewed by means of flues or ventilators, the pieces of ware remaining throughout the time of drying in isolated chambers. These dryers may be divided into three groups:—

(*a*) *Dryers placed by the side of or above the kilns, in order to use their waste heat*, usually employed in brick or tile works possessing a continuous or Hoffman kiln (see Chapter X.). The kiln is covered by a large building shown in transverse section in Fig. 110, divided in its length into six, seven or eight chambers, from 13 feet to 20 feet wide. The air above the kiln is heated by radiation and traverses these chambers before passing under the roof, and escaping by a central flue. The heat furnished by the kiln is usually insufficient, and this arrangement has no advantages over that represented in Fig. 109.

(*b*) *Dryers formed by chambers entirely isolated, and heated by means of a lower system of pipes, the aeration taking place by means of a flue at the top.* This arrangement is frequently employed in faience manufactories. The heating of these chambers can be constant, the ware being placed on or removed from the shelves by the workmen who enter the dryer. As the work is very difficult it is preferable to arrange several drying stoves, and to make them work intermittently by stopping the heating when the ware is dry in one of them, and by commencing it again when the stove has been emptied and filled afresh. Circular stagings which rotate round a vertical axis are also used. They are enclosed in a circular framework provided with one or more sliding doors (Fig. 111), to enable the damp pieces of ware to be placed and the dry ones removed. The heating is done by steam piping arranged spirally, the air entering at the lower end and out at the top. The action is continuous. For larger outputs several of these frames can be grouped together round a main vertical axis (Fig. 112).

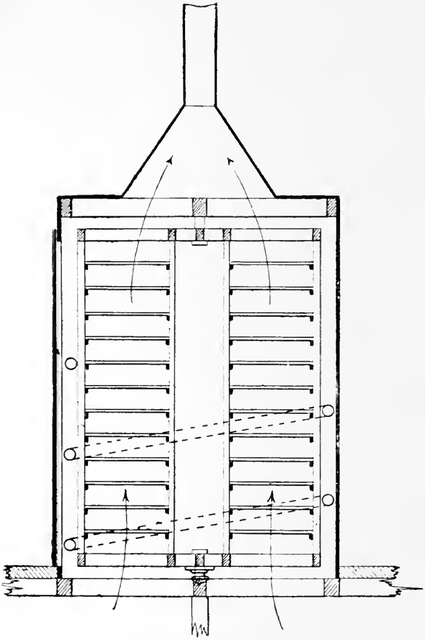


Fig. 111.—Stove-dryer.

The rotary movement is only to facilitate the manual work and has no influence on the drying.

(c) Drying stoves, in the form of tunnels, the wares being placed on fixed shelves, or mounted on wagons; but in this latter case they are not moved during the drying, this arrangement only having the purpose of reducing the labour of filling and emptying the dryers. The heating is done by currents of hot air and flues or fans.

A very simple dryer of this kind is shown in Fig. 113 and consists of parallel tunnels in which are placed shelves. The hot air from a heater is distributed to one end of each tunnel by an underground longitudinal flue and it passes out charged with moisture at the other end, being drawn out by a fan. In this kind of stove it is easy to evaporate the water from the ware placed at the entry of the tunnel, but as the air passes along towards the other end it cools, causing the steam to condense on the pieces of ware placed there and softening and distorting them.

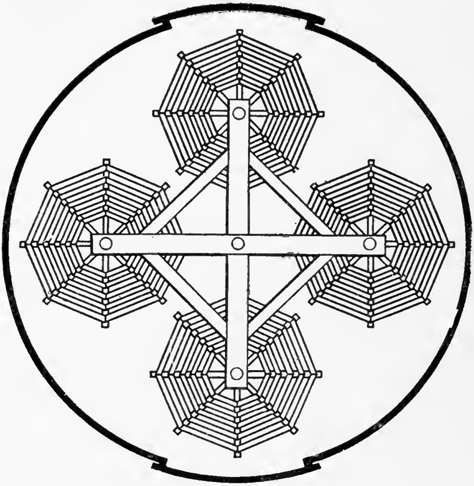


Fig. 112.—Revolving dryer.

In the dryer shown in Fig. 114 this drawback is partially avoided. The stoves are, as in the preceding case, placed side by side, but the introduction of hot air takes place uniformly throughout the length of the floor. Waste heat or steam can be utilized or special furnaces may be used.

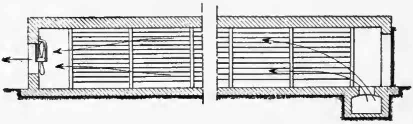


Fig. 113.—Plan of intermittent tunnel dryer.

The subdivision of the drying can be pushed further still as indicated in Fig. 115. In this arrangement proposed by Hotop, the shelves are fixed in a long gallery. The hot air entering by an upper pipe is distributed through the apertures between the ranges of shelves and passes out through a series of similar openings in the floor communicating with a flue, or vice versa. All these drying stoves must be carefully regulated to avoid too speedy a drying at the beginning, and a waste of heat at the end by heating the ware already dry.

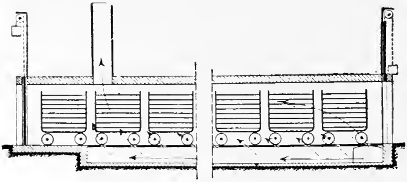


FIG. 114.—Section of tunnel dryer.

Dryers heated and ventilated, with movable shelves, have a continuous action. The pieces of ware are placed on shelves mounted on wagons, which are methodically pushed through a tunnel, the damp pieces of ware being introduced at one end and the dry pieces of ware being removed at the other. The arrangements employed for this purpose are of three kinds:—

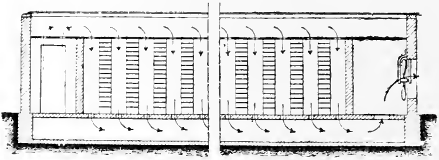


FIG. 115.—Hotop's dryer.

(*a*) *Drying stoves in which the air moves in a contrary direction to the ware* (Fig. 116), the hot air being introduced at one end of a tunnel and removed at the other by a fan. When the last wagon on the side of the entry of the air is dry, it is drawn out and another, laden with damp pieces of ware, is pushed in at the opposite end. The

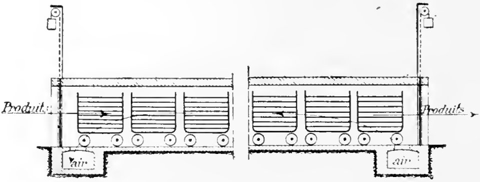


FIG. 116.—Inverse dryer.

wagons are moved by winders or cranes, the tunnel floor being slightly inclined so as to facilitate the process.

As stated on page 150, it is desirable to heat the air as much as possible considering the nature of the goods. If the air enters the dryer at 60° C. and passes out saturated with water vapour at 24° C., there is an expenditure of 1030 calories per kilogramme of water evaporated. When the air enters at 100° C. and passes out at 31° C. the expenditure is 930 calories. It is necessary to add to these figures the heat removed by the body, say 60 calories in the first case and 100 in the second, the exterior temperature being supposed equal to 0° C. Finally, it is desirable to increase the expenditure by 25 per cent in order to take into account the various losses of heat, so that in the most favourable case the heat necessary to evaporate 1 kilogramme of water will be $(930+100) \times 1{\cdot}25$, or about 1300 calories.

(*b*) *Drying stoves in which the air is displaced in the same direction as the ware by heating progressively* (Fig. 117).

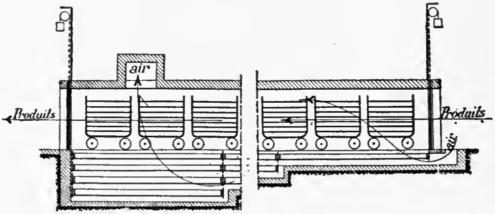


FIG. 117.—Direct dryer.

The air enters at one end of the tunnel, is heated by steam piping and by heaters so that its temperature increases as it advances in the tunnel and becomes charged with water vapour, passing out at the other end with the maximum of heat. The wagons are moved as in the preceding arrangement. The formulæ given on page 145 do not apply in this case.

The heat expended will be:—

For the steam	$606{\cdot}5 - 0{\cdot}695 = 605{\cdot}80$
For the air	$1{\cdot}3 \times 0{\cdot}237 \times 60 \times 7{\cdot}35 = 135{\cdot}72$
For the body	$5 \times 0{\cdot}2 \times 60 = 60$
	801·52

a total which, increased as previously by 25 per cent, gives an expenditure of about 1000 calories. In some cases it can be reduced by employing the departing air to heat that which has just entered. Thus, if the air instead of going out at 60° C. has its temperature reduced to 30° C. by means of calorifers, the heat which can thus be recuperated is 477·01 calories, and recuperation would then allow—in order to evaporate 1 kilogramme of water—of reducing the expenditure to 823 calories.

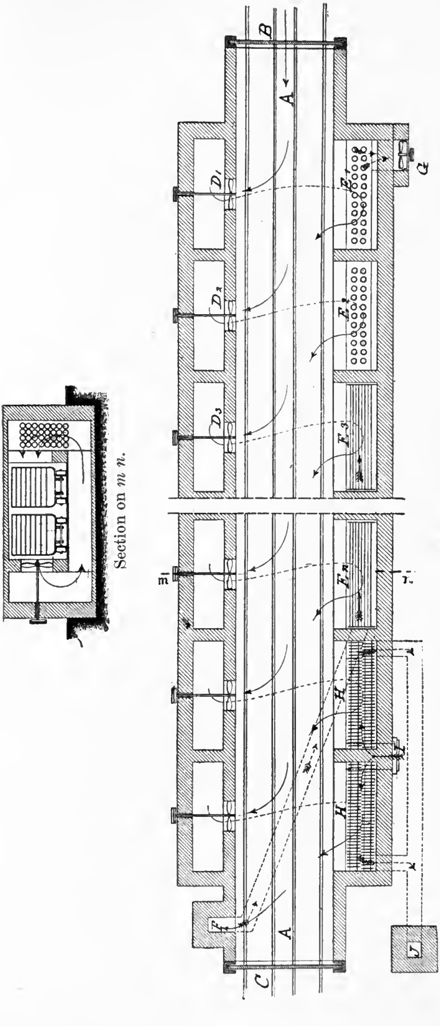
On comparing the two kinds of drying stoves with movable shelves which have just been described, the first are of a lower thermic capability, and must be used only for utilizing waste heat. The second, of much greater use, do not lend themselves well to this utilization, but are preferable when the heat must be specially provided. In direct dryers (Fig. 117) the chief difficulty consists in obtaining a uniform atmosphere throughout the section. If mechanical means are not employed to force the circulation of the air, the upper part of the dryer is filled with a warm, damp atmosphere. The system proposed by Moeller & Pfeiffer (Fig. 118) completely obviates this difficulty. In a tunnel, A. several ranges of wagons laden with ware to be dried enter through the door B, and go out through C. The outside air enters through the door B, which is partially opened, being drawn in by a first fan, D_1, which forces it through an underground flue to the other side of the tunnel, where it meets the pipes of the heater, E_1, E_2; after being heated in contact with them it re-enters the tunnel, travelling obliquely, being drawn in by a second fan, D_2, which likewise forces it to pass on to a second calorifer, E_2, and so on. The air thus follows a spiral path, becoming more and more heated as it advances, before going out through a side opening, F. From F it is drawn through the heaters, E_n, E_3, E_2, E_1, where it gradually loses its heat by transmitting it to the air circulating in the tunnel, until it reaches the fan, G, which discharges into the atmosphere. The water vapour which it contains is condensed while restoring the latent heat of evaporization, and passes out of the dryer in the liquid state at a slightly raised temperature.

The last two or three heaters, H, are heated by a special stove, I, the gas of which escapes by a chimney, J.

Tunnel dryers are only used in brick and tile works (see Chapter X.).

Drying by absorption in plaster moulds is much used in making pottery ware, and in the drying of bodies. The absorbing properties of the plaster act exactly in the same way as evaporation in a dry atmosphere. The body gives off by a capillarity a part of its moisture to the plaster, and this action is the more powerful the drier and thicker the plaster.

The only difference between drying by evaporation and by absorption consists in the impossibility of complete drying by the latter. It, perforce, stops at the moment when the moisture in the plaster becomes equal to that of the body, so that drying by absorption must always be followed by drying by evaporation. Two processes are employed for this purpose, according to the size of the ware, the nature of the body and the arrangement of the works. In the first—which is especially applicable to large pieces of plastic bodies, for small outputs—the article made is left to dry for some time in the mould in the workshop where it is made, and when it has obtained sufficient consistency to enable it to be taken from the mould it is placed on shelves and dried by evaporation by one of the methods previously indicated. In



Section on *m n.*

FIG. 118.—Moeller & Pfeiffer's dryer.

the second process—which is employed chiefly for the manufacture of a large number of small pieces—the mould containing the article is at once placed in the dryer, where the drying takes place simultaneously by absorption and by evaporation; but the article is later taken out of the mould and drying continued until it loses its last traces of moisture.

CHAPTER VII.

GLAZES.

(1) Composition and Properties.

Glazes are vitreous coatings used to cover bodies, either to decorate them or to make them impermeable to water. They should partly combine with the body itself. Their chemical composition is nearly as variable as that of the bodies, but they may be considered as "glass" in the widest meaning of that word.

Glazes differ from glass in not being solely composed of silicates; they sometimes contain quite as much borates, or phosphate of lime, and among the bases may be oxide of tin, while sometimes the alkalies are quite absent. The fusibility of glazes is much more variable than that of true glass; sometimes they vitrify at a temperature lower than that for fusing borax, at other times, however, they need a temperature high enough for burning porcelain.

As in the case of glass, the molecular constitution of glazes is not certainly known.

Glazes, like glasses, are amorphous bodies, that is to say, their molecules have not taken a certain grouping together, as is the case in crystallized bodies. It is only exceptionally that the phenomenon of crystallization occurs in glazes and the presence of "wollastonite" (a silicate of soda and lime) or of "oligoclase" (a silicate of soda, alumina, and lime) can be detected. By increasing the proportion of the alkalies, or by introducing several bases into the glaze and by not giving this latter a definite atomic composition, regular grouping of the molecules is made more difficult and crystallization is prevented. This shows the important place of alkaline silicates, and the mistake into which those potters have fallen who have wished to give glazes a definite chemical formula.

If certain substances are introduced into glazes they do not combine, but remain suspended in it and thus render the mass opaque and are used to destroy transparency.

The oxides of tin, zinc and alumina and phosphate of lime are of this kind. If the temperature of the kiln is increased, these bodies tend to combine, at least partially, and to be dissolved in the amorphous mass.

Quartz acts differently; if some of it is added to a silicious glaze, i.e. one in which all the bases are saturated with silica, it dissolves in it without altering the transparency. But, under certain circumstances, it may separate afresh by crystallizing in the form of tridymite. This change in its constitution, which is characterized by the alteration of its density from 2·6 or 2·7 to 2·2 or 2·3, shows that it has not been simply dissolved, but that this has been accompanied by some action on the bases in spite of their state of saturation.

From the foregoing it may be concluded that glazes are amorphous substances, formed of alkaline silicates and borates, or earthy or metallic alkalies, which are found sometimes mixed, but their molecules are not in regular groupings. They are liable to dissolve certain substances, notably quartz, and to keep others suspended. In fact, their molecules tend under certain circumstances to group themselves together so as to form definite compounds which crystallize in the mass, making it opaque.

Chemical Composition.—Silica is the preponderating oxide in glazes; it may be found either combined with the bases or in solution, but it always has a density of 2·2 or 2·3. Its amount may vary from 25 to 75 per cent; the higher it is the higher the temperature required for fusing the glaze.

Boracic Acid plays the same part as silica, but the borates are much more fusible than the corresponding silicates. It makes the glaze harder and more brilliant, and acts upon the colour of certain metallic oxides, as may be seen in the chapter relating to Decoration. On account of high price, it is only used for certain fine glazes, its proportion scarcely ever exceeding 10 per cent.

Phosphoric Acid is less used. It is only found in glazes in the form of phosphate of lime, suspended in the mass.

Alkalies.—Soda and potash with silica and boracic acid form very fusible compounds, but as they are soluble in water they cannot be used alone, and other bases must be added to form insoluble combinations. They make the glazes more clear and transparent, and give special colours to metallic oxides. Their proportion may be as high as 25 per cent. Potash makes more fusible compounds than does soda.

Lime is often used to make double silicates and borates of alkalies and lime. It has, however, a tendency to cause the formation of crystals. With boracic acid it makes a fusible glass; but with silica at a high temperature it only forms a whitish mass, which is more or less translucent. Its proportion may be as high as 30 per cent.

The other alkaline earthy bases possess the same properties as lime with different degrees of fusibility. *Magnesia* is more refractory; *strontia* more fusible; and *baryta* more so than strontia; the equivalents of these bases vary in the same order as their fusibility, being as follows:—

Baryta	153
Strontia	103
Lime	56
Magnesia	40

Alumina is found in glazes principally in the form of silicate of alumina [clay]. In a small proportion, it forms with alkaline silicates glasses which are transparent, hard and very slightly inclined to crystallize. In larger proportions it remains in suspension, making the glazes partially opaque or translucent. It does not combine so well with alkaline borates or silicate of lead. In every case its introduction into a glaze has the effect of noticeably diminishing its fusibility.

Oxide of lead is much used to increase fusibility. It forms with silica and boracic acid, glasses which are insoluble in water and are attacked by acids, provided they contain at least one equivalent of boracic acid or silica to one equivalent of oxide of lead. It has a slight tendency to cause crystallization, and acts on the colouring of certain metallic oxides.

Oxide of bismuth acts in the same way as oxide of lead, making still more fusible compounds.

Oxide of tin does not form a transparent glaze but remains suspended in them making them opaque. This opacity diminishes with an increase in temperature. It is this property which causes it to be very often used in the manufacture of opaque glazes.

Oxide of antimony fulfils the same part as oxide of tin, though it is more fusible; although colourless in itself it can impart a yellow colour to glazes.

Oxide of zinc also remains in suspension in silicious glazes, but it dissolves in boracic acid. In spite of its whiteness it often modifies the colours of other metallic oxides. It is very slightly fusible.

The *colouring oxides* which are introduced into glazes to give them decorative properties will be studied in Chapter IX.

Action of the Glaze on the Body.—As glazes can dissolve quartz and keep other substances suspended in their mass, it is natural that under certain circumstances they should act as flux or solvent on the body at the moment of their fusion. But in order that this action may take place, it is necessary for the temperature of the fusion to be kept up for a sufficiently long time.

Under these conditions and when the glaze is sufficiently basic, especially if the proportion of the alkalies in it is raised, it can dissolve a certain proportion of free silica. It can also combine with the oxide of iron which certain bodies contain and by spreading into the mass may cause yellowish spots in them. When this action of the glaze on the body takes place, it causes a modification of the chemical composition of the glaze which thus becomes more silicious. The importance of this must not be exaggerated as it is by some potters, so as to assume the definite formula which they give to glazes corresponds with their true composition. On the other hand, it would be equally erroneous to neglect the use of formulæ when studying the agreement which ought to be found between the respective expansions of the body and the glaze. There is, or at least there ought always to be, between the body and glaze an intermediate zone in which they are mixed up, and which serves as a transition point.

Classification and Terminology.—Glazes differ from one another chiefly in their chemical composition, which affords the means of deciding their most important physical properties, e.g. hardness, transparency, solubility, etc. All classification ought to be based on the composition which, whilst taking no account of certain substances in very small proportions, makes a simple method for characterizing them by two, three or, very seldom, four principal bodies. Some potters have classified glazes according to the relative proportions of the acids and bases which they contain, into acid, neutral, or alkaline glazes. This distinction, which does not take into account the different properties of the two acids and of the various bases, rests only on theoretical grounds which are still in dispute, and it has not been generally accepted.

It is preferable in common practice to keep to the following terms which have been sanctioned by use:—

Under the name of *soft glazes* (Fr. *vernis*) are designated transparent glazes fusible at a low temperature, generally very plumbiferous and used to cover thinly certain earthenwares (faience).

Enamels[1] (Fr. *email*) are glazes which melt at a temperature higher than soft glazes and are generally applied more thickly. *Opaque enamels* which are stanniferous and usually plumbiferous are distinguished from *transparent glazes* which are plumbiferous or alkaline. Enamels are specially used in the manufacture of fine earthenware, and in the decoration of most pottery. In glass works all vitreous materials, transparent or opaque, coloured or colourless, which are used for covering over the "metal," are included under the term enamel. In pottery this general definition is applied to the word glaze, and the word enamel has assumed a narrower meaning.

Hard glazes (Fr. *couvertes*) are transparent, hard, applied to form a layer of medium thickness, melt at a high temperature, and nearly always contain alumina or an alkaline earthy base. They are used to cover vitreous pottery or certain kinds of faience made from fine body.

These terms, soft glaze, enamel and hard glaze, do not have a rigid significance and ought really to be considered as synonyms of the word glaze, and it is wise to accompany them with the name of the principal substances which enter into their composition—thus, a boracic alkaline glaze, an alkaline plumbiferous enamel, a calcareous hard glaze, etc.

Finally, in considering the glazes from the point of view of their action on the colouring oxides, they are divided into *plumbiferous*, *boracic* and *alkaline* glazes, according as one or the other of these substances is in a larger proportion and may influence the colouring.

(2) Raw Materials.

Silica and Silicates.—Silica is usually introduced into glazes in the form of quartzose sands, sifted and washed. It is essential to know the proportion of alkalies the sands contain, as a very small proportion may, on account of the large amount of silica in most glazes, exert a certain influence on them. Calcined or powdered quartz or flint may replace the sand (see Chapter III.).

Among the silicates, the *feldspars* are those most used in the manu-

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[1] [In English ceramics it is usual to confine the term "enamel" to opaque glazes, but continental potters do not recognize this limitation.—A. B. S.]

facture of glazes. These are silicates of alumina and alkalies, usually containing a small proportion of lime, oxide of iron and magnesia (p. 38). The purest sorts, particularly those free from oxide of iron, are the only ones to be used. Among the feldspathic rocks *pegmatite* from St.-Yrieix and *Cornish-Stone* from Cornwall are very much used. All these stones should be finely powdered before being mixed with the other ingredients of the glaze.

In some glazes, *kaolin earth* (*china clay*), *plastic clay*, *grog* or *calcined clay* are used. These materials, which have been already described, lessen the fusibility and usually impart an opacity or translucency to the glaze. *Glasses* such as are generally made in glass works, are sometimes used for common glazes. They are more easily worked than feldspars and introduce alkalies without the necessity of fritting. Their only defect is that their compositions vary, so that analysis is necessary to obtain exact mixtures. The following are the usual limits to the variations in their composition :—

	Window Glass.	White Bottle Glass.	Crystal Glass.
Silica	73 to 69	72 to 57	51 to 61
Alumina	·8 „ ·7	2 „ 5	0 „ 2
Lime	11 „ 13	8 „ 31	0 „ 4
Alkalies	12 „ 16	5 „ 17	6 „ 14
Oxide of Lead	—	—	28 „ 40

Boracic Acid and Borax.—Boracic acid is found in the form of crystals containing a large proportion of water—it corresponds to the formula B_2O_3, $3H_2O$. It easily melts in its water of crystallization; but it must be heated more strongly to make it anhydrous. It is sold either in the form of *refined boracic acid*, in fine white flakes containing 96 to 97 per cent of boracic acid, or under the name of *Tuscany boracic acid*, the crystals of which are larger, yellowish, and only contain from 85 to 90 per cent of the pure acid. The impurities in the latter consist of sulphate of ammonia, hydrated silica, organic matter and traces of lime. Boracic acid is often adulterated and should be tested by dissolving it in boiling water, filtering and weighing the residuum. Pure hydrated boracic acid contains 56 per cent of boracic acid and 44 per cent of water. Boracic acid is generally used in the form of white borax, hydrated borate of soda—represented by the formula Na_2O, $2B_2O_3$, $10H_2O$. When exposed to the air, the glassy crystals of borax become cloudy and whitened on account of the evaporation of a part of the water of crystallization. Heated slightly, this water completely evaporates and the borax forms a white powder; at a slightly higher temperature it melts and becomes a vitreous mass. It is found in the form of impure borate of soda and of lime in the north of Chili and is treated with carbonate of soda to remove the lime. From this, refined borax is obtained by several successive crystallizations. It is then almost pure and contains 37 to 38 per cent of boracic acid, 16 to 17 per cent of soda, the remainder being water.

Natural borax or *tincal* and *American borax* which sometimes contain a large proportion of impurities and the composition of which is variable, are also used but are unsatisfactory, unless purified.

It is wise to test borax, because it often contains foreign substances. This test is made by dissolving a definite weight of borax in water, colouring the solution with blue litmus, and pouring into it "normal" sulphuric acid, noting the number of cubic centimetres required to change the colour of the solution to a distinct red. By comparing this with the quantity required for an equal weight of pure borax, the relation of the two numbers of cubic centimetres thus obtained shows the proportion of pure borax in the sample tested.

Alkaline Salts.—*Carbonate of Soda* (Na_2O, CO_2) contains when calcined 58·5 per cent of soda and 41·5 per cent of carbonic acid. Commercial carbonate of soda is sufficiently pure. It must not be kept in damp places, because it is hygroscopic. It is also sold in the form of large crystals of the formula Na_2O, CO_2, $10H_2O$, containing 21·7 per cent of soda, 15·4 per cent of carbonic acid, and 62·9 per cent of water. This was at one time preferred to the former because of its purity, but this preference is now scarcely justified; any carbonate of soda made from ashes must be avoided as this is always very impure.

Carbonate of Potash (K_2O, CO_2) contains, when pure, 68 per cent of potash and 32 per cent of carbonic acid, but it is wise to test it. It is very hygroscopic and ought always to be dried before being weighed for use. That which is made from the ashes of vines is very impure. The quantity of soda or potash in the carbonates may be tested by following the method already described for borax. A certain weight of the salt is dissolved in water, the solution is coloured with litmus, and to it, drop by drop, "normal" sulphuric acid is added until the liquid becomes red in colour. If the "normal" acid contains for example 49 grammes of sulphuric acid per litre, and if *n* is the number of cubic centimetres added by means of a graduated burette, the proportion of carbonate of soda will be $\frac{n \times 53}{49}$, these two numbers representing the relation of the equivalents of carbonate of soda and sulphuric acid. For carbonate of potash the formula will be $\frac{n \times 69}{49}$. If the sample tested contains a mixture of carbonate of soda and potash, this method is no longer applicable.

Sodium Chloride or sea salt ($NaCl$) is sometimes used in glazes, but its most frequent use is for glazing stoneware by volatilization (salt-glazing).

Sulphate of Soda (Na_2O, SO_3, $10H_2O$) is not much used in pottery. It is necessary to calcine it before use because of its large proportion of water of crystallization.

Nitrate of Potash (K_2O, N_2O_5), saltpetre, nitre, was formerly the salt of potassium *par excellence*. Now it is only used to purify glazes which contain organic matter. It is sold commercially in the form of small crystals, generally fairly pure.

Alum (Al_2O_3, $3SO_3$; K_2O, SO_3, $24H_2O$) has sometimes been used to introduce potash and alumina into glazes. It is a double sulphate of alumina and potash, and is sold in the form of crystals containing a large proportion of water of crystallization, or as "burnt alum". It often contains oxide of iron, but may be purified by successive crystallizations. When pure it contains about 20 per cent of alumina and 18 per cent of potash.

Compound Alkaline Earths.—*Lime* is introduced into glazes in the form of the carbonate and the sulphate; caustic lime is seldom used as it is soluble in water.

Carbonate of lime (CaO, CO_2) decomposes slowly at a sufficiently high temperature, giving 56 per cent of lime (p. 39). White marble and Meudon or Spanish white are usually sufficiently pure and need not be tested.

Sulphate of Lime or *Gypsum* is sold in the form of crystals or of powder, as *plaster*. In the latter case it is somewhat impure and contains carbonate of lime, the presence of which is easily detected by the effervescence of carbonic acid gas on the addition of an acid. Crystallized gypsum is a hydrated sulphate of lime (CaO, SO_3, $2H_2O$), which contains, in a pure state, 31·86 per cent of lime and 46·51 per cent of sulphuric acid, which is only given off at a high temperature.

Magnesia may be added to glazes in the form of dolomite, a mixture of the carbonates of lime and magnesia, or of talc—hydrated silicate of magnesia—and magnesite.

Baryta is only used in the form of sulphate of baryta, or heavy spar (BaO, SO_3), containing in a pure state 65 per cent to 66 per cent of baryta; it is a mineral somewhat scattered in nature. The native carbonate (witherite) is also used, but the artificially precipitated carbonate is superior.

Strontia is seldom employed.

Oxides and Salts of Lead are used, in the form of litharge, red lead, white lead and galena.

Litharge or *massicot* (PbO) or lead monoxide, is sold in the form of brilliant lamellar crystals, or of reddish-yellow powder. It is obtained by heating metallic lead in air. Of English, French and German litharge, the first is the best as it contains only traces of iron and copper, and the last is the most impure; [it should be tested no matter from what source it is obtained]. If treated with acetic acid it ought not to produce any effervescence as that indicates the presence of the carbonates of lead, baryta, or lime. Litharge ought to dissolve entirely in dilute nitric acid. If there is any residue it is usually antimonic acid, sulphate of baryta, or even ochres, sand or powdered terra-cotta.

Red Lead (Pb^3O^4 or $2PbO$, PbO^2) is a plumbate of lead monoxide, obtained by heating massicot to about 300° C. It is found in the form of a beautiful red powder, which darkens in the light. Heated to a red heat it is changed to lead monoxide with the liberation of oxygen: 100 parts by weight of pure red lead giving 97·37 parts of the monoxide. Red lead always contains a noticeable proportion of massicot, even if it is heated several times. Thus, red lead fired once contains 50 per cent of it, and that called "eight fires," which has been heated eight times, still contains 25 per cent.

To test red lead it is heated with dilute nitric acid, which ought not to produce any effervescence nor to leave any residue.

White Lead (PbO, CO^2) is a carbonate of lead, which is also found in a basic form, $2(PbO,CO^2), PbO, H^2O$; it should be dried before mixing with other glaze materials. It decomposes on heating, carbonic acid being given off and lead monoxide remains.

Pure anhydrous carbonate yields 83·52 per cent of the monoxide. White lead is frequently adulterated by the addition of sulphate of lead, sulphate of baryta, plaster and chalk.

Lead Ore or galena (PbS) is a grey mineral with a metallic lustre, in the form of granulated layers. Chemically, it is a sulphide of lead, containing, when pure, 13·39 per cent of sulphur and 86·61 per cent of lead. The ores of galena are somewhat diffused in nature, but they are seldom pure, and almost always mixed with gangue (veinstone). Their variable composition, as well as the inconvenience which may result from the liberation of sulphurous flames in the kiln, cause them to be used only for common ware.

Oxide of Tin and Tin Ash.—The oxide of tin used in pottery is the dioxide (SnO_2), or stannic acid, which is sold in the form of a white powder and often in a hydrated form (SnO_2, H_2O). It decomposes at a red heat, giving a slightly yellowish powder of anhydrous oxide of tin.

It may be prepared by adding nitric acid to the metal tin; the white powder thus obtained is washed and ground in water; but it is better to buy it. In trade a distinction is made between oxide of tin manufactured in acid, as described, and that obtained by the oxidation in the air with the action of the heat on the metallic tin.

Oxide of Tin is also used in the form of *tin ash*. This is a stannate of lead into which tin enters from 15 to 50 per cent, and lead from 85 to 50 per cent. It is usually manufactured in the pottery, the two metals being mixed together in the proper proportions, and submitted in an open vessel to the action of the flames of a furnace. The metals melt and are covered over by a layer of yellowish-white powder which is the tin ash; the metallic mass is stirred continuously, and the powder removed from time to time with an iron scraper. For small quantities it is sufficient to put the metals into wide, open, fireclay crucibles, but for larger outputs a reverberatory furnace or frit kiln should be used. The tin-ash powder is afterwards washed to separate any metallic particles that may be left unattacked, dried and ground.

Various Materials: *Fluorspar*, or *fluorite* ($CaFl_2$), which is a fluoride of calcium, and *cryolite* ($3NaFl, AlFl_3$), or double fluoride of soda and alumina, are also used as fluxes. These bodies decompose at a red heat; the bases—lime, soda, and alumina—which form them, mix with the other elements of the glaze, while the fluorine combines with the silica to form a fluoride of silicon, which volatilizes if the temperature is sufficiently high. If such is not the case, or if the glaze is not sufficiently silicious, the fluoride remains separate and may form saline deposits, which spoil the surface of the glaze. Fluorspar is very little used in pottery. Cryolite, more widely used, is found in Greenland in the form of crystals of a pearly-white, sometimes slightly tinted yellow by oxide of iron. It contains 54·16 per cent of fluorine, 32·73 per cent of sodium and 13·06 per cent of aluminium, giving, after being oxidized, for every 100 parts of raw material, 40·73 per cent of soda and 25·06 per cent of aluminium.

Oxide of Zinc (ZnO) may be used to make silicious glazes opaque; it is about the same fusibility as magnesia and is prepared by oxidizing metallic zinc. It is sold in the form of a white powder, which is made yellow by calcining, but regains its previous colour on cooling. The best quality is usually sufficiently pure.

(3) Manufacture and Application.

The Preparation of the Raw Materials and Mixing is done in its most complex form by the following operations. (1) Preparation of the raw materials. (2) Mixing. (3) Fritting or vitrification. (4) Mixing and grinding in water. The raw materials ought to be in the form of very fine powders, as pure as possible, and of a composition that does not change in the air, thus allowing of an exact mixture.

Grinding is done by the different methods shown (Chapter IV.) when speaking of the preparation of the body, but it is very important to avoid mixing particles of iron or of oxide of iron with glazes, and it is, consequently, wise only to use pulverizing machines, the metallic parts of which do not come in contact with the material to be ground. Vertical or horizontal grindstones, mills with blocks, and ball crushers cased in stoneware, or porcelain, and with balls of the same material or of flint are all suitable. Grinding is done either dry or in water, and is followed out to a greater or less degree of fineness, according as to whether it has to be followed by a second grinding with water or not. The harder materiasl, as quartz, flint, feldspar, cryolite, must be ground with water in order to get them sufficiently fine. Dry grinding must be carried on with many precautions, so as to avoid the production of dust, which is very injurious to the health of the workman. Tight covers round the apparatus and systems of ventilation are indispensable, and are not sufficiently replaced by wearing masks. In order to avoid these inconveniences, potters often prefer to buy the raw materials in the form of fine powders. The methods of *purifying* the raw materials have been described for each of them. Mixing may be done by weight, or by volume in pots having the capacity of a certain weight. It is necessary to proceed more exactly than for bodies, and care must be taken to reckon the water and volatile substances—carbonic acid, sulphur, sulphuric acid—which the raw materials may contain, and especially the variable amount of moisture and of water of crystallization which may be present. The materials ought to be dried and kept in closed places, sheltered from damp, before use.

Fritting and Vitrification.—When the materials have to be ground in water, as is most usual, those which are liable to dissolve in the water must first be made insoluble. The chief of these are the alkaline salts, boracic acid and borax. To do this, they are fritted with silica, lime, oxide of lead, etc., according to the composition of the glaze. In making this mixture an attempt should be made to obtain products as fusible as possible, so as to economize the expenses of fritting. At the same time it is wise to avoid having materials of very different densities, which after having been mixed with water, would be deposited unequally and would destroy the homogeneity of the glaze. This applies especially to materials containing lead or baryta, which are much more dense than the others. This defect can be remedied by combining them with other lighter substances—silica, lime, etc.

When a material is to be introduced into the composition of a glaze in a very small proportion, making it very difficult to mix uniformly with the others, it should be added to the frit.

Fritting consists in uniting the materials under the influence of heat, by melting them so as to form a glass. For small quantities this is done in fireclay crucibles heated in special furnaces. When a sufficient heat has been attained, their contents are poured into water to shatter the vitreous mass, and to make it more easy to grind; the crucible is then refilled. Such crucibles should not contain more than 22 lb. of materials if they are to be easily handled. They only bear a small number of heatings, and the furnace should be arranged so as to enable any glaze which may run out, in the event of their breaking, to be gathered up.

In certain cases larger crucibles are used, from which the molten mass is taken by means of iron ladles or rods, or the crucibles can be pierced at the bottom with a hole through which the molten mass runs, and is caught in a vessel of water.

For very large quantities, reverberatory furnaces are used (Fig. 119). The materials to be vitrified are brought through an upper opening into the hearth, which is an horizontal piece raised from the floor. As fast as they melt they run on to an inclined plane to collect at the lower part of the hearth, from which they can be run off by a lateral opening, which, while working, is closed by a plug of fireclay, carefully sealed. A metal or earthenware spout leads the glass into a pot full of water in which it is collected. The working of the furnace is thus continuous, the materials being let in and off at intervals, without stopping the working. The heat is supplied by a fire at one end, while a chimney at the other creates a draught that can be regulated. The furnace should be at the desired temperature before introducing the mixture, and the latter should be frequently stirred with a wooden pole to make it homogeneous before it is run off. Sometimes the mixture is thrown in and levelled through a lateral working door, being afterwards taken out by the same opening when fritted.

In some potteries the fritting is carried out in saggers placed in the kilns for burning the ware, the pieces of vitreous glaze being taken out while emptying the oven. To prevent it sticking to the bottom of the saggers it is necessary to cover the latter with flint, which adheres strongly, so that this method must be regarded simply as a makeshift and not as a regular method of manufacturing frits. In order to carry out the fritting effectively it is essential for the raw materials to be well mixed, but it is not necessary to powder them very finely. The alkaline salts, boracic acid and borax, may be in rather large pieces, and silica and felspar may be in the form of coarse powder.

The heating in all cases ought to be even, and it is especially essential in lead glazes that the atmosphere of the furnace be never reducing or smoky or the oxide of lead will be reduced to metallic lead. [The heating should be continued until the mass is as clear as possible, but must not be unduly prolonged or loss of alkali will result.—A. B. S.] The crucibles and the hearth of the furnace should be made of aluminous fireclay and should not contain obvious grains of free silica, which might be attacked and dissolved by the glaze.

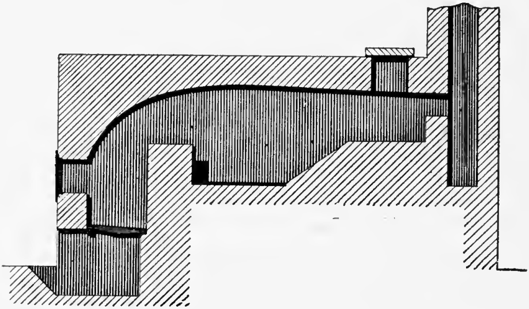

Fig. 119.—Frit-kiln.

Mixing and Grinding with Water.—Certain glazes may be mixed when dry, using substances which are first finely powdered, but this is unusual, and it is preferable to mix the materials composing the glaze at the same time as the last grinding in water, as this makes the mixture very homogeneous. Blunging ought only to be used when the glaze is bought ready prepared.

The grinding of glazes in water is usually done between horizontal grindstones, the lower one being fixed, and the upper having a rotary motion. The latter generally has two holes, through which the glaze enters between the stones. A cock, placed on the lower surface of the grindstone, allows the ground glaze to run out. According to the importance of the ware, the mill may be driven by hand or by steam power (Figs. 120 and 121). The diameter of the vat varies from 14 inches to 16 inches for the hand machine, and from 28 inches to 40 inches for those driven by steam power. Block mills (Fig. 36) may be used, but ball grinders (p. 123) or Alsing cylinders are now preferred.

Those used for grinding glazes can work charges of 20 to 300 pounds for an expenditure of one-eighth to two horse-power (Fig. 122). The smaller models may be worked by power or by hand. The interior lining of the cylinder is of porcelain or stoneware, and the balls are usually flint pebbles. When the grinding is completed, the solid cover is replaced by a grating, which allows the glaze to run out but retains the pebbles.

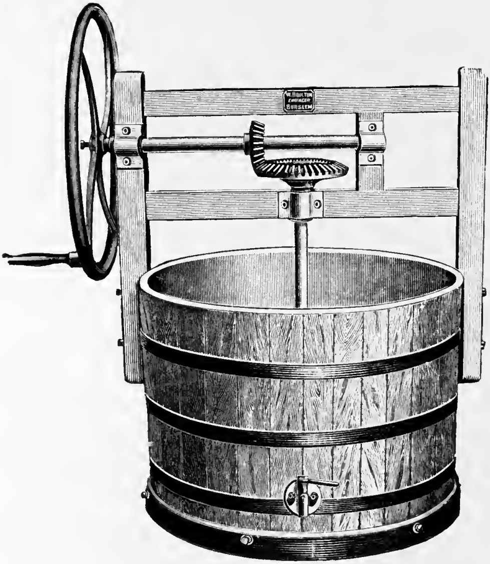

Fig. 120.—Glaze-grinding tub.

If clay enters into the composition of the glazes, it ought to be added to the ground mixture in the form of a liquid or paste towards the end of the operation, because it would hinder the powdering of the harder materials.

The glazes ground thus are generally sifted to keep out the coarser grains or lumps. When the sieves are fine the glaze must be very liquid to pass through them, and it is best to let it settle in basins for it to become of a suitable consistency.

The liquid glaze should always be freed from particles of iron by being treated in a vat (Fig. 123) containing electric magnets, some fixed, others movable, which act as agitators. The purified glaze is emptied through a cock, while the magnets, which can easily be taken out, are from time to time removed, cleaned, and then replaced.

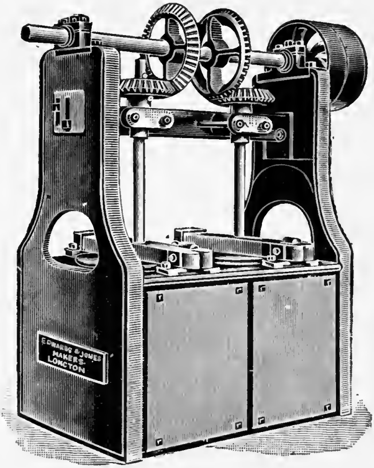

Fig. 121.—Glaze-grinding machine.

The Application of Glazes may be carried out on dry ware or on biscuit. In the first case, the ware must be dry and sufficiently resisting not to be spoilt either by the actual application, or by the dampness of the glaze. In the second case, the articles to be glazed may have undergone a definite burning at a high temperature, or they may have been warmed to make the application easier. Whatever the method employed, it is essential that the body should be sufficiently porous and absorbent for it to absorb the glaze and make it adhere.

Six methods of applying glazes are used: dipping or immersing, pouring, sifting or sprinkling, spraying, dusting, and volatilization.

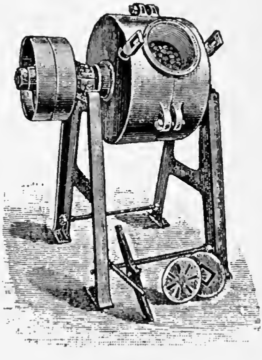

Fig. 122.—Glaze-grinding machine.

In applying by *dipping* or *immersion* the articles are dipped in a basin containing the liquid glaze; the article, in consequence of its porosity, absorbs a certain quantity of water and there is deposited on its surface a layer of glaze. For success it is necessary that there be

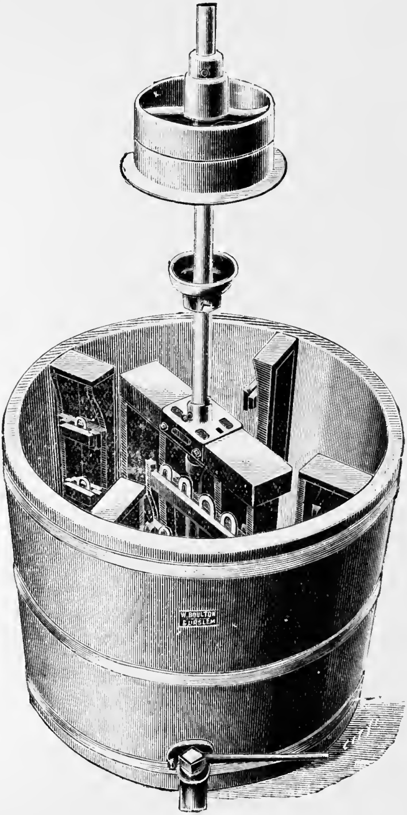

Fig. 123.—Electrical glaze purifier.

a resistant body, sufficiently empty of water, and a glaze which has a consistency corresponding to the absorption of the body and to the thickness of the layer of glaze desired. The suitable consistency, which generally is about that of cream, can only be ascertained by trial. Care must be taken that, when the glaze has dried on the article, it is not to be powdery and liable to drop off at the least touch. Glazes containing slightly plastic materials, as clay, lime, white lead, etc., have not this fault if they have not been first fritted. For this reason the fritting ought never to be carried out with the entire components of the glaze, and it is best to keep the more plastic materials to add to the others when they are being ground in water.

Glazes which are not sufficiently pliant, settle unequally and too rapidly; they may then be mixed with vinegar, milk, starch, and gums, but these additions often cause other troubles, and it is better to try to find a glaze composition which does not have this fault.

Before dipping articles, any dust on them must first be carefully removed, they are then held by the fingers by the parts that do not need to be covered with glaze. If there are no such parts, it is better to take them up with pincers having pointed claws, so as only to leave small places on which the glaze is defective. These places can be touched afterwards with a brush filled with glaze.

For pieces that need care, retouching is inevitable. The parts on which there is too much glaze (as drops or streaks) are equalized either with the finger or a scraper; some glaze is added to the edges (which generally get too ittle) with a brush; some parts, as the feet, plinths, etc., on which the piece ought to stand, are cleaned.

In *pouring*, the glaze is poured over the article which is given a suitable motion to spread the glaze uniformly. The unused glaze falls into a receptacle over which the article is held. This method is employed when the glaze is to be put only on the inside or outside of a vessel. It is also used for those bodies which are not very porous and which, by dipping, would not retain a sufficiently thick layer. In this case the glaze ought to be made thicker, and, if necessary, its viscidity should be increased with milk, starch, or gums; these materials afterwards disappear (in burning). Any retouching is done in the same way as in the preceding case.

Sprinkling, which is scarcely ever used now, consists in sprinkling the objects with liquid glaze. It is done with brushes that have short, hard hairs, which are dipped in the glaze, shaken to get rid of the surplus liquid, and afterwards the ware is sprinkled from them. This method was employed for bodies which, whilst unbaked, were friable or covered with reliefs, which could not, without being spoilt, have been dipped or poured.

At the present time for this kind of work, *spraying or diffusion* with a small apparatus known as a sprayer (E in Fig. 124) is preferred.

This consists of two tubes at right angles, one of which is in contact with a reservoir of glaze, and the other with some kind of air blast. The openings of the two pipes are arranged in such a manner that the current of air from one makes a draught and draws up the liquid in the other. For small objects, the blast may consist simply of an indiarubber ball; for very large surfaces, an air pump that can give a pressure of about 8 inches of mercury must be used (Fig. 125).

The sprayer is placed 12 inches to 18 inches from the object, according to its size and the force of the jet. The sprayer or the object is moved, or both simultaneously, so as to spread the glaze uniformly over all the surface. The whole thickness of the layer should not be put on at one time, but in two or more operations, allowing each layer to dry before putting on another. This prevents trickling and gives a more even thickness.

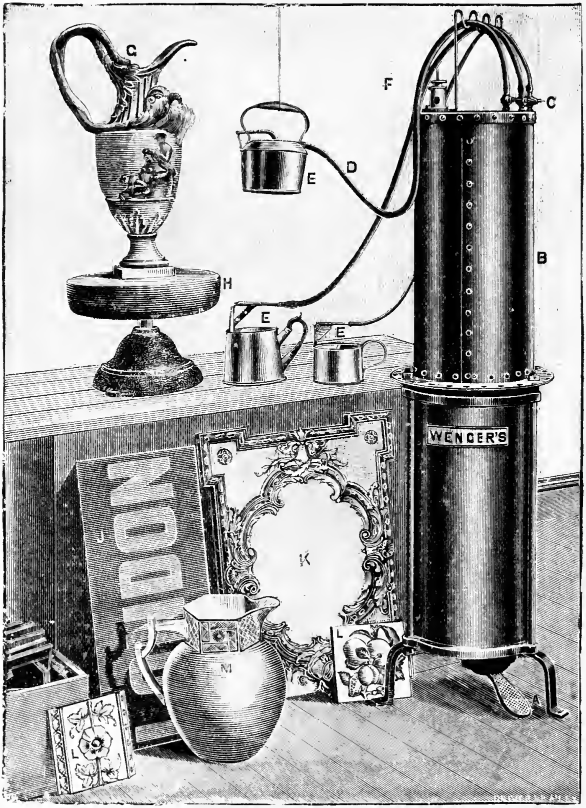

Fig. 124.—Glaze-spraying.

In all the foregoing methods the glaze is used as a liquid paste or slip; for the application by *dusting*, on the contrary, it is a dry powder. The articles ought to be of unbaked body that is still damp, so as to retain the glaze which is applied to them by means of a sieve. This method, which is now scarcely used except for coarse ware with a plumbiferous glaze, is very dangerous to the health of the workman because of the dust it makes.

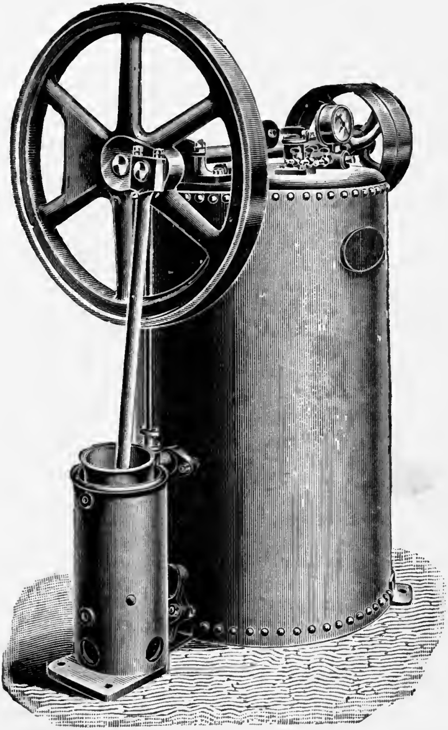

Fig. 125.—Air-pump for use in spraying.

Volatilization consists in volatilizing the glaze by heat inside the kilns used for burning the paste and thus insuring its deposit on the surface of the ware, where it vitrifies by combining with the silica of the paste. This method is only used in the manufacture of stone ware (see salt glazing).

CHAPTER VIII.

FIRING.

(1) PROPERTIES OF BODIES AND GLAZES DURING FIRING.

THE firing is the last, the most important, and the most difficult operation in the manufacture of pottery. Its object is to make the body permanent, to give it resistance or impermeability and to vitrify the glazes, by giving them the physical properties of glass.

The temperature to which the body must be raised to make it unchangeable, depends on its chemical composition and on the fluxes it contains. It varies from 700° to 1500° C. The temperature for vitrifying the glazes is still more variable and ranges between 500° and 1400° C. Naturally it must be below, or at the most equal to, that needed for the firing of the body. When it is equal, the firing of both glaze and body may comprise a single operation; when it is lower, the body must first be biscuited, then, by a second firing at a lower temperature, the glaze must be vitrified.

On principle, a single firing ought to be chosen, not only because of the economy, but also because the firing at the same temperature of both body and glaze makes their union more complete, giving to the ware certain special qualities of resistance. But it is necessary to resort to a double firing if it is intended to apply certain fusible glazes on a hard body which can only be obtained at a higher temperature. [There are commercial reasons why it is often better to fire twice even when the finishing temperature of the glaze and body are identical. One of the chief of these is the greater commercial value of defective burned but unglazed articles than of those defective ones which have been glazed and fired at once. There is also less damage to articles during glazing if these have been fired.—A. B. S.]

The porcelains are manufactured by a single burning, but the body is nearly always heated first at a low temperature so as to facilitate the application of the glaze.

Fired ware can still be submitted to one or more other firings afterwards, each at decreasing temperatures, so as to make the decorations or colours of greater and greater fusibility adhere to them.

The study of firing may be subdivided into three parts: (1) the modifications made in firing, in the properties of the bodies and glazes; (2) the kilns; and (3) the methods of working them.

Modifications in the Constitution of Bodies.—Bodies which are dried and ready to be fired still contain some hygroscopic water, which is evaporated in the first stage of the firing, called, rather unsuitably, "smoking" or "stoving". This water disappears at a temperature slightly above 100° C., at the same time as the organic matters are deprived of their volatile elements, and as the hydrated silica, or iron oxide, as well as certain hydrosilicates of alumina, such as allophane and collyrite, are decomposed.

If the temperature continues to rise it does not produce any further changes till nearly 400° C., when pure clay begins, in its turn, to decompose, at the same time as halloysite, lenzinite, cymolite, talc, bauxite [?], magnesite, etc., etc. This decomposition may proceed slowly up to 600° C. At that temperature the carbon from the organic matters is burnt by the oxidizing air of the kilns.

Then at about 700° C. the bodies form an anhydrous mixture of free silica, crystalline silica, alumina, the oxides of iron, alkalies, carbonates of lime or magnesia, and several silicates, including feldspar, and analogous stones, and "grog". The other mineral substances which the bodies may still contain are only found very rarely, or in proportions too insignificant to exert any influence on the firing. Up to that temperature all the bodies act in the same way, their constituents remaining mixed without any fresh chemical affinity for one another.

Above 700° C. the alkalies, then the oxide of iron (if in sufficient proportions and in the presence of alumina), begin to unite with the free silica to form various silicates. Any single one of these bases could not at this temperature combine with the silica; they can only act when mixed. Hence in the bodies which only contain a small amount of fluxes the silicates do not begin to form until a higher temperature is reached.

The heat continuing to rise, the carbonates begin to decompose, carbonic acid is given off, and the bases set at liberty, joining the alumina and other fluxes, unite with the free silica, forming new silicates, which are more complex, so that at a temperature of about 900° C. the different bodies show considerable variations in their constitution; it then becomes necessary to divide them into four subdivisions:—

(1) *Bodies containing a large proportion of fluxes and not much crystallized silica, or in which the latter is only found in the form of an impalpable powder.*—In these bodies nearly all the bases are combined with silica. There remains, however, a certain quantity of carbonates that are not decomposed. The crystallized silica has been attacked in its turn and disappears in the midst of the silicates. The bases, and chiefly the alumina, being entirely combined, the baking may be considered finished near 900° C. If the raising of the temperature still continues, the mass softens, rapidly gets out of shape, and melts into a dark-coloured, blackish-brown or green slag, in which may often be noticed some bubbles, which are formed by the carbonic acid arising from the decomposition of the carbonates.

(2) *Bodies containing a large amount of fluxes and having an important amount of crystalline silica in the shape of grains of a fairly*

large size.—In these bodies nearly all the bases are equally united with the free silica, but the crystalline silica has remained intact, and forms in the middle of the mass of silicates a sort of rigid skeleton. The burning of these bodies is also finished or nearly so at 900° C. If the temperature rises, the silicates begin to soften and to vitrify, but the mass keeps its shape, thanks to the unchangeableness of the crystalline silica. It is only at a temperature of 1100° to 1200°, sometimes even higher, according to the proportion of the fluxes, that the crystalline silica is attacked in its turn and the mass becomes misshapen and melts to a slag.

(3) *Bodies containing a small amount of fluxes, the quantity of crystalline silica being slight or in an imperceptible form.*—In these bodies the formation of silicates has scarcely begun at 900° C., the temperature must be raised to nearly 1200° before the alumina, added to the small amount of the flux, will combine with the silica. This combination is made the more easily as the proportion of silica is higher, without, however, passing certain limits. The mass vitrifies at various temperatures, according to the proportion of the fluxes.

(4) *Bodies containing little flux, but a large proportion of crystalline silica in coarse grains.* As in the preceding body, the combination of the silica and alumina only takes place at about 1200° C. But at higher temperatures the mass vitrifies without softening owing to its silicious skeleton. When there is only 1 or 2 per cent of fluxes, the body is only melted at the highest temperature that can be produced in the industry.

It is well understood that these four classes of body are not clearly marked out, and that wares are met with that have all the intermediate characteristics, but in a general way, it may be considered that the *firing, properly so called*, of a pottery product is finished when all the bases, and especially the alumina, are turned into silicates. If the temperature is raised above this point in firing, either the body softens again, becoming misshapen and ends by melting in the form of slag, or else it vitrifies without going out of shape, then melts just the same. In this latter case the *vitrification* of the body which until then was porous, has the effect of making it impermeable.

The Part Played by the Different Materials Constituting Bodies, with Regard to their Fusibility.—*Alūmina.*—This base ought to be considered as the refractory element *par excellence* of all the pottery products. [Cobb has found it is a flux in some glazes.]

Fluxes.—Included under this head are potash, soda, ferrous oxide, lime, magnesia and lead oxide. Each of these fluxes taken alone only combines with silica at a high temperature. But a mixture of equal parts of potash and soda is more fusible than potash or soda alone; a mixture of potash, soda, and oxide of iron is more fusible than the alkalies alone, etc. The cause of this singular action is still unknown.

The relative fusibility of the five fluxes, according to Richter, is proportional to their chemical equivalents, that is to say, that forty-seven parts by weight of potash act as thirty-six of oxide of iron, thirty-one of soda, twenty-eight of lime, and twenty of magnesia. This principle, which seems correct at high temperatures, is not so exact at low ones nor for a high proportion of fluxes, because the temperature at which these different bases begin to act on the silica is not the same. It is the alkalies which combine first; then comes the oxide of iron. The order of the other fluxes is not yet fully determined. Ferric oxide is not a flux; it acts as a refractory material, although in a less degree than alumina unless (as often happens) it is reduced.

Silica plays a complex part because, according to circumstances, it increases or diminishes the fusibility. Pure silica is very refractory, consequently when some silica remains uncombined in a body, it reduces the fusibility. But silicates are formed which fuse more easily than the basic silicates. From these observations it is possible to decide the parts played by the silica. At a relatively low temperature, below 1000° or 1100°, it is only the free[1] silica, or the crystalline silica in an imperceptible powder, which is susceptible of being united with the bases and of helping the fusibility. At a higher temperature the crystalline silica is itself set free[1] and helps to increase the fusibility so that the alumina remains the only refractory material. If, however, the proportion of the silica becomes large enough, it can not only neutralize the affinity of the bases, but a certain quantity of it may remain uncombined. From this moment the excess of silica again plays a refractory part, as opposed to the silicates with which it is mixed.

These statements about silica and alumina, from the point of view of fusibility, are more clearly shown when the mixtures of the two substances are carried to very high temperatures without the intervention of the fluxes. As long as the proportion of alumina is higher than that contained in pure clay, the mixture is infusible; then the fusibility increases at the same time as the proportion of silica, until the composition corresponds to $Al_2O_316SiO_2$. After that, the mixture again becomes more and more refractory.

Grog, having the same composition as the body (p. 36), acts as a refractory element, at temperatures below that required for vitrification, but from the moment it softens (at the same time as the body) it no longer exercises any influence on the fusibility.

Modifications in Volume and Density.—The evaporation of the moisture causes a diminution in the density of the body because the shrinkage, if there is any, through that means is very slight, and is not made up by the increase of empty spaces. The giving off of the water of combination acts in the same manner, and up to about 600° to 700° C. the volume of the body slightly decreases while the density becomes continually less. But from the moment when the silicates begin to be formed, the body contracts, and has a tendency to fill up the empty spaces made by the evaporation of the water and by the contraction of the organic materials. This action proceeds regularly

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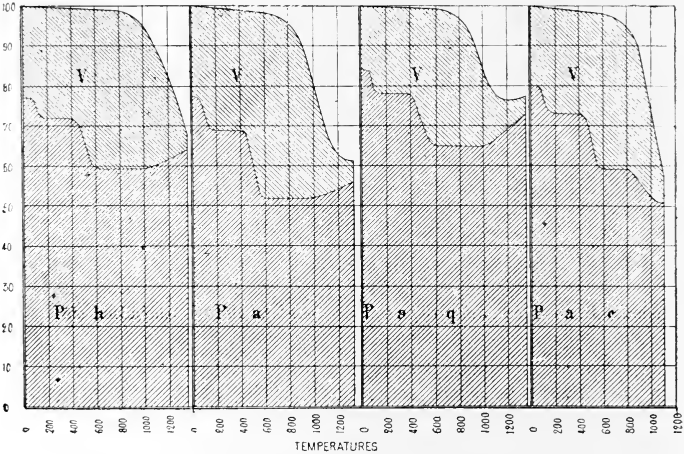
[[1] By "free" silica, Bourry apparently means amorphous or colloidal silica, which is more readily attacked by bases than is the crystalline variety.—A. B. S.]

to the moment when, vitrification beginning, the spaces have a tendency to disappear; the body becomes impermeable, and the apparent density attains its greatest point. The shrinkage is at first constant, rather low, nearly proportional to the temperature, until the latter corresponds to the finish of the firing of the body. After that, the shrinkage increases fairly quickly, this increase becoming more rapid as the temperature of vitrification is approached. Some bodies, however, show remarkable variations in firing. These variations are due to the variable proportion of water (both hygroscopic and of combination), to the shrinkage of kaolin earths and of the clays not taking place at the same temperature, and, finally, to considerable variations in the volume, caused by a high percentage of quartz or carbonates.



V = Spaces. P k = Kaolin paste. P a = Plastic paste. P a q = Silicious paste. P a c = Calcareous paste.

Fig. 126.—Variations in volume on heating.

These changes have been graphically represented (Fig. 126), the variations in the total volume and those in the empty spaces for four sorts of body which are looked upon as types being shown. But these sketches must only be regarded as examples, without attributing to them an exactitude which, in the actual state of our knowledge, it is impossible to give them.

The first type is that of the *kaolin earth* bodies (china clays). The total volume of the dry body, say equal to 100, diminishes very slowly and very slightly until about 800° C. After that time the shrinkage increases more and more quickly to about 1350° to 1375°, the temperature for burning hard porcelain. The volume of empty spaces contained in the dry body at first increases quickly between 50°

to 130° C. on account of the evaporation of the hygroscopic water, then remains nearly constant, and again between 400° and 600° C. increases rapidly on account of the decomposition of the hydrosilicate of alumina (clay). The volume of empty spaces between 600° and 800° diminishes, at first because of the shrinkage, and afterwards because the body, above about 1000°, decreases in absolute density. This diminution is due to the formation of silicates, which are the least dense when they have been produced at the highest temperature. The simultaneous reduction of the volume and the density of the body then occurs. The drawing shows that the explanation is the reduction of empty spaces which hides the expansion of the body of which the weight remains constant, while its density diminishes.

All the natural silicates—feldspars, granites, porphyry, etc.—equally undergo a reduction of density when they are heated to a temperature near that of their fusing point. Thus, for the kaolin body, the absolute density (measured in the powdered body) is at first about 2·4 and increases in consequence of the giving off of water to nearly 2·7, then it diminishes again, falling to about 2·5. The apparent density (the weight of unit of volume) starts at 1·6 to 1·7, then it diminishes, at first regularly, until the moment of the evaporation of the water, but increases rapidly afterwards, according as the empty spaces disappear. It never becomes equal to the absolute density, because even in those bodies which are completely vitrified there always remains a certain proportion of empty spaces.

Plastic bodies of nearly pure clay differ from the above in the larger proportion of water (*a*) because the shrinkage is nearly complete about 1200° C. and (*b*) because, after that, the volume only diminishes very slowly. This last difference, unexplained up to the present, is very characteristic, and thus (*c*) distinguishes the plastic clays from the kaolin earths (china clay).

When the bodies contain a noticeable proportion of quartz, the expansion which the latter undergoes in passing from the density 2·7 to the density 2·2 (to which attention has already been drawn) is added to that of the clay, and it may be that the reduction of the empty spaces are no longer sufficient to hide it. This is the case which is represented in the third type (clayey bodies containing quartz) in which the volume of the body having diminished at about 1200° C. as in the preceding case, afterwards increases. The fact can easily be noticed in practice in fire-bricks rich in silica.

When bodies have a sufficiently high proportion of carbonates the elimination of carbonic acid above 800° makes a third increase in empty spaces which is represented in the fourth type (calcareous clays). As these bodies are usually fusible, the shrinkage continues up to the fusing point, this sometimes taking place before the evolution of the carbonic acid is complete.

Thus for each composition of the body there correspond, during baking, different changes in the volume and density, the importance and nature of which may be imagined from the four preceding examples, even though the sketches only represent in an approximate manner phenomena which have up to now been too little studied.

Modifications in Colour.—Among the different substances which enter into the normal composition of bodies for pottery, only the compounds of iron and organic materials have colouring power. It is unusual for the oxides of manganese, titanium and vanadium, which are also coloured, to be found in noticeable quantities. This does not apply to bodies in which a colouring metallic oxide is voluntarily introduced for the purpose of decoration.

Under the influence of the burning, the organic materials disappear, while the body becomes grey in colour when it contains oxide of manganese, and a deep greyish-blue when there is a large amount of titanic acid. Vanadic acid produces a yellow or green efflorescence. The iron is nearly always the only colouring element in the body, and the different oxides give shades varying from greenish-blue to black, from yellow to orange or red, from yellowish-brown to green. The study of the conditions under which these different combinations can be produced is one of the most complex problems in pottery.

Whatever may be the form in which iron is found in plastic bodies, it is changed into red iron oxide when it is heated in an oxidizing atmosphere. If the body only contains a small proportion of lime or magnesia the colour varies from light yellow to yellow, then to orange and finally to red, according to the proportion of iron oxide it contains. Five per cent of iron oxide is sufficient to give a clear tint of red, which reaches the maximum of intensity at the proportion of 8 or 9 per cent, the colouring not being changed by higher amounts.[1]

As the temperature of the firing is raised, the shade deepens and tends to pass into brown, owing to the formation of a double silicate, which has the colour mentioned. When the body contains lime or magnesia, as long as the temperature of the kiln remains below 700° or 800°, the colour due to the iron oxide remains the same as the preceding, but if it passes this temperature, a multiple silicate is formed which is yellowish when the proportion of lime or magnesia is double that of the iron oxide. In other words, these two bases neutralize the colouring of a proportion of iron oxide equal to half their weight. Thus, a body containing 10 per cent of lime or magnesia and 7 per cent of iron has about the same colour as a body that is made of alkaline earthy bases, and which contains only 2 per cent of iron oxide. If the temperature continues to rise, the silicates of lime and iron take a greenish-yellow tint, which becomes quite green at the moment of fusing, as may be noticed in some bottle glass and in Portland cement clinker. When the kiln gases contain sulphurous fumes, these combine, in the form of sulphuric acid, with the lime in the body to form, mostly on the surface, calcium sulphate; the lime thus combined can no longer enter into the formation of the multiple silicates and loses its property of discolouring the iron oxide. As this

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[[1] It has, however, been repeatedly found that the colour does not bear any definite relation to the proportion of iron present.—A. B. S.]

action is only produced on the surfaces which are exposed to the gases of the fire, it follows that they sometimes have a red colour, while the inside parts, which are more protected, keep the yellow or greenish-yellow tinge of the silicates of lime and iron.

Such are the variations of colour produced by oxide of iron when the firing is done in an oxidizing atmosphere. If, on the contrary, this atmosphere is reducing, i.e. if it no longer contains any oxygen, but rather an excess of hydrogen and of carbonic oxide, the iron peroxide is changed into monoxide and gives rise to new colours.

If in small proportion, the compounds of ferrous oxide have a light bluish tinge, such as one may see in most porcelains. If the proportion increases, the colour deepens rapidly and passes into black with blue metallic reflections. The presence of a certain proportion of lime or magnesia does not alter these colours nor have sulphurous fumes any action in a reducing atmosphere, because they remain in the form of sulphurous acid.

The atmosphere in a kiln may often be *alternately oxidizing and reducing*, especially at high temperatures; the degree of oxidation of compounds of iron may then be modified several times during the process of firing, but the final colour is that which corresponds to the composition of the atmosphere at the time of cooling. If this, as nearly always is the case, is oxidizing, the repeated changes in the kiln atmosphere have the effect of diminishing the intensity of the colour.

The oxidation or reduction of the iron oxides can only be produced in a porous paste, which allows the gases of combustion to penetrate into it. If the burning is carried to a temperature high enough to cause vitrification, or if the paste is covered with a glaze, it will keep definitely the colour corresponding to the composition of the atmosphere at the time of its vitrification or of the fusion of the glaze. This is of enormous importance in the manufacture of porcelain and stoneware, because it allows the burner to give the paste the bluish colour of the ferrous silicate, by the reducing tendency during the principal firing, while afterwards having a decidedly oxidizing atmosphere during the cooling.

For thick or close bodies, the changes in the composition of the atmosphere can only act at the centre of the object at the end of a certain time. Thus, it may happen, that in certain cases the iron in the centre may be in a state of (black) monoxide, and on the surface in the form of (red) peroxide. The contrary case, although more rare, may equally be found.

If the reducing action of the kiln atmosphere was intense and prolonged it might cause a complete reduction of the oxides of iron, which would change it, at least partially, into metallic iron. This case is only found quite exceptionally in working. But if the cooling of the porous pastes is effected in an atmosphere charged with hydrocarbons, these decompose in contact with the paste when heated to red heat. The hydrogen combines more or less with the small proportion of oxygen contained in the atmosphere of the kiln, while the carbon is deposited in the pores of the paste, giving it a grey or black colour.

This property is sometimes used to obtain black or bluish-black terra-cottas. If such an article is heated a second time to redness in an oxidizing atmosphere it becomes discoloured, and takes a reddish tint.

Defects in Bodies due to Firing.—(1) *Defects arising from the moulding* (*pressing*) [which have been mentioned in Chapter V.] consist in the articles getting out of shape on account of differences in density, the result of an unequal pressure on the body during the moulding.

(2) *Defects due to a bad charging or setting of the kiln* are described in the sections relating to the process of charging the kiln.

(3) *Defects arising from too low or too high a temperature in firing.*—For porous bodies too low a firing makes the ware too tender, but slightly resistant, and badly bearing exposure to weather; for impervious bodies, vitrification remains incomplete and the ware is porous. An excess of heat on the contrary distorts the goods, or scorifies and then melts them.

(4) *Defects arising from too rapid a heating*, viz. the formation of steam (aqueous vapour) in the interior of the mass which may make them burst. The body once dried can be heated more rapidly, the giving off of the water as well as that of the carbonic acid taking place without new difficulties occurring. But as it is difficult to heat all the parts of an article equally, variations may occur in the shrinkage, and may cause breakages which might be avoided by heating it sufficiently slowly and regularly at first.

(5) *Defects arising from a too rapid cooling* may be occasioned either during the cooling after burning, or by the admission of cold air coming suddenly on to the ware during the burning. In both cases it produces cracks or dunts.

(6) *Defects due to a wrong composition of the atmosphere of the kilns* are shown by an irregular colouring, or one different from that which is desired (see p. 185). Coal smoke and hydrocarbons cause a deposit of carbon in the interior of the pores of the paste. In very porous wares this deposit is consumed during the period of cooling, this being nearly always oxidizing, but in impervious wares it may, on the contrary, remain sealed up in the pores at the moment of vitrification, and give a yellowish-smoky tinge that cannot be removed.

(7) *Defects arising from the presence, in the atmosphere of the kilns, of sulphurous fumes, or of those of alkaline salts*, in which the acid combines with the lime of the body and often causes spots on the parts which were more particularly exposed to the circulation of the gases. In non-calcareous pastes, and with a reducing atmosphere, these sulphurous fumes have no noxious action.

The ashes of the fuel always contain a rather large proportion of alkaline salts, which may be carried in by the draught, and fix on the surface of the ware, causing the formation of the more fusible silicates. In the beginning of the firing, when the kiln is still damp, these may also dissolve in the water that the bodies still contain, and be added to the soluble salts naturally in the body and so form a scum.

(8) *Defects arising from the soluble salts contained in the bodies* are not due to the burning, but to the composition of the bodies; they

are mentioned here, however, because they do not become clearly visible until after the burning. These soluble salts (sulphates, chlorides, silicates of lime, soda, potash, and magnesia) follow, during the drying, the movement of the water from the centre to the surfaces, and form whitish efflorescences there. When the gases of combustion do not contain sulphurous fumes, which is scarcely ever the case except in wood-firing, the result from it is simply a thinning of the colour of the surface, these salts at the time of the full fire entering into the formation of the silicates. If, on the contrary, sulphurous fumes are produced, the sulphuric acid formed unites with the bases of the soluble salts to make sulphates and forms white spots on the ware.

If the temperature of the burning is not sufficient to convert the soluble salts that remain in the body into silicates they may be dissolved when the burned wares are moistened again, by rain, for example, and thus form new efflorescences even after several months. These are, however, less to be feared than the preceding, because, the salts being soluble in water, the spots produced can be removed by simple washing.

Salts of vanadium also produce yellow and green efflorescences. This defect is noticed principally with clays of a lignite formation, which are very much used in North Germany. Such efflorescences are produced when the burned ware is exposed to damp, when efflorescences of an intense yellow colour due to vanadic acid are formed, and these under the influence of the coal dust of the atmosphere take a bluish-green colour because of the reduction of the vanadic acid to oxide of vanadium.

(9) *Defects arising from the lime and magnesia contained in the bodies* remaining in the form of grains of lime or caustic magnesia, make the ware split by becoming hydrated and increasing in volume. By plunging the bodies, while still warm as they come out of the kiln, into water this defect is noticeably decreased.

Firing Glazes.—Glazes may be applied to a body which is simply dried, or to a body which has first been fired. In the first case the precautions which it is necessary to take in order to obtain a perfect firing of the body are usually sufficient to insure the success of the glaze. In the second case, the operation is much easier, the temperature may be rapidly raised to the point at which the glaze begins to vitrify, as it is only from the moment at which the glaze is changed into glass that it attains the properties which are noticeably different from those of the body.

For each composition of the glaze there is a corresponding temperature at which it begins to soften, according to the combination of its raw materials in the form of silicates and borates. Then, becoming more fluid, it spreads equally over the surface of the body in the form of a viscous adhesive layer. If the temperature continues to rise the fluidity would become sufficient to destroy adhesion to the body, and it would run towards the lowest parts. Hence the temperature for firing glazes is confined between very narrow limits; and it is necessary to so proceed that the liquefaction shall not take place suddenly, but shall be preceded by a fairly long period of pasty moistness. When the vitreous layer is spread uniformly, the temperature is kept constant for a period of time which varies with the nature of the ware, then it is allowed to sink regularly and slowly enough to prevent some of the defects mentioned in the preceding section.[1]

The chief defects of glazes after being fired may be divided into four classes:—

(1) *Defects arising from the non-adhesion of the glaze* because the surface of the body is too compact, or may even be covered with dust or be oily, in which case the glaze cannot very well adhere to it. The result after firing is fissures in the vitreous layer, which seems to contract.

(2) *Defects arising from the body being too absorbent* so that the glaze when vitrified penetrates the pores and may completely disappear in them. The same effect may often be seen when the ware is put in kilns by the side of pieces made of porous bodies which are not glazed, as, for example, the saggers which are used in charging, or the walls of the kiln. In this case there is a more intense volatilization of the glaze which is carried on to the unglazed bodies.

(3) *Defects which are the result of too low or too high a temperature in burning.*—In the first, the vitrification is incomplete, and the glaze has the appearance which is characterized by the name of *egg-shell.* In the second, the too fluid glaze runs towards the lower parts of the ware, leaving the others bare. This defect of *trickling* is also produced when the glaze is too thick for it to be entirely kept up by the adhesion of the body. In certain cases too high a temperature may also cause a boiling of the glaze, which then, on cooling, is filled with *bubbles* or *blisters.*

(4) *Defects in the composition of the body of the glaze.*—In this case also the glaze may contain *bubbles* or be dotted with numerous little blackish points. The cause of this defect is a gaseous decomposition of the glaze (the giving off of carbonic acid, oxygen, etc.) or a chemical reaction which is produced by the elements of the body on those of the glaze.

Agreement between the Bodies and the Glazes.—If the burning is completed in a single operation it is necessary that there be *an agreement between the temperatures for firing* the body and the glaze. This agreement is generally easy to arrange by varying the proportion of the refractory elements or of the fluxes, either in one or the other or in the two simultaneously. This problem no longer exists when the burning is done in two operations, the first being the firing of the body, and the second, at a lower temperature, the vitrifying of the glaze. But, no matter what process of firing is adopted, the moment the glaze is spread as a glass on the surface of the body, these two elements of the ware become united, and like all solid bodies and glazes expand under the influence of heat, and return to their original

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[[1] Excessively slow cooling at first should be avoided; it tends to cause crystal formation and devitrification of the glaze.—A. B. S.]

size when cooled. It is necessary for them to have during cooling *an agreement between the contraction of the body and that of the glaze.* If the glaze contracts more than the body, it will be subjected to a tension which may cause its rupture, either in connection with the cooling, or later by the influence of an external cause (concussion, heating, etc.). This breaking usually takes place in the form of numerous cracks, larger or smaller, called by the name of *crazing.* The nearer together or the more numerous these cracks are, the greater the antagonism between the body and the glaze. Sometimes when the glaze is very thick, this defect may become serious enough to cause the body itself to break.

If, on the contrary, the glaze contracts less than the body, it is compressed, and if this compression passes the limit of its elasticity, it breaks, forming chips, which are detached from the body, sometimes taking portions of it with them. This defect which is the opposite of crazing is called by the name of *scaling* or *peeling.*

The problem of obtaining a perfect agreement between the contraction of the body and that of the glaze is the most difficult one met in pottery. It can only be solved by a series of trials, and the difficulties which beset the ancient potters, who did not know the exact compositions given by chemical analysis, and who were ignorant even of the cause of their failures, were often insurmountable to them. The quickest method of solving the problem consists in determining the exact composition of the paste and the glaze and then firing trial pieces. If these show crazing, the composition of the glaze is modified by diminishing the proportion of alkali, and increasing that of the silica or the boracic acid, as these make the compounds that expand the most; oxide of lead occupies a middle place, while the compounds of the alkaline earth bases, alumina, lime and magnesia, have the least expansion. On the other hand, the monosilicates have a greater expansion than the bisilicates. Boracic acid gives compounds which act like the bisilicates.

When, on the contrary, the trial pieces are scaled, the composition of the glaze is modified in the opposite way. Generally after some failures, the desired result is obtained. If, however, such is not the case the composition of the body must be modified, and a new series of trials begun.

When *crazing* occurs, the following modifications should be tried with the body:—

(1) Increase the proportion of silica.
(2) Grind it more finely.
(3) In non-vitrified bodies increase the amount of the fluxes.
(4) In vitrified bodies, on the contrary, diminish the amount.
(5) In bodies containing ball-clay and china-clay increase the proportion of ball-clay and diminish that of the china-clay.

If, on the contrary, there is *scaling,* the reverse modifications are made.

Silica has a much greater expansion than clay, and its addition to a body diminishes crazing and increases scaling. This action is the more noticeable as the grains are finer. Hence crazing may be reduced by grinding the silica more finely, or, on the contrary, the scaling may be diminished by using coarser grains of silica.

The action of the colouring oxides is mentioned in the following chapter, which treats of Decoration.

The fluxes affect the temperature needed for firing the body.

In non-vitrified bodies, the expansion rapidly increases as the temperature of the burning rises. The result is that in vitrifying a glaze on three specimens of the same body, one slightly, the other medium, and the third very highly fired, if it agrees with the second, the first will have crazes and the third will be scaled. In this case the increase in the amount of fluxes acts like the raising of a temperature by diminishing the crazing and increasing the scaling. Vitrified bodies in which the expansion diminishes, on the contrary, change more and more into a vitreous production and an increase of fluxes causes crazing and diminishes scaling. Bodies which are not vitrified but are rich in silica act in the same way; their expansion, after having reached the maximum, begins to diminish with the further raising of the temperature. This fact can be explained by the progressive change of silica with a density of 2·6 to 2·7 into silica with a density of 2·2 to 2·3, the first having a greater expansion than the second.

The foregoing suggestions show the line to be followed in solving the problem of the agreement between bodies and glazes, but they equally show the difficulties present as well as the perseverance and professional skill needed for its solution.

Fusibility and Firing Tests.—Trials in burning are of considerable importance and many must often be made before a new work is started. Hence it is necessary to possess a test-kiln, which will allow of a high temperature being readily obtained and modified so as to give at pleasure an oxidizing, neutral, or reducing atmosphere.

The fuel employed in test-kilns is charcoal or illuminating gas. With the former, for temperatures not exceeding 1000° C., one of the reverberatory furnaces used in chemical laboratories may be used. For higher temperatures a blast is necessary. For trials on vitreous ware and of glazes, satisfactory results are only obtained by heating with gas.

Fig. 127 shows an apparatus designed by Perrot which easily gives a temperature of 1200° C. The gas, the pressure of which is measured by a manometer, enters by a lower ring from which it passes by a series of tubes placed circularly, drawing a certain quantity of air through with it. The flames from the ends of the tubes penetrate to the centre of the kiln, pass round the crucible or the piece to be heated, then descend again along the outside walls of the kiln and escape by the chimney. This kiln is constructed with six, nine, twelve, and even twenty burner tubes.

The kiln shown in Figs. 128 and 129, which easily allows the temperature for burning hard porcelain to be obtained, is preferable. The gas is led in by a series of burners B, through a circular pipe A, while the air enters at C into an horizontal tube, then vertically, and enters into the kiln at D. The combustion takes place at E, and the flames first rise, afterwards descending round the pieces to be burnt, which are placed upon a little table F. Thence they continue to descend, and the products of combustion enter the pipe G, where they warm the air, and escape to the chimney. The management of this kiln is easily regulated by opening the little plug H, and seeing whether air goes in or flames come out.

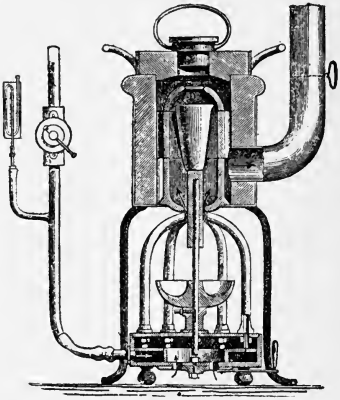
Fig. 127.—Test-kiln.

[An electrically heated furnace is often more convenient where electricity is available.—A. B. S.]

Trials for fusibility are made with pieces of body, shaped like little bricks, or better still little pyramids. For trials of impervious ware, or of glazes, little plaques about 5 to 20 cm. square, and 10 mm. thick [or "3 in. tiles"] are used. It is always wise to try two or three pieces alike because of accidents in firing which it is not always easy to avoid. The temperature is measured by means of pyrometers (described later).

(2) Description of the Kilns.

All kilns are for the double purpose of producing and utilizing heat. The production of heat is by means of the fire box and the apparatus for creating the draught, including the arrangements used for introducing the fuel into the kiln, to mix it with air and thus insure its combustion.

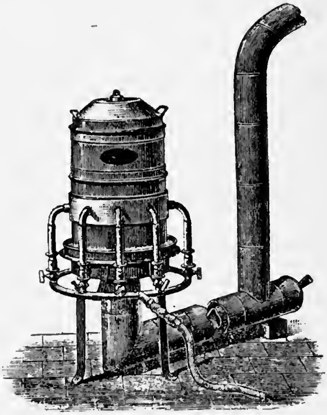
Fig. 128.—Test-kiln.

The draught apparatus insures the introduction of air and creates the circulation of the gases and flames in the interior of the kiln. The utilization of the heat is done in one or more "chambers" in which the flames or hot gases are brought into contact with the goods or with the receptacles in which the goods have been placed. To these essential parts must be added another one, intended to utilize indirectly a part of the heat which has not been used for the direct heating of the ware. The kilns at present used in the ceramic industries are of several different types. This diversity is justified by the variety of wares and by the differences in the temperatures needed for burning them. Some of them should be condemned. In selecting a kiln all the arrangements of it must be studied for the special manufacture in view, the nature of the fuel, the various properties of the bodies, glazes, and other materials and the general necessities of the manufacture. It is only by satisfying in some measure these multiple conditions that a kiln can be obtained which works efficiently and economically.

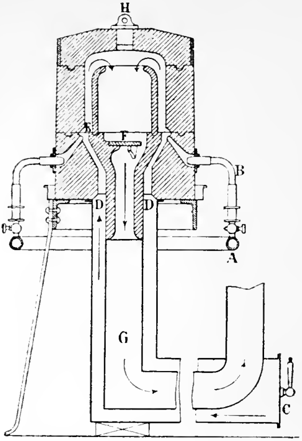

Fig. 129.—Test-kiln.

Fuel.—As in other industries, the first fuel that was used in pottery was wood, but in the course of last century it has been almost entirely replaced by coal. Wood, however, is still used in certain districts and has advantages for wares in which the expense of fuel is a small part of their total value. Lignite, peat, and occasionally vegetable materials, grass, straw, mineral oils and natural gases, are also used.

On account of the distance between the fire box and the goods to be fired, only flaming fuel can be employed, and it is only in exceptional cases and during the commencement of the burning that short flamed fuel can be used. Dry fuels which contain very little cinder are preferable. For high temperatures, fat coal, or open burning coal, or gas produced from inferior coal may be used.

Wood is used in the forms of logs, faggots, or sawdust, but the last can only be used when mixed with coal. The hard woods, oak, beech, elm, ash, give more heat than birch, fir, pine, larch, poplar, and aspen, but produce a shorter flame. The lighter woods last named give off long flames and are usually better for the burning of pottery goods, but cannot be used for the production of high temperatures. For burning the bodies, fir, pine and larch are generally preferred, and for burning glazes, birch, beech or ash.

Coal is classed under five heads, according to the proportion in it of volatile materials, and the manner in which they behave during combustion :—

(1) *Anthracite* and sandy coals can only be employed in gas producers and for the production of medium temperatures.

(2) *Open burning coals* can only be used directly in pottery when the combustion is done in the midst of the objects to be burned.

(3) *Fat Coals,* called smithy coal or blacksmith's coal, give a bulky coke and can only be used when mixed with close-burning coal (sandy coal) on account of their tendency to cake.

(4) *Gas Coals,* when they do not cake, are specially suitable for the heating of kilns needing long flames and a high temperature.

(5) *Sandy Coals* with long flames, giving a sandy non-caking coke, are used for baking pottery, but give lower temperatures than the preceding ones.

The proportion of ash is rarely below 5 per cent and may reach 25 or 30 per cent, the average being 7 to 15 per cent. Ash not only diminishes the heating power of the coal, but also hinders combustion by filling up the gratings, forming clinker and needing frequent cleanings.

It is advisable in the manufacture of fine ware and for obtaining high temperatures, to use coals of better quality than those often employed, or gas generators may be used with a lower grade of fuel if it contains a sufficiently large proportion of volatile material.

For ware of less value, and fired at a low temperature, it is often possible to use coals of inferior quality, but it is only by actual trial that the most economical fuel can be ascertained for any particular case.

Coke is very useful at the commencement of the burning because of its regular combustion, but it cannot be used when flames are necessary. It may sometimes be mixed with fat coal.

Lignites and peat of good quality are suitable for firing pottery at moderate temperatures. They should be as dry as possible.

Grasses and straw have been used in the absence of other fuels for burning common bricks. *Natural gases* are used in America but not in Europe. *Natural oils* have also been employed in the United States and in the Caucasus, but are not likely to be used outside the countries where they are produced.

The effective value of a fuel can only be determined by an actual trial, the fire-boxes being adapted to it. The calorific power of a fuel is interesting, but is not conclusive for industrial purposes If there is the danger in the use of an unknown fuel spoiling the burning, it is easy to mix it in increasing quantities with that ordinarily used. It is useful, especially for coals, to determine the proportion of ash, and of the principal materials volatile at a good red heat.

The combustion of the fuel in the midst of the ware is only used in the manufacture of bricks, etc., which are not harmed by contact with ashes or flame. This method of heating is, in theory, the most economical, because it uses the heat as soon as it is liberated, and ought to be preferred to all others whenever it can be used.

Combustion of the fuel in fireplaces with grates is suitable for burning all kinds of pottery. The fuel is spread on the surface of the grate in a uniform layer, sufficient air being allowed to enter so as to ensure complete combustion. For high temperatures such fireplaces are inconvenient; they get dirty, are difficult to clean, and the grates quickly wear out. The grates may be of metal or of fire-clay.

The combustion in furnace-fireplaces is common in the pottery industry. The fuel is used in a comparatively thick layer, the fireplaces can be with or without a grating.[1] There are ordinarily two zones, one in which the distillation of the fuel takes place, and the other in which the coke is formed and consumed. The shape of the fireplace can easily be modified to suit special needs and does not present any particular difficulty. There are usually several air inlets which can be regulated at will. These furnaces are very suitable for the production of high temperatures, but it is more difficult to regulate them for slow firing. The fuels used are logs of wood or long-flamed coal.

Gas generators are special fireplaces in which the fuel is converted into gas, which is led into the kiln through pipes or flues where it catches fire on coming out of the burners into contact with the air. The management of kilns thus heated by gas is remarkably easy and is suitable for all methods of working and for all temperatures, but the conversion of fuel into gas naturally involves a loss of heat, which must be compensated by other advantages.

Heating by Wood.—Wood can be burnt in the midst of the goods when the latter are not injured by contact with ashes which are easily carried about by the draught. This method of heating presents no other difficulty than that resulting from the putting of wood into the kiln, an operation which must be frequently repeated, though it causes the entrance of cold air and a serious loss of heat. These defects are specially noticeable when faggots are used, and to remedy them openings for charging should be lengthened outwardly to the shape of tunnels (Fig. 130), closed by a sheet-iron plate suspended at the upper part. These charging tunnels hold so much wood that any air drawn in by the draught is warmed while the charging is taking place. This arrangement, which is used especially for faggot fuel, is also applicable to intermittent kilns as well as to continuous kilns. Wood in the form of logs may be introduced into the latter kilns exactly as if it were coal.

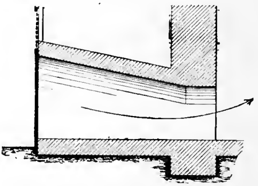

FIG. 130.—Furnace mouth for wood.

Blocks of wood may also be burnt in fireplaces with gratings as in Fig. 131. The hearth should be prolonged beyond the front of the kiln, and the wood charged through an upper passage, the dome of which is placed immediately underneath the kiln and carries the

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[1] [These are sometimes known as "half-gas producers," being intermediate between the ordinary grate and the true gas generators.—A. B. S.]

goods to be burned. The air enters by a lower passage which forms an ashpit and leads into the upper passage through the openings arranged regularly in the dome of it, but not opposite those of the first one. A part of the fuel falls into this ashpit and is consumed there while heating the air. This arrangement is specially applicable to up-draught kilns and can easily be modified when necessary.

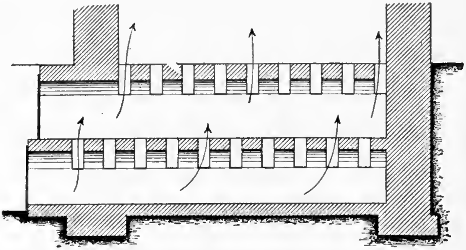

Fig. 131.—Furnace for burning wood.

For the production of high temperatures, various patterns of fire-boxes are used. The type represented in Fig. 132 gives good results provided all the logs used are of the same length. These are piled in the upper opening of the fireplace and rest on two brickwork projections. The combustion takes place by the air passing between the logs, the flames following the direction shown by the arrows. The embers which fall to the bottom of the fireplace help the burning, owing to the air entering through the ashpit door. This type of fireplace is built into the kilns; it gives very long flames and is suitable for all kinds of work. For slow firing, the logs must be replaced by faggots, or the upper opening may be closed with a damper.

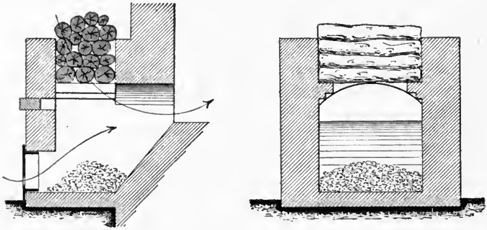

Fig. 132.—Furnace for wood.

Heating by Coal in Fireplaces made by the Ware.—Common bricks may be burned by filling the kilns with alternating layers of bricks and fuel, as is done in lime burning. This method, which is specially used in Flanders, is described on account of its very special characteristics in the paragraph devoted to the manufacture of bricks (p. 296). The contact of the fuel with the ware and the necessity of preventing the formation of cakes of coke make it preferable in this case, and as a solitary exception, to use rather sandy coal.[1] In kilns with an horizontal draught the fuel can equally well be fed directly on to the ware, which is arranged so as to make a kind of fireplace with steps (Fig. 133).

In A, each fireplace is a kind of well in which bricks project at intervals and keep back part of the fuel thrown in through the top, the feed-holes or pots being provided with covers. They are 28 inches to 60 inches apart.

In B, the setting is arranged to leave a bay, in which the bricks are set so as to make regular projections, and cross the empty space forming stages or steps. The small fuel used lodges on these stages and burns there in the current of warm air, which passes horizontally through the kiln. The charging ought to be done in small quantities, frequently, and at regular intervals. As the ash cannot soil any of the objects except those forming the well or the bays, more delicate wares, such as tiles, paving tiles, etc., can be put in other parts of the kiln.

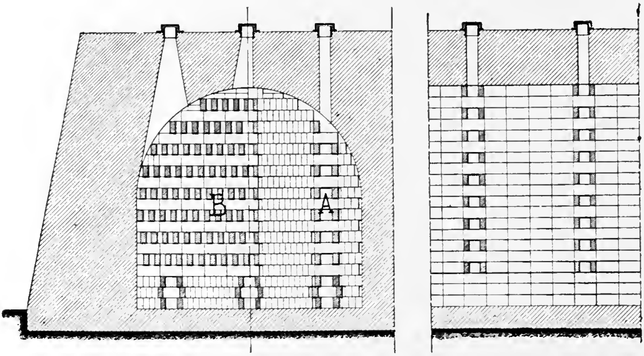

FIG. 133.—Arrangement for burning coal among the goods.

A rather small open-burning coal is generally used, but wood is equally good if the projecting bricks are not used.

Heating by coal with fireplaces with gratings which are placed either below or by the side of the kiln. In the first case they are narrow but very long. In Fig. 134 the grate is placed on a level with the lower bed of the kiln, but the fireplace could equally well be

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[1] In Great Britain this process is now seldom used.—A. B. S.]

covered with a perforated dome as shown in Fig. 131. The fuel is fed through a door placed at one end; this door and the coal is then thrown on to the grate by one or more openings arranged in the top of the kiln, somewhat similar to those shown in Fig. 133, the air always being brought in through the ashpit. When, on the contrary, the fires are at the side, it is preferable to make the grate inclined, so as to be able to push the coke more easily towards the back and to put the fresh fuel near the charging door (Fig. 135).

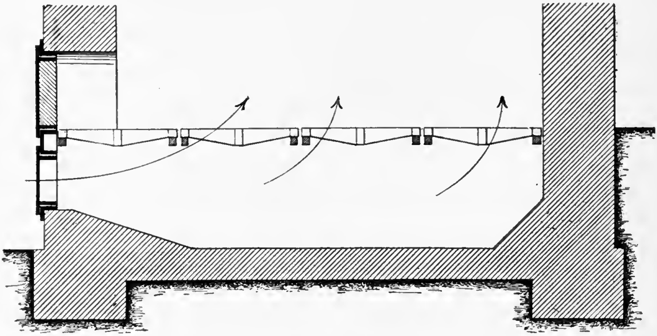


Fig. 134.—Furnace with level grate.

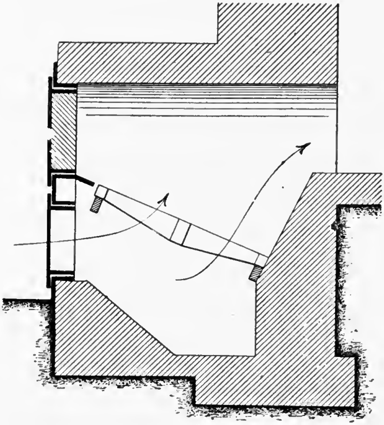


Fig. 135.—Furnace with sloping grate.

The grates are always made of metal, the size depending on the nature of the fuel. Moving grates or mechanical stokers are seldom used, as the heating being intermittent it is usually possible with good fuel to prevent the blocking up of the grate during the burning. There is no reason, however, why a mechanical grate, as shown in Fig. 136, should not be used with excellent results. The fronts of the kiln fireplaces ought to be very solidly built, otherwise they are better left out altogether, and replaced by plates of sheet-iron simply put against the doors used for charging and the ashpit.

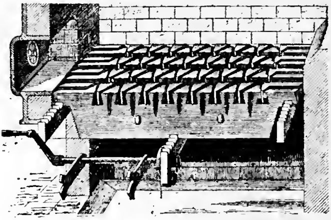
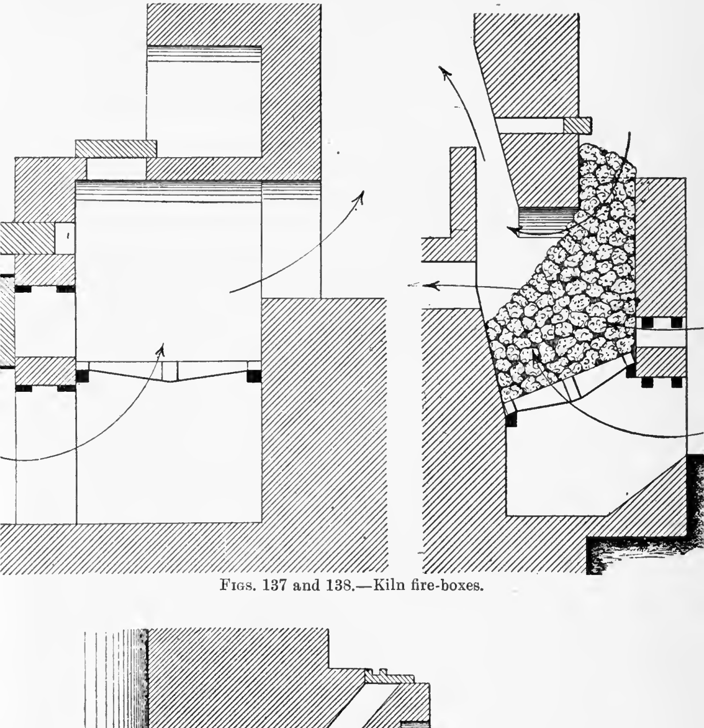


FIG. 136.—Mechanical grate.

Heating by Coal with Furnace Fireplaces.—These furnaces resemble fireplaces with grates, on which is a thicker layer of fuel (Fig. 137).[1] The door at the side on the level of the grate is only used for cleaning purposes, the ashpit is partially closed by an iron sheet, and an opening placed between the opening for charging and the door for cleansing allows of an extra supply of air. This furnace is very suitable for slow firing, but in full firing the fresh fuel falling on to the burning coke causes irregularities in the combustion. This is avoided in the fire-box shown in Fig. 138, which is used for continuous charging. The fresh fuel distils in the upper part, while the coke is burnt by the air coming in through the cleaning door and through the grate. The flames may pass out of the fireplace by two openings, one vertical and the other horizontal, but this arrangement is a detail, and a single exit, as in Fig. 137, would be sufficient.

The more recently designed kilns get farther and farther away from the grate-fireplace type and approach that of the gas generators. Fig. 139 shows a very recent fire-box in which the grate, very much sloped, is suspended at its upper part, and has, at its lower end, between it and the brickwork, a space through which the ashes and rubbish accumulate and fall into the ashpit, from which it is easy to take them out. As in Fig. 138, the fuel distils in the upper part, and the coke formed burns in contact with the air which comes in through the grate. There is an extra supply of air entering on each side and heated by circulating through channels placed in the side walls of the furnace. The charging door is usually closed. The cleansing is done easily and almost automatically by the descent of the fuel, or a rake may be passed between the bars. This furnace gives very good results for full firing, and allows fuel to be used which contains much rubbish, but does not lend itself to a prolonged slow firing, unless the area of the grate is reduced during the first portion of the burning by

[1] See footnote on p. 194.]



FIGS. 137 and 138.—Kiln fire-boxes.

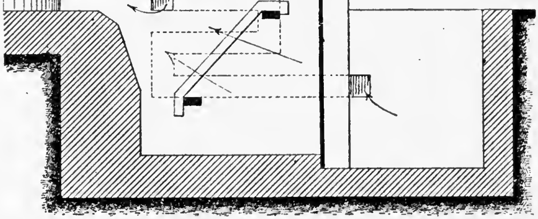


FIG. 139.—Fire-box with secondary air-supply.

putting a fireclay slab on the sloping grate, and drawing it off gradually when a more intense fire is desired. In the furnace shown in Fig. 140 the grate is vertical in one part and sloping in the other. During the slow firing, the former is closed by fire-brick dampers, and the fuel forms a thinner layer, A. Afterwards, the damper on the vertical grate is opened gradually so as to lead to the full firing with a thick layer, B, and a large amount of air.

There is a supplementary channel of warm air, but this is seldom used, as most of the air required enters through a series of vertical openings placed on the hearth.

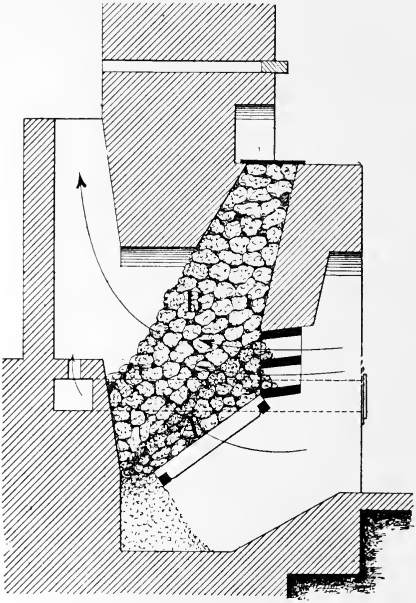


Fig. 140.—Fire-box designed by E. Bourry.

Heating by Gas necessitates the use of one or more gas generators with a system of flues connecting them with the kiln, the burners, which consume a mixture of gas and air, being placed in the kiln.

The principal object of the *generators* is to change the carbon of the coal into a combustible gas, 3 lb. of carbon combining with 4 lb. of oxygen to make 7 lb. of carbonic oxide. This gas, when it burns, is changed into carbonic acid gas and produces theoretically 1090 units of heat per lb.

The great difficulty in gas production consists in the formation of clinker and rubbish, which are very troublesome to remove, and often causes a considerable loss of fuel, and grave disarrangements in the working. To this must be added the tendency of fat coal to cake and form a compact mass, which may completely stop the passage of the gas.

These inconveniences disappear when anthracite, very sandy coal or coke is used as fuel, but these fuels usually produce gases which have too short a flame and often too little heating power for a pottery, so that it is necessary to use open-burning coal in order to obtain good results. Two types of gas generators are used, (1) with a natural draught, and (2) with a blower. Exhaust generators in which it is necessary to cool and purify the gases before allowing them to pass in the exhaustion apparatus are of no use in pottery.

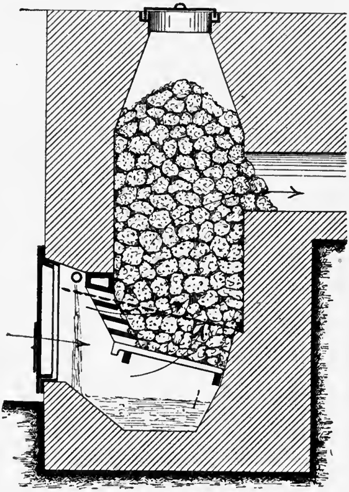


Fig. 141.—Gas-producer for non-caking fuel.

In *generators with natural draught*, the air is drawn in by the chimney draught, and by placing the generators sufficiently below the level of the burners to profit by the ascending force of the warm current of gas.

In the gas generator shown in Fig. 141 the fuel is fed in through an upper opening, and fills a space of square or rectangular section. It rests on a stepped grating and on an ordinary grate slightly inclined.

The gases escape through a side opening; a pipe pierced with holes allows water to trickle constantly into the ashpit. The latter is closed by a door which has an opening that can be regulated at will, allowing the introduction of air. During the cleaning of the grate a movable grate with round and pointed bars is put in and takes the position shown by the dotted line, resting on the last step in the grating and on a projection in the masonry.

The "fixed" grate is then raised, the rubbish and clinker are drawn out and fall into the ashpit. The "fixed" grating is then replaced, and the movable grating taken out. This cleaning is repeated every four to twelve hours. The fuel in the upper part feeds the generator during the interval between two charges.

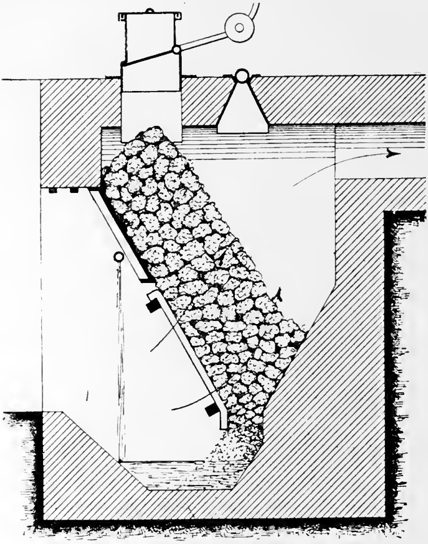


FIG. 142.—Gas-producer for coking fuel.

For fat and caking fuels this arrangement would not be suitable and that shown in Fig. 142 should be used. A special hopper, arranged to prevent the gas escaping, is used for charging. The fuel falls on an inclined plane where it distils; then passes on to a steeply sloping grating where the carbon is changed into carbonic oxide. The ashes are easily removed by means of a fire-hook passed between the bars or descend into the ashpit by a space which is left between the lower end of the grate and the masonry. An upper opening, closed with a ball, allows of poking the fuel and of separating the pieces which have caked together. Lastly, an arrangement similar to that in the preceding figure serves for feeding the water to the ashpit. These gas generators are usually made without doors.

In the *blast gas generators* the air is introduced by pressure, either by means of a fan or an injector. They have the advantage over those with natural draught of allowing the pressure and also the production of gas to be regulated at will independently of the draught from the chimney; this is often valuable in working the kiln.

A fan must usually be driven by a separate engine, but an injector only needs a small auxiliary boiler, which is easily worked by the kiln fireman, so that the latter is simpler, less costly, and furnishes the gas generator with the steam necessary for its economical work.

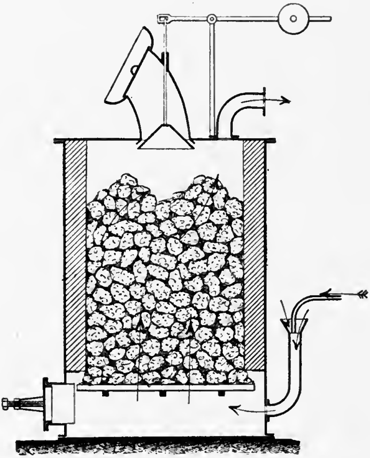


Fig. 143.—Gas-producer with air-blast.

The air-blast can be adapted to the two types of generators already shown, providing the door of the ashpit can be hermetically closed. It is, however, preferable to make the generators cylindrical in shape, and to place them on the level of the ground. For coke, anthracite, or sandy coal, the arrangements shown in Fig. 143 (Dowson) may be used, the fuel being introduced through an upper hopper with double doors and resting on a horizontal grate, under which is injected a current of air and steam. The gas produced passes out through a pipe placed at the upper end. The ashes, etc., are cleaned out every twelve hours through one or two lower doors. This type of gas generator is particularly suitable to the production of short-flame gas such as is used for the production of motor-power, but they have not much prospect in pottery.[1]

The gas generator shown in Fig. 144 (Taylor) allows of the use of richer fuel. It differs from the preceding by its automatic cleansing, which is done by turning over the lower cast-iron plate, on which the cinders and rubbish collect, by means of a crank.

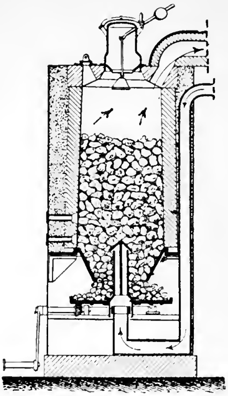


FIG. 144.—Taylor's gas-producer.

The gas used in pottery kilns does not need to be purified or stored in gasometers. The flues which join the gas generators to the kilns may therefore be very simple. They may be laid underground and made of brickwork, or metallic pipes in the open air may be arranged—lined inside with fire-brick masonry. In all cases, the flues ought to be air-tight and fairly non-conductive to prevent the cooling of the gas. When the gas generators are working slowly and use rich fuels, tar is deposited on them; this is removed from time to time by putting fire in them.

The firing of the gas in the kilns takes place at its exit from the fire-brick *burners* which are made for the purpose of dividing the gas up so as to insure it mixing with the air. The air thus introduced into the kiln is called *secondary air* in opposition to the name of *primary air*, which is given to that which helps in the production of the gas in the gas generators.

Chimney draught may be natural or forced. The former is the result of the difference in weight between warm gases and cold ones. The weight of one cubic metre of gas at temperature t is equal to its weight at 0° C. divided by 1 + at, a being the co-efficient of expansion of gases = (0·00366). In this connexion the differences of pressure, which are always negligible in kilns, may be neglected and a uniform pressure of 760 millimetres of mercury assumed. If, then, a chimney 10 metres high, 1 metre square, contains air at (say) 200° C., the weight of a cubic metre of air at 0° C. being 1·3 kilogramme, the weight of this column of air of 10 metres at this temperature will be

$$\frac{1{\cdot}3}{1 + (0{\cdot}00366 \times 200)} \times 10 = 7{\cdot}5 \text{ kg.}$$

The weight of a similar column of air at 0° C. would be 13 kilogrammes. If there is an opening 1 metre square at the base of the chimney, the layer of air there supports, on the outer side, a weight equal to the pressure of the atmosphere, measured at the upper part of the chimney,

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[1] This is Bourry's opinion. The construction of gas producers has been greatly improved during recent years.—A. B. S.]

plus 13 kilogrammes, while on the inner side it only supports a weight equal to the same pressure, plus 7·5 kilogrammes. There is, thus, a difference in weight of 5·5 kilogrammes or 0·55 gramme per square centimetre, which displaces this layer of air and forces it to rise in the chimney.

Indicating the height of a chimney by H, the gas at temperature t of weight d per cubic foot at 0° C., while the atmospheric air of a weight δ is at a temperature θ, the difference in weight at the base of the chimney of section S will be given by the formula

$$\frac{HS\,\delta}{1 + a\theta} - \frac{HS\,d}{1 + at}$$

If e represents the height of a column of water expressed in millimetres of water, having for its base the section of the chimney which balances this difference in weight, the depression caused by this chimney, measured in a column of water, is

$$e = H\left(\frac{\delta}{1 + a\theta} - \frac{d}{1 + at}\right)$$

In the present case, the weight d of the gases passing up the chimney is higher than that ($\delta = 1{\cdot}3$ kilogrammes) of the air, in consequence of the presence of a certain quantity of carbonic acid gas; from this fact it can at most amount to 1·41 kilogrammes. On the other hand, the steam tends to reduce it, and the result is that on an average $d = 1{\cdot}35$.

The difference between δ and d is so small that it may be neglected, making $\delta = d$, and consequently the depression caused by a chimney is equal to

$$e = Had\,\frac{t - \theta}{(1 + a\theta)\,(1 + at)}$$

It is proportional to the height H, and also to the difference of temperature $t - \theta$. If, in fact, $\theta = 0°$ C. for $t = 100°$, 500° and 1000° C., the expression $\frac{t - \theta}{1 + at}$ gives the following values: 0·73, 1·76 and 2·29, that is to say, proportional to 1, 2·41 and 3·19, or approximately, to the square root of the temperature.

This draught (e) should be sufficient to overcome all resistance (r) which this gas current encounters in its passage through the kiln, and to give it a sufficient speed in the chimney not to be too much affected at its exit by the wind. The ascending motion is produced proportionately to the depression $e - r$. The corresponding speed is given by the formula

$$v = \sqrt{\frac{(e - r)\,(1 + at)\,2g}{d}}$$

It must not be less than 1·5 or 2 metres. Knowing t and r, the height H of the chimney may be calculated, and assuming that (r = ae), the volume of gas V delivered by the chimney is

$$V = S\sqrt{\frac{2gHa\ (1 - a)\ (t - \theta)}{1 + a\theta}}$$

Summarizing, it may be concluded that—

(1) That the draught produced by a chimney is proportional to its height and to the square root of the difference between the interior and the exterior temperature.

(2) That the volume of gas delivered by a chimney is proportional to the area and to the square root of its height and of the differences in the temperatures.

(3) That if in the preceding formulæ H = 1 metre, $\theta = 0°$ C., S = 1 square metre, the following quantities represent the depression, the volume, and the weight of air delivered in a second by a chimney 1 metre high and 1 square metre in section for the temperature t stated in the first column :—

Temperature. (t).	Depression. (e).	Volume. (V).	Weight. (P).
10	0·046	0·848	1·071
50	0·201	1·897	2·073
100	0·347	2·683	2·538
150	0·459	3·286	2·741
200	0·547	3·795	2·829
250	0·619	4·242	2·861
300	0·678	4·648	2·860
350	0·727	5·020	2·841
400	0·769	5·366	2·811
500	0·837	6·000	2·736
700	0·931	7·098	2·572
1000	1·016	8·485	2·349

The weight of the air delivered from a chimney $= P = \frac{1 + at}{Vd}$ increases when the temperature of the chimney passes from 0° to 300° C., till it attains a maximum, and afterwards decreases again. Practically, after t = 150° C., P scarcely varies, and there is no object in exceeding that temperature in order to increase the weight of air delivered. On the other hand, the temperature must not fall below 50° C. or it would need large chimneys which would work badly, because they would be too dependent on atmospheric variations, and the excessive cooling of the gases might lead to the condensation of the steam which they contain. A temperature slightly above 100° C. is the one to be preferred.

Instead of chimneys, mechanical appliances may be used, and thus a forced draught be obtained. Fans and steam injectors have been used for this purpose. They are not to be recommended except when great draughts are necessary, which is never the case in the ceramic industries.[1] The presence of sulphurous gas and water vapour also cause the formation of sulphuric acid which at a sufficiently high temperature may rapidly spoil the fans.

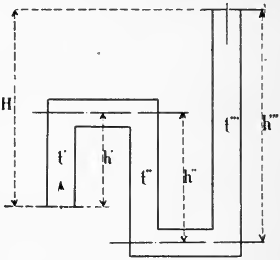

Fig. 145.

Draught in the Kilns.—Kilns by their vertical position are themselves chimneys, and the foregoing remarks and formulæ apply equally to them, the height H being the difference in level between the openings for the air and the escape of the gases. Certain parts of kilns tend to increase or diminish the draught. For example, in a kiln with a circulation represented by Fig. 145 the depression will be shown by the difference

$$e = \frac{H\delta}{1 + a\theta} - \left(\frac{h'd}{1 + at'} - \frac{h''d}{1 + at''} + \frac{h'''d}{1 + at'''}\right)$$

the ascending parts increasing the depression and the descending ones diminishing it.

If Fig. 146 is examined, in which the circulation is formed by an ascending current of temperature T, and by a descending one of temperature T′, it will be seen that in a section MN the difference of pressure is

$$\frac{hd}{1 + aT} - \frac{hd}{1 + aT'}$$

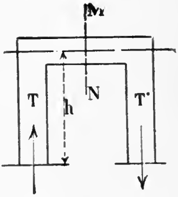

Fig. 146.

If T is greater that T′, the motion of the gases is produced in the direction indicated by the arrows going from the current T to the current T′. In the contrary arrangement (Fig. 147) the same reasoning shows that the circulation is produced in the reverse manner, going from T′ to T.

This may be expressed in another way, by saying that the draught is increased when the temperature of the ascending gases rises and that of the descending gases is lowered, and vice versa. It is not

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[[1] Since E. Bourry's time much progress has been made in the use of fans for artificial or forced draughts, and whilst his remarks are true for single chamber kilns they are quite erroneous as regards continuous ones. For the latter, fans are becoming increasingly popular and have many advantages over ordinary chimneys.—A. B. S.]

necessary that there should be a difference in the level between the entrance for the air and the escape gases in order to set up a gaseous circulation in a kiln.

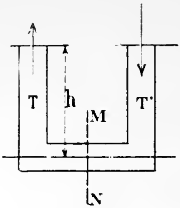

FIG. 147.

In the burning space the movement of the flames and the gases may be ascending, descending, or horizontal. When this circulation is *ascending* (up-draught) it is necessary, in order that it may be regular, that the temperature should be absolutely uniform on each horizontal plane. If in any one place the temperature is raised, it tends to make a quicker circulation there and, consequently, to attract the flames there, so that the defect is more and more aggravated. Vertical currents that are very great and very hot, called "chimneys," are then formed in the middle of the ware in the kiln. It is often very difficult to stop these and they may endanger the success of a firing.

It is not the same when the circulation is descending (down-draught). If there is a rise in the temperature at one point, the draught becomes less, the flames are carried there less, until the evenness of the temperature which was interrupted for a moment is re-established. Thus the down-draught tends to make the temperature uniform after any irregularity caused by faulty working, while an up-draught, on the contrary, tends to aggravate the fault.

When the burning space is crossed by a horizontal current, if this is hotter than the ware being fired, it tends to rise and follow the top of the kiln; if, on the contrary, it is colder, it descends and circulates along the lower part. Irregularities in temperature are then likely to be aggravated. This may be avoided by increasing the resistance to the current in the upper part and diminishing it in the bottom by judicious stoking or charging.

Draught Regulation.—The regulation of the draught in the kilns is for the purpose of varying the speed and the weight of the circulating gases.

The regulation of the *speed* is necessary (1) to produce a good combustion in the furnace, because the speed ought to be between certain limits, which vary with the dimensions of the fuel and the thickness of the layer; (2) to make good use of the gaseous current, which ought to circulate slowly enough among the ware to transmit its heat to them. The *weight* of the gases, on the contrary, depends on the quantity of fuel consumed, and consequently on the intensity of the fire.

This double regulation is obtained by giving, while constructing the kilns, special narrow sections to certain parts of them, and by putting openings of various sizes in others. At certain places also, air can be made to enter. The openings of a certain size are usually placed between the fireplace and the burning space, and between the latter and the chimney. The regulating openings are at the entrances for air and at the exits for the gas. For this purpose clack valves with hinges, dampers and valves are used. The clack valves are placed at the top of the chimneys; they are worked from below by a chain and a balance weight, and have scarcely any use other than to completely close the opening when the working of the kiln is stopped, because they are not suitable for an exact regulation of the draught.

When the dampers are vertical, they are hung by a chain which passes over a roller and are balanced by a counterpoise. They should work easily but do not close hermetically. In order to obtain the latter, horizontal or sloping dampers, which slide on their seat and are kept in place by their weight, must be used. The dampers may be either cast-iron or fire-brick, according to the heat to which they are to be subjected.

Valves are usually round covers, often of a conical form. In order to allow of their closing hermetically they may be ground on the surface which comes in contact with the seat, or their edges may be dipped into a sand seal. They are lifted and lowered by a screw or a differential tackle or by hand. Valves are made of cast-iron, and though they form very good regulators for moderate temperatures, they cannot be used when exposed to a great heat.

These appliances, by varying the opening for the passage of the air, increase or diminish the volume of gas which circulates in the kiln, but do not act in the same way on the depression or draught. In the working of a periodical kiln, the temperature of which rises evenly after the time when the gases passing into the chimney have reached a temperature of 150° C., the volume given out becomes almost constant but the draught keeps on increasing. If it needs reducing, so as to keep a regular working of the fire, it is often necessary to partly close the damper or valve to such an extent that the weight of gas given off becomes insufficient. Then a special opening at the side of the damper must be opened to allow a certain quantity of air to come in from the outside. This diminishes the weight of the gases given out, but acts in a much more efficient way on the draught. This inrush of cold air has also the advantage of cooling the damper as well as the chimney, and, consequently, of preserving them from the action of too great a heat.

Classification of Kilns.—The heat is used in one or more spaces or chambers which constitute the kiln. The arrangement of these spaces is a characteristic of the kiln and serves as a basis for classifying them.

In most pottery kilns the heat is used direct, that is to say the ware or the receptacles which contain it are directly exposed to the action of the flames and of the hot gases. In some kilns, called muffle kilns, the action is indirect, the flames heating the outside walls of the chambers without going inside them. The kilns of the first class are used for the burning of goods which are not spoilt by contact with the flames, and for those which need to be protected by special receptacles, called by the name of saggers, and yet require to be burned at a high temperature. The muffle kilns are only used for delicate ware which requires a moderate temperate for burning.[1]

[[1] Muffle kilns are regularly used for sanitary ware fired at 1300° C.—A. B. S.]

In these two classes of kilns the burning may be intermittent or continuous. If intermittent, there is usually only one single burning chamber, but if continuous either the single chamber forms a continuous circuit or a series of chambers, also forming a circuit, are joined to one another.

For industrial purposes, which are the object of this work, it is preferable to classify kilns in seven divisions: (1) Intermittent kilns with up-draught; (2) intermittent kilns with down-draught; (3) horizontal intermittent kilns with one fire-hole; (4) continuous kilns with one burning space; (5) continuous kilns with several burning spaces; (6) horizontal intermittent kilns with several fire-holes; (7) muffle kilns.

Intermittent Kilns with up-draught.—In olden times the goods were simply placed in the middle of a brazier of wood, this method making it possible to manufacture the large jars used by the ancients, which it was impossible to move in an unburnt state and which it was therefore necessary to bake at the place where they were moulded. Even now a similar method is employed in burning ordinary bricks in clamps, made by piling up the goods, putting alternately a layer of bricks and a layer of coal. This particular method of burning is described in Chapter X.

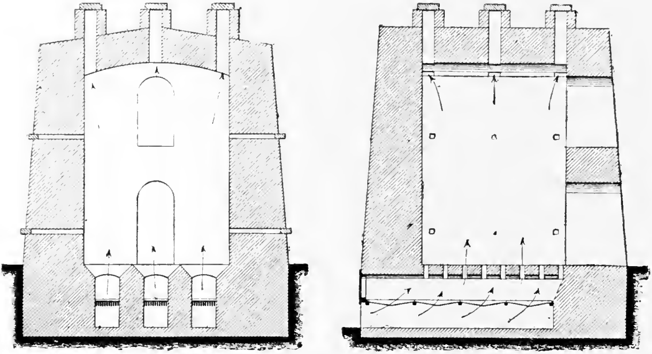

FIG. 148.—Rectangular up-draught kiln.

The first improvement on this type of kiln consisted in surrounding the ware with the brickwork, the hollow interior of which formed the burning space; next, the fireplace was isolated, being placed under the chambers; and later was vaulted, several openings forming chimneys being arranged in this vault. The kiln shown in Fig. 148 was thus obtained and for a long time was the chief type of pottery kiln. It can still be of service in new countries, where skilled kiln builders cannot be obtained, where fuel is cheap and the output limited.

In the drawing, fireplaces suitable for heating with coal are shown, but fireplaces for heating with wood could just as easily be adapted to it (Figs. 130 and 131). Two side doors, placed over one another and walled up during the burning, are used for charging and emptying. The openings for exit of smoke, made in the dome, are covered over with terra-cotta slabs, which help to regulate the draught. It is wise to strengthen the kiln by means of vertical supports of wood or iron, fixed at their base in the ground, and joined at the top by iron bands passing over the dome. The shape of the burning chamber may be square, rectangular or circular.

A second type of intermittent kiln with up-draught is shown in Fig. 149. The burning chamber is round, as this shape lends itself better to the distribution of the heat. The heating is done by several lateral fireplaces, spaced regularly on the outside of the kiln, the flames penetrating to the burning chamber through openings in the walls and in the lower hearth. The draught is caused by openings arranged in the dome, and the fuel is fed through one or two doors the thresholds of which are on a level with the hearth. Circular iron bands, principally put above the fire-holes and on a level with the springing of the dome, help to strengthen the kiln.

This type of kiln is still frequently used, and it was, at the time of its invention, a very great improvement on earlier ones, marking one of the principal stages in the history of pottery burning.

Setting aside the clamp kiln, which is quite a special kind, and apart from the cases mentioned for square and rectangular kilns, intermittent kilns with up-draught ought, in a general way, to be condemned. They have the double defect of being wasteful and giving an unequal distribution of heat. In this same class ought also to be put square open kilns, round kilns with an upper story and up-draught, and other up-draught arrangements which only deserve to be forgotten.

Intermittent Kilns with down-draught are represented by four types:—

(*a*) The rectangular kiln; (*b*) the round kiln; (*c*) the round kiln with an upper dome; and (*d*) the round kiln with a lower dome.

In all these kilns the heating is done by side fire-holes for which, in certain cases, gas burners can be substituted. The *rectangular kiln* shown in Fig. 150 can be built with a single independent chimney, or with a series of chimneys in side walls. The right hand part of the figure shows the first arrangement, and the left the second one. The burning chamber, of rectangular form surmounted by a crown, may be extended in length to any desired size, but for a great length the arrangement of separate chimneys is preferable, the draught not being so easy to regulate uniformly with a single chimney. A door at each end is used for setting. The kiln should be strengthened by girders on each side of the fire-holes, joined together by tie-rods above.

This kiln is used for burning bricks and terra-cotta, the setting of which is difficult in round burning chambers, but its employment

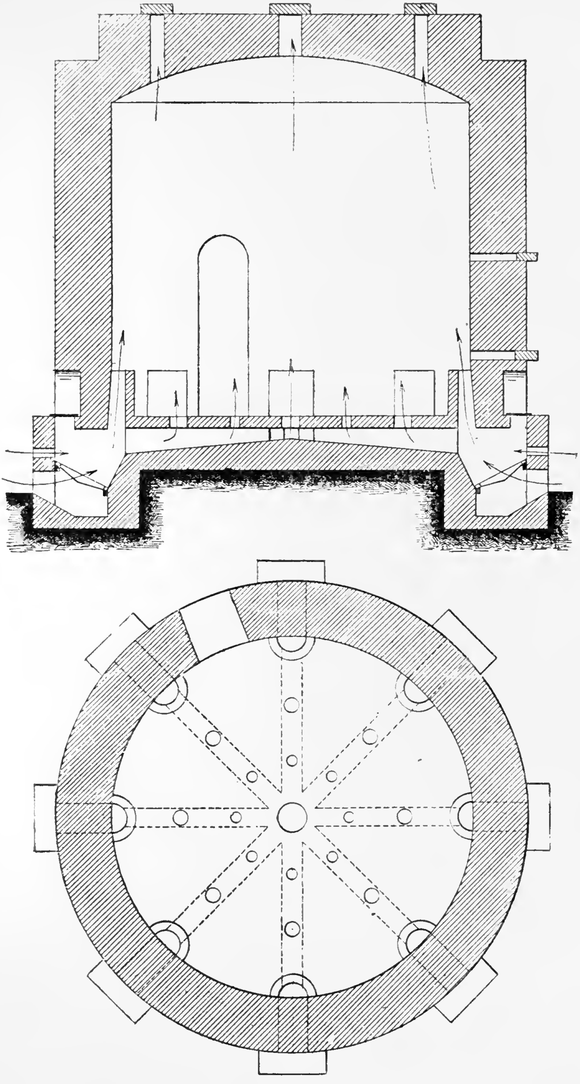

FIG. 149.—Round up-draught kiln.

should be strictly limited to goods which, for reasons explained in Chapter X, cannot be burned in continuous kilns.

The *round kiln* (Fig. 151) is built in various sizes according to

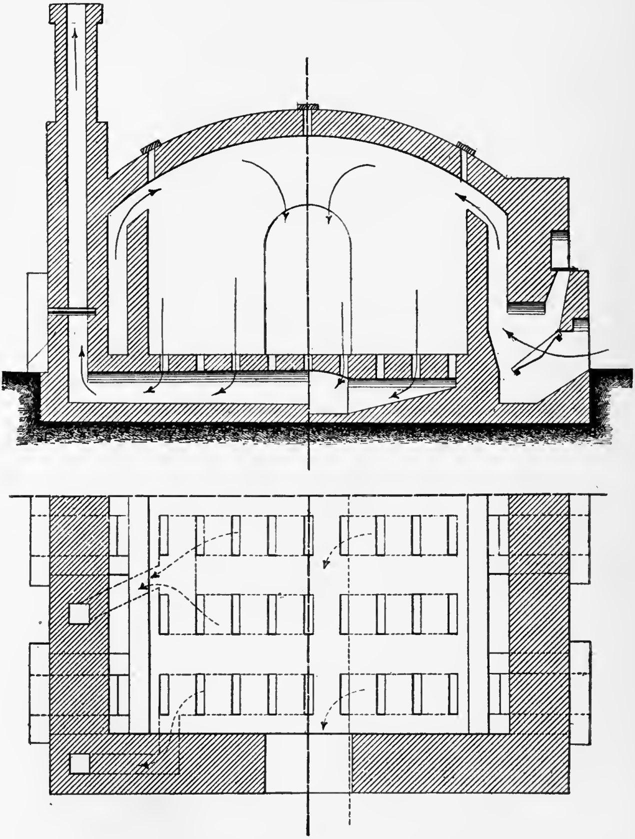

FIG. 150.—Rectangular down-draught kiln.

the goods to be burned and to the temperature to be obtained. The fireplaces, which number two to twelve, are placed regularly on the circumference. When the diameter of the kiln is large they are united together by conduits, placed beneath the floor, which join in one central

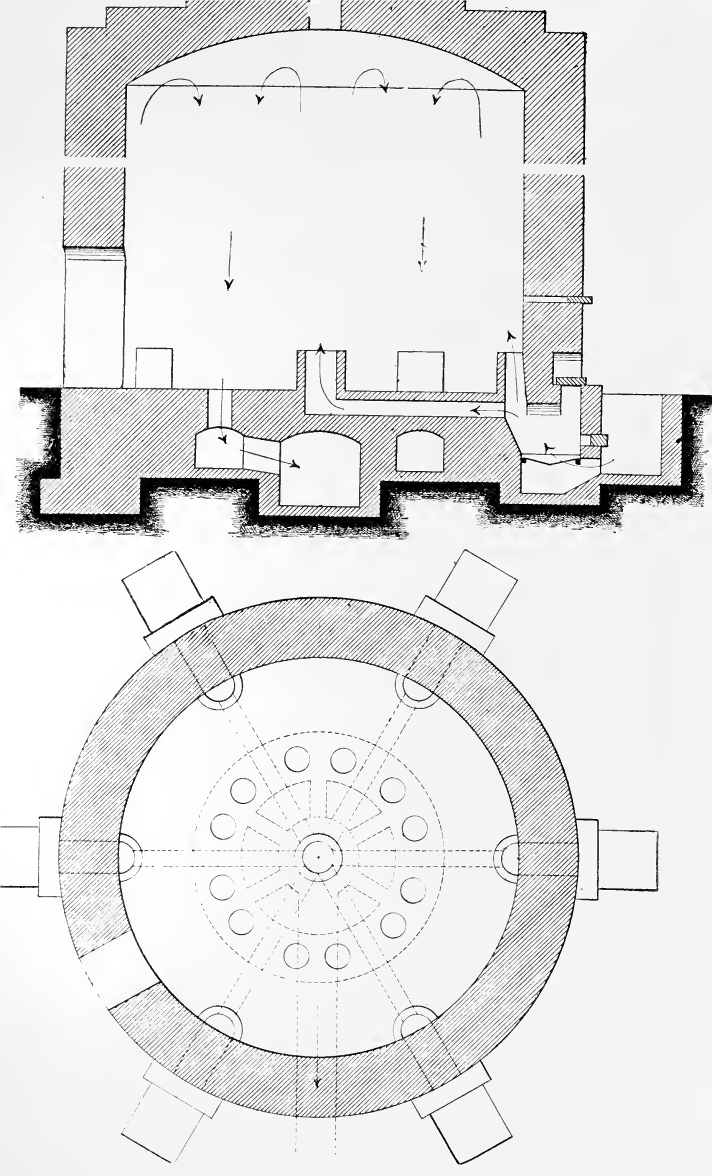

FIG. 151.—Round down-draught kiln.

entrance for the flames, as in the figure. When, on the contrary, the diameter is small, the direct entrance for the flames suffice. In any case the gases pass out through openings in the floor, the arrangement, number, and dimensions of these depending on the goods to be burned and the method of placing them. All the openings lead into a central space, which communicates by an underground passage with an outside chimney which usually serves for several kilns. An opening in the dome is used for hastening the cooling after the burning is finished; one or more doors on the ground level allow it to be emptied. This kiln is specially used for burning faience and stoneware; its working, although slightly better than that of round kilns with up-draught, is only medium, but when properly filled the distribution of the heat is satisfactory.

The *round kiln with an upper dome* (Fig. 152) is used for burning pottery which has to be burned or heated before receiving the glaze, this heating being done in a second burning chamber, called a dome, by means of the flames rising out of the first. The working of the latter is the same as that of the lower round kiln, but the flames instead of being united in a collector, to pass thence into the chimney, rise through a series of vertical flues arranged in the walls, and pass through several openings in the bottom of the dome. There they continue upwards, crossing the crown of the dome, and going into the chimney which is over the kiln.

Fig. 153 shows an arrangement, *with a lower dome*, in which the flames, coming out of the bottom of the upper chamber, descend by flues in the walls to the bottom chamber. There they rise towards the crown, then descend in the middle of the goods, and pass out by lower openings, collecting again in a receiver, to go afterwards to an outside chimney.

In these two types of kilns with domes, the utilization of the heat is fairly good, slightly better in the second than in the first, in which it is sometimes necessary to finish heating the dome with supplementary furnaces placed on the upper floor. If heating by gas is adopted, it must be fitted to the kiln shown in Fig. 153.

Connected kilns with down-draught distribute the heat much better than those with up-draught, but the utilization of the heat, although generally better, is still imperfect. It is increased by heating with gas, which makes the kilns as economical as is possible with intermittent burning. It is convenient to use these kilns for burning all pottery needing a careful firing, and for which continuous kilns are unsuitable.

Horizontal intermittent kilns with a single furnace are characterized by their shape, and by a single fireplace at one end, while the chimney is at the other. The types are numerous, but it will be sufficient to mention the three following:—

Fig. 154 shows a kiln with flames that are exclusively horizontal; when several of these kilns are placed side by side, the draught is formed by a single chimney which communicates with a smoke receiver; in the opposite case, the kiln is finished by a chimney as in the following examples.

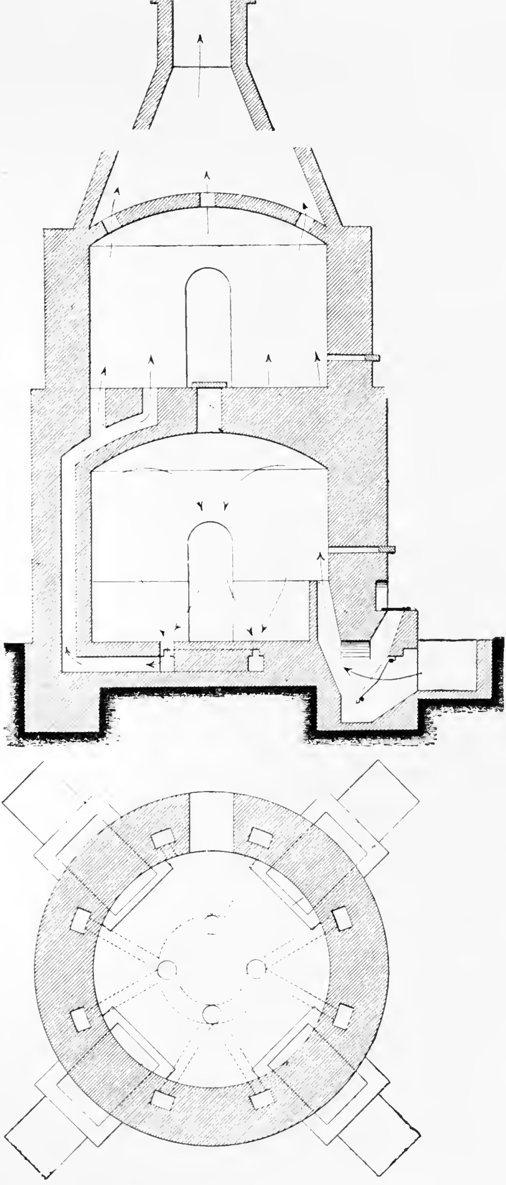

Fig. 152.—Round kiln with upper dome (Minton).

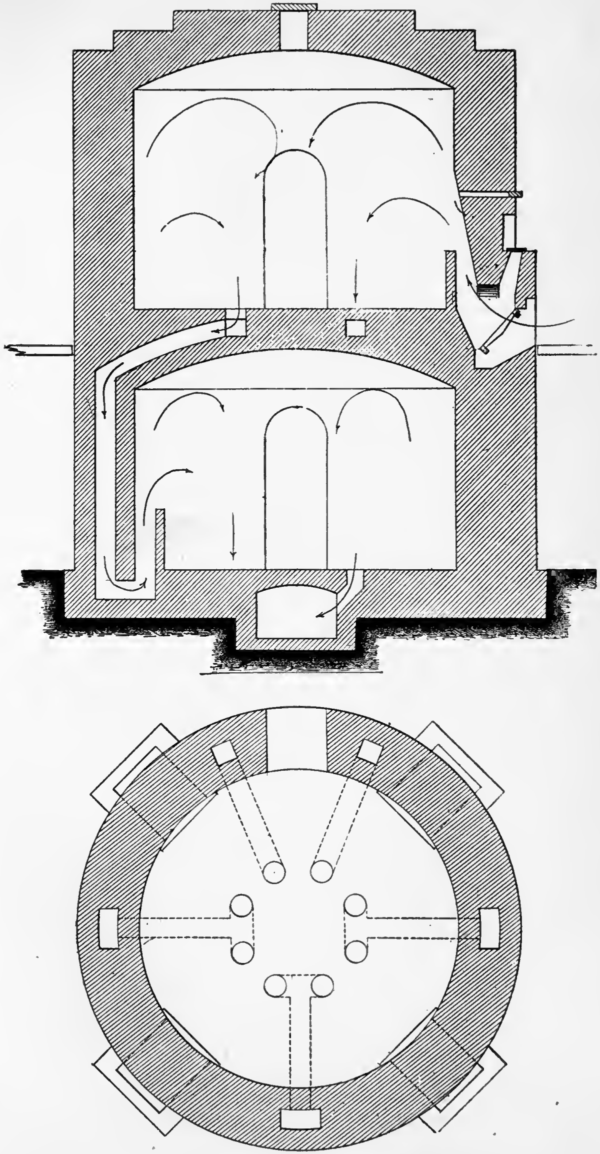

Fig. 153.—Round kiln with lower chamber.

Fig. 155 is a kiln with flames that ascend first and are then horizontal.

Fig. 156 is a kiln with descending flames which are more or less oblique.

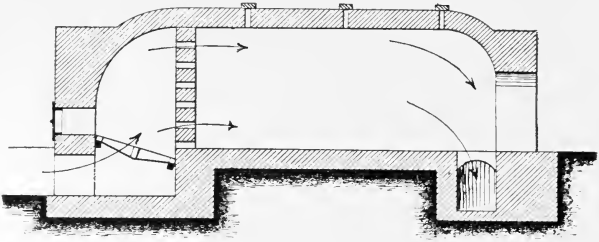

FIG. 154.—Cassel or Newcastle kiln.

All the kilns of this class are inconvenient, because either the kiln is short, the distribution of the heat fairly good but the utilization of it very bad; or else the kiln is long, the utilization of the heat better, although still very moderate, but the distribution is very bad.

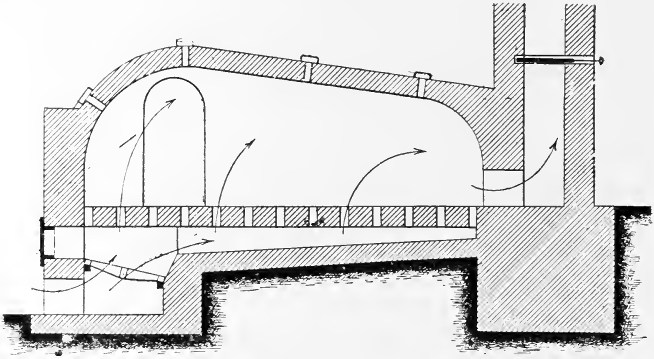

FIG. 155.

Before the invention of round kilns they were frequently used for high temperatures, but they ought now to be absolutely condemned.[1]

Continuous kilns with a single firing chamber can be obtained by two very different methods. Goods piled on carriers may travel

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[1] [Few users of Newcastle kilns would agree with the sweeping condemnation of a kiln which is remarkably successful in the North of England.—A. B. S.]

in a continuous or intermittent way past fixed fireplaces, or these fireplaces can be placed in the midst of stationary goods. The first method in spite of the numberless attempts has now been entirely abandoned.[1] Besides it is easier to see that it is much simpler to move the currents of gas than the very heavy goods, which are at a very high temperature.

In the second method, the fireplaces, even while in action, can either be moved about over the fixed goods, or else they can be spread about in the burning chamber, where they are lighted and then put out as required. The first arrangement (Barbier, 1855) has also been given up; so that only the second one remains.

The principle of burning with a continuous fire (Hoffman & Licht, 1858) is shown in elevation in Fig. 157. A circular burning chamber, A, having twelve doors for filling, B, communicates by means of twelve flues, C, which can be shut by valves or bell dampers, F, with a main flue which itself is connected with the central chimney, D. A movable damper, which completely shuts off the burning chamber, can be placed near each door; in the drawing it is shown by door No. 1. The space enclosed between two such consecutive dampers is called a chamber. The kiln shown has twelve chambers, each having a door, for filling, at one end, and a flue opening at the other.

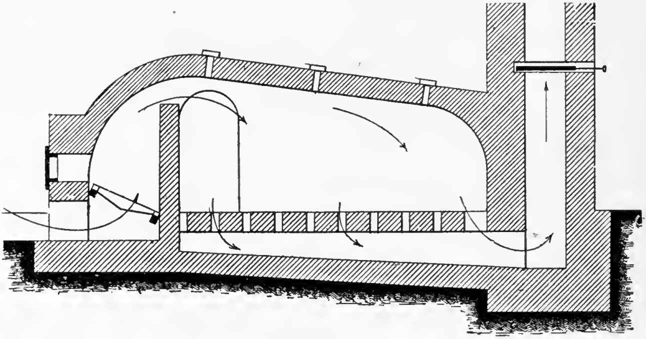

FIG. 156.

Supposing the kiln is working normally, chamber 1 being empty and 2 being filled through door No. 2; chambers 3, 4, 5 and 6 contain goods which are cooling; chambers 7 and 8 are being heated by the fire, and chambers 9, 10, 11 and 12 contain goods which are being gradually heated. The air necessary for combustion enters through door 2 (which alone is open, all the others being built up) and passes

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[1] Since Bourry wrote this statement this type of kiln has been revived successfully under the name "Tunnel kiln".—A. B. S.]

through the whole length of the burning chambers. It cools the burned goods in its progress, and arrives in the chambers which are being fired, having a temperature equal to that of the burning fuel. After having being used in combustion, it continues its progress, traversing the ware to be burned later, and, heating it in its progress, finally arrives at the last compartment of which the draught valve, F, is open (all others being closed) and goes thence into the chimney.

When the burning of the seventh chamber is finished, the damper between the twelfth and first is taken away, and put between the first, which has just been filled, and the second, which is empty. The bell damper of the first chamber is opened, while that of the second is shut, the door 3 is undone, and door 2 is built up; the different phases of the burning then go on in the same order, but have advanced one chamber. This is continued indefinitely, progressing at the rate of one to two chambers every twenty-four hours, the filling, emptying and burning being done continuously.

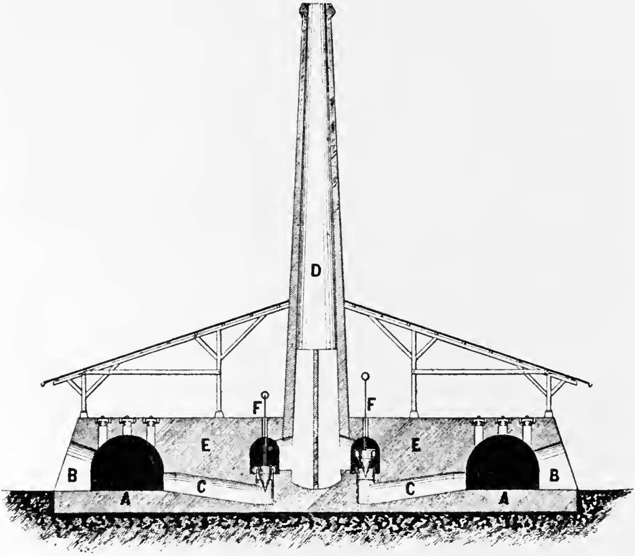

FIG. 157.—Section of circular Hoffman kiln.

The fire is started by building temporary fireplaces in some part of the burning gallery, and by this means the ware is sufficiently heated to ensure the fuel thrown in through the nearest heating shafts catching fire. These furnaces are kept going until the kiln has begun its normal working and are then broken down.

In kilns of this type the burning chamber was at first circular, as shown in Fig. 157; later, to secure economy of construction, they were given an oblong form (Hoffman, 1870), then a rectangular form, composed of two parallel galleries united by two flues of communication at the two ends (Bührer, Hamel, Simon). This shape, now almost the only one used, is shown in Fig. 158. The chimney is generally outside, as shown in the last figure. For small outputs different forms, such as zigzag, have been used; one of these is shown in Fig. 159, but except in special cases they are not to be recommended.[1]

The fuel is burnt in fireplaces formed amongst the goods as shown in Fig. 133. Coal is the usual fuel, but logs of wood may be used, or for burning more delicate ware, glazed brick, tiles, etc., gas firing may be employed. One form of gas burner which has given good results consists in introducing the gas through firebrick pipes, called "candles," as shown in Fig. 160 (Society of Schwandorf, 1875). These "candles" are pierced with numerous holes, forming burners, throwing the flames perpendicularly to the current of air. The pipes are connected to a movable iron pipe, which communicates with the gas main in the wall of the kiln. The gas is introduced simultaneously through several rows of candles, and the pipes are moved forward as the fire advances (see also Fig. 248).

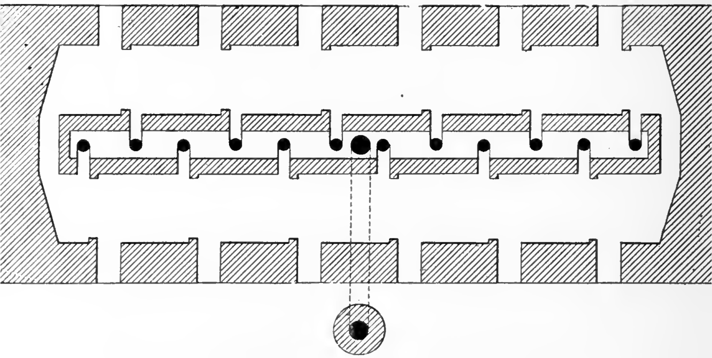

FIG. 158.—Plan of continuous kiln.

There is a second type of continuous kiln in which special furnaces are placed at regular intervals in the gallery. This gallery is divided by walls into a series of chambers from which the name of *chamber*

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[1] [With a kiln somewhat similar to that shown in Fig. 159 and a fan in place of the chimney, Bührer has obtained remarkable results in several works. Bourry's statement must therefore be taken with caution.—A. B. S.]

kiln has been given to it: historically, this is older than the preceding one (Arnold, 1839; Jolibois, 1852).

Kilns with partitions of this kind give the best results when heated with faggots; straw or other similar fuel is used for continuous burning. Fig. 161 shows one arrangement, the fuel being fed between two openwork walls, through an opening closed by a sheet of iron. Kilns of this type are also termed *channel kilns.*

When coal is used, the solid hearth of the kiln forming the fireplace may be replaced by a grate, the feeding of the fuel either being done through a side door or through openings in the crown, a certain quantity of air being admitted under the grate as well as through vertical channels built in the side walls of the burning chamber. Fig. 162 shows an arrangement of this kind, fairly often used for tile burning (Gilarddoni, Virollet[1]); the grates are 24 to 28 inches in width (see also Fig. 249).

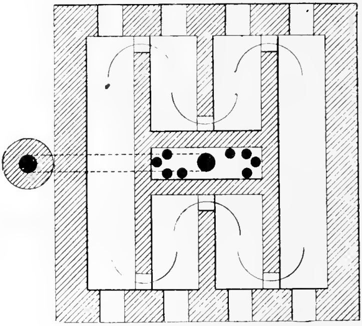

FIG. 159.—Zigzag continuous kiln.

Gas heating has also been used in chamber kilns by putting burners in the place of the grates or pipes as in Fig. 160. In continuous kilns, the first phase of the burning, known by the name of *smoking*, ought, in a normal way, to be done by the general circulation of the gases before they pass out to the chimney, but this method has serious inconveniences when the goods contain much water, as at the commencement of a firing of a new compartment the gases there are so cool that the steam they contain condenses on the ware. This softens the goods, and deposits of soluble salts are often formed on their surface. To prevent this trouble, each compartment should be independently heated to a temperature of about 120° C. before putting it into the general circuit. This is done in kilns of the first type by

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[[1] This kiln is known in Great Britain as the Belgian kiln, but the use of grates and partitions is also an important feature of the Dean-Hetherington and other well-known continuous kilns.—A. B. S.]

means of movable furnaces, placed against holes in the wickets or fitting into openings made in the roof for putting in the fuel. For very damp goods it is better to use fixed furnaces, built along the outside walls of the burning chamber, with flues under the bottom of the kiln. In chamber kilns the ordinary furnaces are used for this purpose.

The open kiln with no partitions or grates and with the fuel distributed among the goods is the most economical method of heating, but kilns with partitions are to be recommended for heating with wood (especially when in the form of faggots) and when it is desirable to burn exclusively such wares as would be spoiled by contact with the fuel. Gas heating also gives a satisfactory solution of the problem.

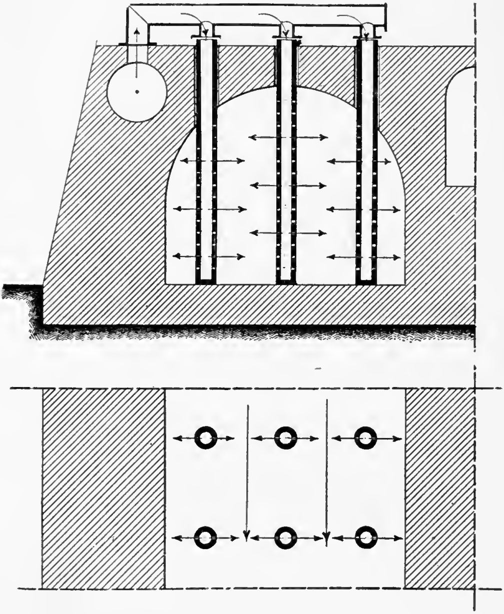

Fig. 160.—Gas-fired continuous kiln.

Continuous Kilns with Several Firing Chambers.—Burning in continuous kilns with only one burning chamber is very difficult when the ware is very delicate, especially for that which needs a high temperature, because it is not possible to regulate the composition of the atmosphere in the kiln, and because the horizontal direction of the gaseous current is not suitable or does not give a satisfactorily equal distribution of the temperature. In these cases it is better to use kilns that have several burning chambers which lead into one another.

Of this class of kiln there are three principal types:—

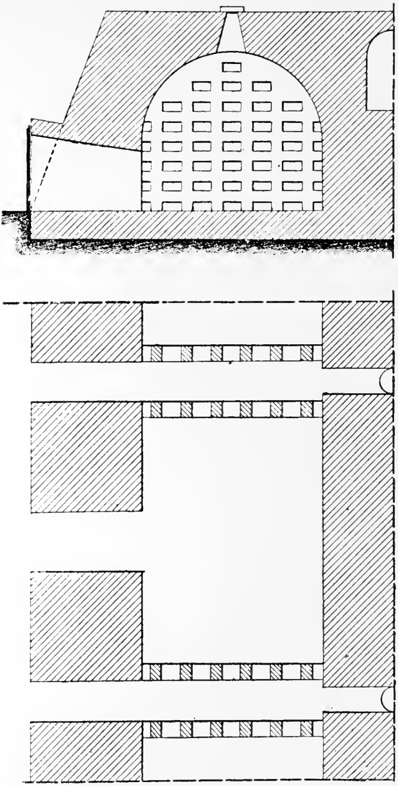

FIG. 161.—Channel kiln using faggots.

(1) *Kilns with a gallery for burning, divided into several chambers by means of partitions, intended to modify the direction of the gaseous current* (Fig. 163). In these a horizontal damper, A, permits the chambers to be isolated. The heating is done by one of the methods already mentioned (channels or troughs, grate-furnaces, gas burners,

etc.). The best distribution of the heat may be obtained more simply in single chamber kilns by suitable methods of setting the goods and by movable dampers.

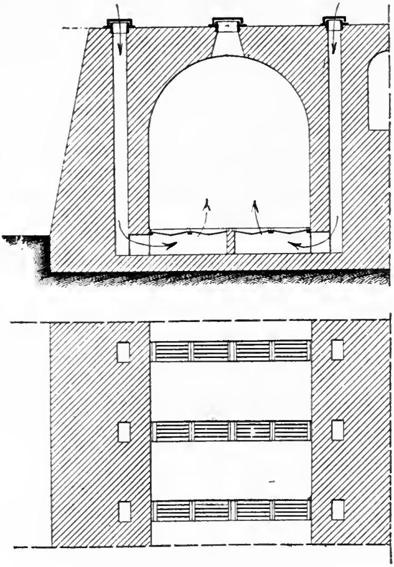

FIG. 162.—Continuous kiln with grate.

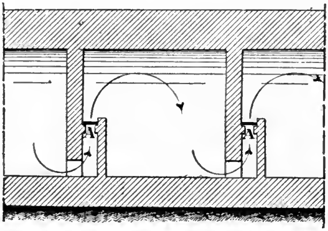

FIG. 163.—Chamber kiln.

(2) *Kilns with separate burning chambers, of which there are several varieties, usually of square or rectangular shape, placed side by side and grouped together, so as to form two parallel series, the outside chambers being joined together by two cross flues.*

Fig. 164 shows a longitudinal section of a kiln heated by coal, by means of four furnaces placed at the four corners of each chamber; the draught is formed by openings spaced regularly in the bottom, which communicate with the next chamber through a network of flues. A supply of outside air is brought into the chamber under fire, independently of the general circulation. (A detailed drawing of this kiln is shown on page 423.)

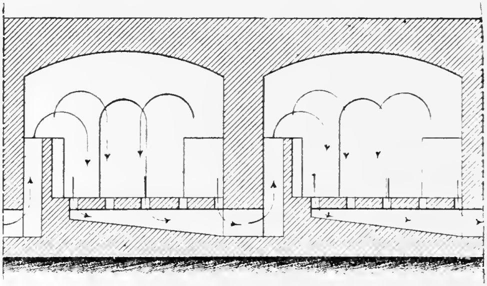

Fig. 164.—Chamber kiln.

Fig. 165 shows a kiln, heated by gas (Mendheim), with burners spread about the bottom; the air from the preceding chamber, coming through a series of lower flues, rises vertically to descend along the partition wall and goes into the next chamber. (A detailed drawing of this kiln is given on p. 415.)

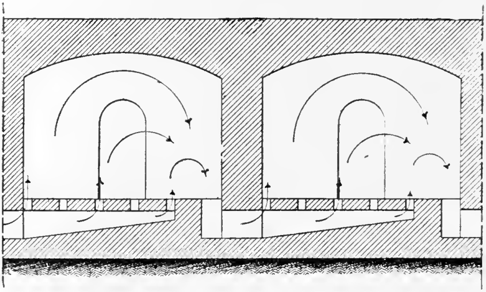

Fig. 165.—Chamber kiln.

Fig. 166 shows a kiln also heated by gas, which enters through burners in the crown, while the air, coming from the preceding chamber, ascends along the partition wall to descend again across the chamber and passes out by openings, spaced at regular intervals in the hearth, into the following chamber.[1]

(3) *Kilns with isolated burning chambers, each capable of being heated separately as an intermittent kiln, or capable of being united with the one before and the one after it.*—Several systems of this kind have been suggested, but have not been very successful because of their complications and the loss of heat in the flues.

Horizontal intermittent kilns with several fireplaces, often termed *semi-continuous* kilns, are really only portions of continuous kilns, a quarter, a third, or a half of a continuous kiln being constructed. The burning is naturally intermittent, but during the period of firing the working is almost the same as that of a continuous kiln.

Fig. 167 shows a kiln of this kind, taken from the type represented in Fig. 168. The fireplaces are at one end of the kiln while the communication with the chimney is at the other.

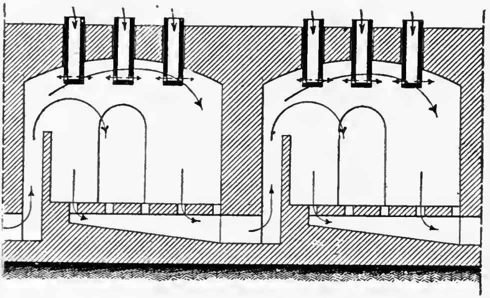

FIG. 166.—Chamber kiln.

These kilns are used when the output of a continuous kiln would be too great, as their transformation into a continuous kiln is easy. They ought, in any case, to be chosen in preference to intermittent horizontal kilns with one fireplace (p. 215).

In **muffle kilns** the flames and hot gases do not reach the goods as the space containing them is heated through outside walls, the heat being transmitted to the ware by conduction and radiation. This arrangement is used for burning wares which would be spoilt by contact with flame, and which cannot be conveniently placed in saggers. The great loss of heat which results from this method of transmission prevents muffle kilns from being used for firing wares which need a very high temperature. A temperature of 1400° C. in

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[1] [Many improvements in these types of kilns have been made in recent years in Great Britain, the most successful builders being Brown Patent Kiln Co., Dean Hetherington & Co., and Osman & Co. Numerous firms have also designed special modifications for their own use.—A. B. S.]

the interior of a large muffle is the highest that can be obtained in practice.

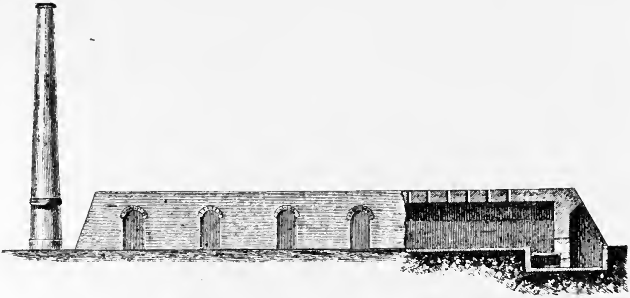

Fig. 167.—Semi-continuous kiln.

These kilns are generally arranged as shown in Fig. 168, the flames and gases circulating in the space between the outer walls and the muffle. The setting is done through a door in front, which is afterwards closed by a thin partition and a wall, having between them

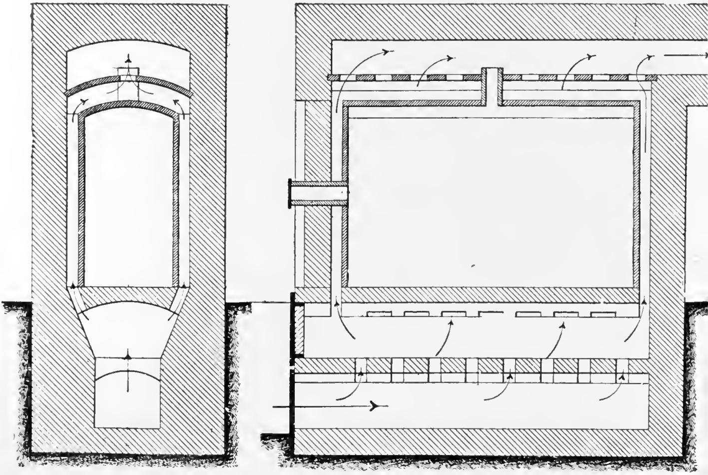

Fig. 168.—Muffle kiln.

a space to allow of the even heating of this part of the kiln. An air-hole in the upper part allows the exit of the expanded air from the muffle, and a trial hole allows the progress of the burning to be watched. The gases escape by an upper flue and pass into the chimney, which is usually connected with several kilns. The heating is done by means of fireplaces underneath (or at either end); wood or coal being used and gas burners but seldom. According to the ware to be burned, the size of the internal space varies from 2 feet to 3 feet 4 inches, the height from 2 feet to $6\frac{1}{2}$ feet, while the depth is only limited by the practical length that can be given to the fireplace.[1]

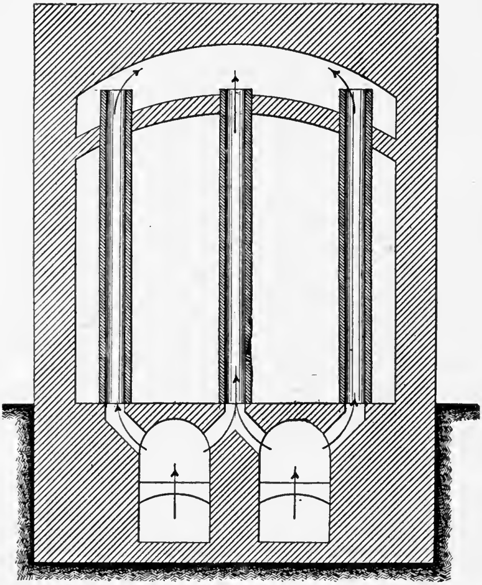

FIG. 169.—Muffle kiln.

A second type of muffle kiln, not often used, is shown in Fig. 169. In this the heating is done by vertical pipes, through which the flames pass. These pipes are arranged in parallel rows in groups.

To work continuously, two parallel series of muffles are built side by side in such a manner that the warm gases pass from one to the

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[[1] It is customary in the North of England to use muffle kilns for sanitary ware which have an internal length of 30 feet, an internal width of 10 to 12 feet, and an internal height of 6 to 8 feet.—A. B. S.]

other, the working being the same as that of the continuous kilns with several burning spaces. Gas heating in this case is preferable to coal.

Recuperators and Regenerators.—The best action of chimneys is obtained by a temperature slightly above 100° C., and if gases are passed out at a higher temperature, the excess of heat constitutes a loss, which may be lessened by using regenerators and recuperators.[1] These may be for intermittent or continuous working.

Intermittent regenerators (Siemens) are formed by two or more chambers, filled with bricks, placed between the kiln and the chimney. While passing through one of these chambers the gases yield up part of their heat to the bricks, until the temperature of the latter is so high that it is advisable to shut off the gases and to make them pass through a second space. The heat accumulated in the first can then be used for heating a current of air which is carried in an opposite direction to that of the preceding current of gas. Regenerators of this kind have been of great use in glass-making and metallurgy, but have not been much used in pottery, where continuous regenerators or recuperators are preferred to them.

These continuous recuperators differ in design, but are always composed of tubular firebricks or pipes placed in such a manner that they can pass through the gases coming from the fire in one direction and the air to be heated in another. Fig. 170 (Gaillard and Hallot) represents a tubular brick of this kind, and Fig. 171 shows the manner in which they are put together to form a continuous regenerator. The warm gases enter by A, and follow the path A B C D E, to pass into the chimney. The cold air enters by F, rises through the holes in the bricks, and passes out heated into another chamber, G. Stoppers allow of cleaning the horizontal channels. The difference in the temperature between the exit gases and the hot air is usually from 150° to 200° C. By making the recuperator large enough, the difference can be reduced to the heat required for the gases to pass up the chimney.

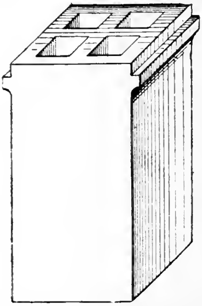

Fig. 170.—Regenerator brick.

Recuperators and regenerators can naturally only be used in pottery with kilns for intermittent firing, as continuous kilns give off gases with a temperature only sufficient to ensure the draught in the chimney. The air heated in the regenerators and recuperators can be used either for drying ware or raw materials, or for starting the heating of another kiln, or to supply the secondary air which is necessary for the combustion of gas in gas-fired kilns. They absorb a large quantity

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[1] [Care should be taken not to confuse these two terms. In regenerators the gases and the air to be heated may come into contact with each other, the same passages being used alternately for both. In recuperators, on the contrary, the gases and air are kept quite separate.—A. B. S.]

of heat before attaining their normal working, so that it may happen that they are only efficacious when the firing is nearly finished, i.e. when they are no longer needed.

Construction of Kilns.—In spite of the diversity in kilns used in the ceramic industry, there are certain general rules for construction which should be observed. The first condition which all kilns ought to fulfil is that they must *bear the temperature* to which they are subjected and also the action of the flames and gases from the fireplaces. It is usually sufficient to make the walls of the burning space of bricks having the same power of resistance to the fire as the goods burned in it. This does not apply to muffles or to the masonry near the fireplaces, as these have to resist the destructive action of the ashes and ought always to be made of good fire-bricks.

It is often more difficult to obtain materials that will well stand the action of a large number of successive heatings and coolings, but this question is discussed with the changes that take place in the special manufacture of fireclay goods in Chapter XI.

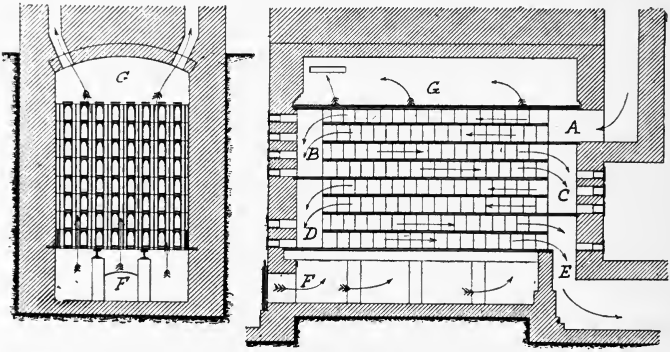

Fig. 171.—Regenerator.

The second condition that kilns ought to fulfil is to resist *the alteration of form* caused by the expansion of the masonry under the influence of heat. In fireclay ware of good quality this expansion is $\frac{1}{250}$ to $\frac{1}{200}$ at a temperature of 1000° C. It is greater in ordinary terra-cotta. The inner walls of the kiln, being more strongly heated, increase in volume during the burning and may force the outer walls, which do not expand, out of shape and crack them. This action has no serious consequence if, when the kiln has cooled, the cracks close up again and if all the masonry returns to its original shape, but it is another thing if the changes are permanent. With each new burning they then increase speedily, necessitating repairs which are always unsatisfactory and end by completely ruining the solidity of the kiln. These inconveniences are remedied either by strengthening the kiln, or by separating the inner walls from the outer ones. Round kilns are easily strengthened by means of iron hoops, tightened by wooden wedges or screws and, from this point of view, are to be preferred. Flat walls and angles are strengthened by upright iron or wooden supports, bedded in the ground at one end and joined at the top by iron tie-rods and bolts. The space between the inner and outer walls is filled with a layer of cinders or clean sand, the outer walls being arranged so that they naturally return to their original position if disturbed. This method is specially necessary in continuous kilns which by their large dimensions would, otherwise, require very costly reinforcements.

It is essential to avoid leakages of air as much as possible, as they interfere with the regular working of kilns. These may be caused by displacement of the masonry or by its porosity. Leaks are specially prevalent in flues, and it is best to avoid all complicated arrangements and all flues in projecting parts, such as vaults, where they are subject to great expansion, and all thin walls. Many kilns which, on paper, appear to be very ingenious give bad results at the end of a short time because all the flues leak and communicate with one another.

When the surface of the walls through which air may leak is large, it is necessary to prevent this leakage by a layer of cinders or fine sand spread between the masonry or by covering their outer surfaces with a "daub" or glaze. The kilns must be protected against damp, for many kilns work badly because, being built on damp or permeable ground, the water from the subsoil, drawn up by capillarity, cools the lower parts and prevents the burning of the ware in them, or forms steam and spoils the draught.

(3) WORKING OF THE KILNS.

General Remarks on the Working of Kilns.—Whatever may be the nature of the ware to be burned and the type of kiln employed, the burning includes five operations:—

(1) *The setting*, putting the ware into the kiln.

(2) *Smoking*, which consists in heating the ware to a temperature of about 120° C.

(3) *The burning proper*, which is most usually subdivided into slow firing, full fire, and annealing.

(4) *Cooling* the ware in the kiln.

(5) *Emptying* or drawing.

Three usual methods of setting are used, the choice of which depends on the nature of the ware.

For strong and not vitrified ware, which does not soften in burning, the goods are piled on one another in such a manner as to fill the kiln completely with the exception of the spaces necessary for the circulation of the flames and gases and to spread the heat uniformly. Fig. 133 shows one method of setting plain bricks in a continuous kiln and other examples may be found in the chapters relating to the special industries. This method of setting is applicable to most terra-cotta and to certain kinds of stoneware. The more fragile goods which usually need less heat are placed in the upper parts, which are further from the fireplaces. Open setting is only applicable to wares which do not suffer from contact with the flames, unless the burning is done in muffle kilns, which is less economical. Glazed goods can seldom be burned in the open unless they only partially cover the goods, and then only the unglazed surfaces may be in contact. They are usually burned in muffle "boxes" or saggers.

Setting with quarries or slabs is employed for fragile and vitrifiable wares, or those which are covered with glaze. This is done either in ordinary kilns or in muffles according as the ware can or cannot be exposed to the flames. Fig. 172 shows an example of this kind of setting in which A represents the walls of the kiln; B, small pillars of fireclay often made of bricks on thick slabs, and C, fireproof slabs. The latter are perforated in such a manner as to allow the gases to circulate. The goods rest on these slabs on an unglazed face. Setting in saggers is used for unglazed, non-vitrifiable ware, which suffers from the action of the flames, but which need not be burned in the muffle; for glazed wares, and for those which are liable to get out of shape by the combined action of heat and pressure.

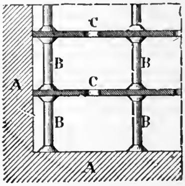

Fig. 172.—Setting in "cupboards".

Saggers are fireclay boxes of various shapes and dimensions, which are glazed inside when glazed goods are burned in them. They often have the form shown in Fig. 173, and are placed one on the other, in piles, with rolls or "wads" of thin fireclay between them. The latter serve at the same time to join them together and to make them firm. The diameter of the saggers varies according to the size of the objects; they are usually oval, but are sometimes square or rectangular.

Putting the ware in place in the saggers is called *placing* or setting. If the body is unglazed and non-vitrifiable, it is placed in the inside of the sagger, piled up; a fireclay slab from time to time is put inside the sagger (Fig. 173) to divide the pile into a series of cases, placed over one another so that the lower goods do not bear the whole charge. This arrangement is indispensable when the goods are of such a shape that they cannot be placed in a high pile.

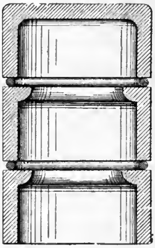

Fig. 173.—Saggers.

If the goods are covered with glaze they are stood upright on an unglazed part, but they cannot be piled, because the fusion of the glaze would make them stick together. In this case each sagger is shaped like the top one in Fig. 173, but inverted. Under certain conditions, it is sufficient to place small supports in holes in the sides of the saggers on which the object can rest. The sharp top of these supports prevents the glaze from adhering too much, and leaves, when burned, only a slight mark. In the same way, very light goods may be piled on one another by separating them with small fireclay pieces (stilts) which only come in contact with the ware at points, thus producing only a little prick on the glaze. In Chapter XII. are examples of the latter methods of placing, which are specially used for faience.

When the bodies soften in the kiln, the difficulties of setting are much greater because it is necessary to prevent them coming out misshapen.

The goods can no longer rest on spikes or points and each one must be set separately in a case formed on one side by saggers and on the other by other fireclay pieces of suitable shape. This method of setting, peculiar to porcelain, is described in more detail in Chapter XIV.

Having taken all the precautions needed for the special nature of the ware, and having arranged for the good circulation of the flames and gaseous currents, it is necessary—to economize fuel—to allow the largest possible quantity of air to enter the kiln.

Smoking, sometimes improperly called "stoving," is intended to evaporate the water contained in the body, the glaze, the pieces used in setting, and, finally, the walls of the kiln. It is finished when the interior of the kiln is at a uniform temperature of about 120° and when the gases passing to the chimney no longer contain steam other than that derived from fuel.

Smoking is very simple when the ware is thin and comparatively dry, but is much more delicate when the goods are thick and damp, as there must be evaporation without bubbling, so as to avoid steam being formed in the ware, which would make it split. At the same time, the steam given off from the goods near the fireplaces must be prevented from condensing on the ware farther off and still cool, or it will soon soften them and cause spots. For this purpose, the steam formed must be removed as quickly as possible—which is not always easy with kilns with down or horizontal draught, because the steam being lighter than air tends to accumulate in the top of the kiln. It is best to make as much use as possible of an up-draught for this operation. The fuel used should be dry, with a slow, regular combustion, and not much flame. Hard, dry wood and coke give the best results. The proportion of air entering the kiln should be large and gradually reduced as the temperature increases, but the object of this heating should always be to obtain moderately warm air, and not to raise the temperature of the kiln.

To determine the extent of the smoking, mercury thermometers graduated to 200° C. or 250° C. are used, and iron rods which are plunged through the trial holes into the different parts of the kiln and are drawn out again at the end of some moments. The height of the temperature shows the progress of the heating, and the drops of moisture which settle on the cold iron rods allow the proportion of moisture in the corresponding part of the kiln to be ascertained. It is only when the rods come quite dry out of the trial holes which are furthest from the fireplaces that the smoking may be considered as finished.

Firing Proper.—This operation lasts from the end of the smoking to the moment when the ware has reached the highest temperature to which it has to be subjected. It may be divided into three stages which are more or less distinct:—

Slow firing in which the temperature rises to about 500° C. until the true clay (hydrosilicate of alumina) is decomposed. This stage needs a slow and gradual heating.

Full fire, beginning at 500° C. till it reaches that of the finishing and is characterized by a quicker and sharper heating.

Lastly, *annealing*, a state of variable duration, according to the thickness of the ware and the method of setting. During this period the necessary temperature having been reached, it should be maintained until the ware has been evenly heated throughout.

The manner in which the firing is done depends entirely upon the nature of the ware, the type of the kiln used, the method of heating, and on the quality of the fuel. Some remarks on this subject have already been given in the first paragraph of this chapter; others will be found *à propos* of the different special industries; but it is necessary to study in greater detail the composition of the atmosphere of kilns, the measurement of the draught and that of the temperature.

The Atmosphere in the Kilns.—The influence that is exerted on the burning of the bodies and glazes by the composition of the atmosphere of the kilns has already been mentioned (p. 184). This atmosphere is *oxidizing* when the combustion takes place in an excess of air in which there is, consequently, some free oxygen. The normal composition of air is 21 per cent of oxygen and 79 per cent of nitrogen by volume or 23 per cent of oxygen to 77 per cent of nitrogen by weight. Consequently, if in the gases passing out of the kiln there remains 10·5 per cent of oxygen by volume or 11·5 per cent by weight, then the combustion has been carried on with a quantity of air double that strictly necessary. This proportion corresponds to the most oxidizing working employed in pottery kilns.

The atmosphere is *neutral* when it contains neither oxygen nor combustible gases, and in this case would contain about 21 volumes of carbon dioxide to every 79 of nitrogen, if pure carbon were used as fuel, but as there are always hydrogen or hydrocarbons, the combustion of which produces steam, and traces of oxygen and carbon monoxide are always present, the proportion of carbon dioxide seldom rises above 18 or 19 per cent.

The atmosphere is *reducing* when there is an excess of combustible gases, carbon monoxide, hydrogen or hydrocarbons; when all the oxygen has disappeared and the proportion of carbonic acid gas is below the limit just mentioned.

The composition of the atmosphere in the kilns depends on the arrangement of the fire, the nature and method of feeding the fuel, and, finally, on the draught. An oxidizing atmosphere can easily be obtained in all fireplaces by putting on comparatively little fuel and using a strong draught, thus introducing plenty of air. On the contrary, a decidedly reducing working needs a thick layer of fuel, a small draught and a small quantity of air; only furnace fireplaces and gas heating can produce it with a normal working.

By referring to the fireplaces shown in Figs. 130, 131, 133, 134 and 135, it can easily be seen that periodical addition of fuel each time lowers the working of the fire, as after each charge there is a considerable evolution of combustible gases which are only partially burnt, as may be seen by the black or brown colour of the smoke. After several moments the combustion becomes complete, and air is in excess, until a time when the new charge causes the same disturbance. A very methodical heating, with stokings at very short intervals, as in kilns with continuous firing, decreases these irregularities without getting rid of them. In order that fireplaces of this kind may work well, they should be worked oxidizing and only allowed to become neutral or even reducing for a few moments after each charging.

It is different with fire-boxes (Figs. 132, 138, 139, 140), the feeding of which ought, when well done, to cause only slight changes in the kiln atmosphere. This is more affected by the periodical cleaning of the grates, which, by reducing the resistance to the circulation of the gases, gives a constant draught, and causes a variation in the weight of air entering the fire. But as the clearings are less frequent than the feeding it is usually possible to avoid clearing them during certain periods of the burning. In fire-boxes it is easier to regulate the thickness of the layer of fuel, and, consequently, the composition of the atmosphere of the kiln. The thickness of the layer of fuel suitable for the different stages of firing depends on the nature of the fuel, its size and the proportion of ashes and clinker in it. The larger the pieces and the purer the fuel, the thicker should be the layer. A medium coal with a thickness of 12 to 16 inches gives a neutral atmosphere, a less thickness makes it oxidizing, while with a greater one it becomes reducing.

Gas heating gives a regular composition to the atmosphere of the kiln and one easily regulated, but only when the working of the gas generators is itself very regular.

It is impossible to obtain during the whole of the burning, or even during a long space of time, an absolutely regular atmosphere, and all that is possible is to reduce the errors to the narrowest limits.

If the temperature of the burning is low or medium, it is easy enough to manage the heating with a decidedly oxidizing or reducing working, but if a high temperature is required the introduction of a large excess of air, or an incomplete combustion, lowers the temperature of the gases passing out of the fires and it becomes almost neutral and does not leave more oxygen or combustible gases than are strictly necessary to act upon the iron oxides.

Another consideration which necessitates a neutral atmosphere is the necessity of making the flames of a sufficient height to reach right across the kiln. When a large excess of air is used, the flames are made shorter than if the proportion of air were that strictly necessary. In that case the combustion is only due to the burning of the gases circulating in the middle of the charge, and the temperature more easily becomes uniform. A final point of importance when using saggers is the various speeds with which the different gases can pass through a wall of fireclay. If the speed of the diffusion of air is 1, oxygen has only a speed of 0·949, combustible gases and hydrogen have 3·800, carbon monoxide 1·015, saturated hydrocarbons 1·344, and unsaturated hydrocarbons 1·019. Hence the atmosphere inside saggers tends to be more reducing than that in the kiln proper.

Analysis of the Gases.—The determination of the composition of the atmosphere of a kiln may be made by direct observation of the flames and gases passing out of the chimney, by chemical analysis and by measuring their density.

However primitive and uncertain the method of direct observation may be, it is, except in certain special cases, the only one commonly used. It is based on the following signs: when the flames are short, brilliant, with clearly marked edges, and when their extremity ends in a recognized point, the atmosphere is oxidizing. If, on the contrary, they are long, cloudy, with uncertain edges, their extremity dying out and followed by a smoky ending, the atmosphere is reducing. If the gases passing out of the chimney have a bluish or black colour, but only at the time of stoking, it is a sign that the combustion is moderately complete. If, on the contrary, the colour is constantly yellow or red, with a black colouring after the stoking, the combustion is incomplete.

These observations suffice for most practical purposes; but not when an atmosphere of specified composition is required at certain moments of the burning. Chemical analysis must then be employed. For this purpose the Orsat apparatus is used, or that shown in Fig. 174 (Coquillon) which is based on it. A graduated glass tube *m*, or measurer, surrounded by water to keep the temperature constant, is divided into 100 cubic centimetres; in the lower part, of a lesser diameter, the graduation is made in tenths of a cubic centimetre. An indiarubber tube connects the apparatus to a bottle containing water. The top of the tube is connected to a capillary tube R, fitted with a tube *t*, at one end for the introduction of the gas, at the other with a bell E, and also communicating with four receptacles: P , containing potash; P, pyrogallate; C, cupric chloride, and B, a burner surmounting the bell C'. All the connexions with tube R being closed, the measurer, *m*, is filled with water by raising the flask; then after having placed the tube, *t*, in connexion with the gas to be analysed, the bottle is lowered again, so as to fill the measure exactly with 100 cubic centimetres of gas. After having closed the tube, *t*, the communication with the receptacle P^1 is opened, into which the gas is forced by raising the flask. In a few moments the gas is passed back into the measurer by again lowering the flask, and the new volume is read on the graduated scale, the difference showing the proportion of carbon dioxide. The analysis is continued in the same way by making the gas pass into the reservoir P, which absorbs the oxygen; into C, which takes out the carbon monoxide; into E, in which are added some drops of bromine, to retain the unsaturated hydrocarbons; and lastly into B, where, by the addition of a definite quantity of oxygen, the hydrogen and saturated hydrocarbons are fired by an electric current. The volume of carbonic acid gas produced and afterwards absorbed in the receptacle P indicates the proportion of hydrocarbons, and the reduction in volume shows the proportion of hydrogen. The remaining gas is nitrogen.

This method of analysis, when applied to the combustible gases produced in gas generators, shows accurately the composition of the gas manufactured. For the combustion gases it is usually simplified by merely determining the proportion of carbon-dioxide, oxygen and carbon-monoxide. Except for scientific research, this shortened analysis is preferable, as it can be done in a few minutes; and the variations in the composition shown by the gases during the progress of a burning make a lengthy analysis delusive. The latter is only made with continuous kilns in regular work, three or four short consecutive analyses being preferable to the results of a single one.

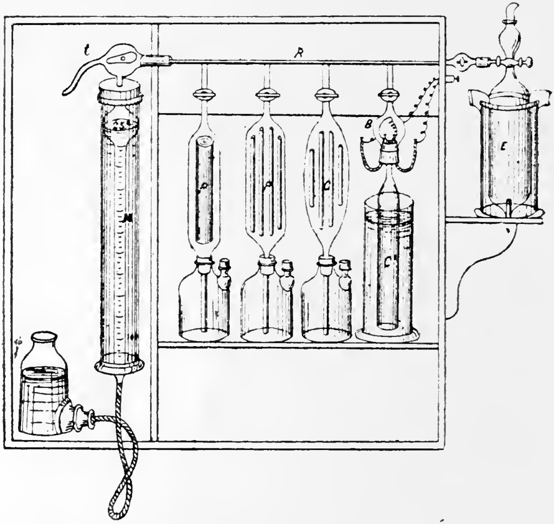

FIG. 174.—Apparatus for gas analysis.

The density of carbon-dioxide is considerably greater than that of air (1·529); by measuring the density of the gases of combustion it is possible to reckon, indirectly, the proportion of carbon-dioxide they contain, and consequently to deduce the composition of the atmosphere inside the kilns. Two forms of apparatus have been invented on this principle, which show the proportion of carbonic acid continuously on a dial. They are so extremely sensitive that the least dust or the slightest impurity in the gases makes the result false, and so they are only applicable to kilns with a constantly oxidizing atmosphere, because all combustible gases being lighter than air it is impossible to draw any conclusion from the density of the gaseous mixture in which they are found, even in a small proportion.

Measuring the Draught.—The draught is regulated according to the desired intensity of the fire, the length of the flames and the composition of the atmosphere. Direct observation is usually sufficient to enable practical men to regulate the position of the dampers, but it is advisable to measure the draught caused by the chimney, as the results thus obtained make it easier to carry out later burnings.

The different gauges used for measuring draught are very simple; all give good results, but the apparatus shown in Fig. 175 is the one usually preferred. It is composed of two flasks, each with an area ten times as large as the U tube joining them. One flask is connected by an india-rubber tube and iron pipe to the part of the kiln where the measurement of the draught is desired and the other is open to the atmosphere. They are filled with two liquids, chosen in such a way that they do not act on one another, and having densities sufficiently at variance not to mix together, for example, water and phenol coloured black. They are so arranged that the surface of the separation of the liquids is opposite the zero of a scale, the position of which can be altered to suit. The depression in one of the flasks causes a difference of level which is multiplied by 10 in the U tube, so that the draught measured by a difference in height in millimetres of water is shown as centimetres on the graduated scale.

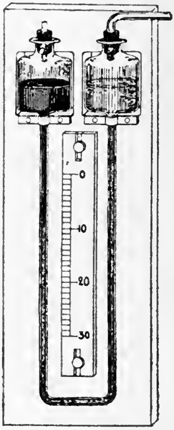

Fig. 175.—Draught gauge.

The iron or copper tube to which the gauge is connected is usually put into the kiln between the burning space and the damper.

Measuring the Temperature.—The temperature of the kilns may be observed by the eye, according to the colour of the ware or the walls of the kiln. The figures in the following table, due to Poillet, are generally adopted.[1]

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[1] These results are too high; the orange tints appear after 1000° C. and the white ones after 1200° C. It is wiser, therefore, to go only by the colour noticed and not by the temperature, according to Poillet's table.

	Degrees C.
Red—just visible	525
Red, dark	700
Cherry red—just visible	800
Red—clearly visible	900
Red, bright	1000
Orange, dark	1100
Orange, bright	1200
White, bright	1300
White, dull	1400
White, shining	1500

In order to be accurate, the observer should first be in the dark so that his eye may not be influenced by the varying brightness of the sun's light. The tint of the inside of the kiln can then be easily recognized, if the atmosphere is not too disturbed, but is more difficult with a reducing atmosphere. The brightness of the flames, which are white when hydrocarbons are burning, and blue when produced by carbon-dioxide or hydrogen, is also disturbing to an inexperienced eye.

In kilns set open, the advance of the burning can also be reckoned by the shrinkage, or by the extent to which the height of the goods in the kiln has been lowered. This does not measure the temperature, but only shows whether a certain degree of burning (heat effect) has been reached. The shrinkage is measured with an iron rod, on which is marked the distance between a fixed point in the kiln and the upper part of the ware.

For all pottery needing more exact firing, *pyroscopes* are used to determine whether the temperature necessary for the burning has been reached. *Tests* or *trials* are used for this purpose; these consist of specimens of the body, covered, when needed, with glaze, which are put into the kiln and are drawn out through special sight holes during the burning to find out whether the body has attained the suitable hardness or colouring, or to see whether the glaze has vitrified. When the last test taken out has proved that the burning has reached the desired state, it is still necessary to continue the firing for a certain time, regulated by experience, so that the goods (which are usually thicker or more protected by the tests) may reach the same degree of heating.

Certain metals may be put in the kiln instead of clay test pieces; these melt and volatilize at specified temperatures. The following table shows the metals which can be used and the temperatures corresponding with their change of state :—

FUSION POINTS.

	Degrees C.
Tin	233
Lead	325
Zinc	433
Aluminium	625
Zinc (volatilization)	930
Silver	954
Gold	1045

	Degrees C.
Copper	1054
White pig-iron	1130
Grey pig-iron	1220
Nickel	1410
Palladium	1500
Platinum	1775

The layer of oxide formed usually falsifies the results, and it is preferable to replace them by pyrometric tests, such as those devised by Seger, who made a series of pieces, the composition of which, as well as their order number, is shown in the Table on p. 242. In this table

Na^2O represents one molecule of soda.
PbO „ „ „ „ plumbic oxide.
Al^2O^3 „ „ „ „ alumina.
CaO „ „ „ „ lime.
Fe^2O_3 „ „ „ „ peroxide of iron.
K^2O „ „ „ „ potash.
SiO^2 „ „ „ „ silica.
Bo^2O^3 „ „ „ „ boracic acid.

The following are the numbers of tests generally used in pottery:—

	Seger Cone
Muffle firing for decoration	022 to 010
Burning fusible bodies	015 „ 01
Burning slightly fusible bodies	1 „ 10
Stoneware burning	5 „ 10
Burning body for fine faience	3 „ 10
Burning glaze for fine faience	010 „ 01
Burning fireclay ware and porcelain	10 „ 20

Cones 20 to 36 are only used in experiments on fusibility.

The mixtures composed as in the table on p. 242 are moulded into the form of the largest prism shown in Fig. 176.

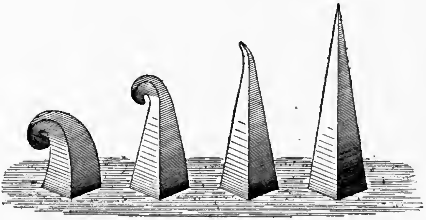

Fig. 176.—Seger cones.

This illustration shows the manner in which, under the influence of heat, the prisms diminish in size and bend over before melting. For a first measurement of temperature, a series of cones must be placed in the kiln opposite a sight hole; when the heat of the burn-

Order No.	Composition of Seger Cones.[1]					
022	0·5 Na^2O	0·5 PbO	0·0 Al^2O^3	2·0 SiO^2	1 Bo^2O^3	
021	,,	,,	0·1 ,,	2·2 ,,	,,	
020	,,	,,	0·2 ,,	2·4 ,,	,,	
019	,,	,,	0·3 ,,	2·6 ,,	,,	
018	,,	,,	0·4 ,,	2·8 ,,	,,	
017	,,	,,	0·5 ,,	3·0 ,,	,,	
016	,,	,,	0·55 ,,	3·1 ,,	,,	
015	,,	,,	0·6 ,,	3·2 ,,	,,	
014	,,	,,	0·65 ,,	3·3 ,,	,,	
013	,,	,,	0·7 ,,	3·4 ,,	,,	
012	,,	,,	0·75 ,,	3·5 ,,	,,	
011	,,	,,	0·8 ,,	3·6 ,,	,,	
010	0·3 K^2O	0·7 CaO	0·2 Fe^2O^3	0·3 Al^2O^3	3·50 SiO^2	0·5 Bo^2O^3
09	,,	,,	,,	,,	3·55 ,,	0·45 ,,
08	,,	,,	,,	,,	3·60 ,,	0·40 ,,
07	,,	,,	,,	,,	3·65 ,,	0·35 ,,
06	,,	,,	,,	,,	3·70 ,,	0·30 ,,
05	,,	,,	,,	,,	3·75 ,,	0·25 ,,
04	,,	,,	,,	,,	3·80 ,,	0·20 ,,
03	,,	,,	,,	,,	3·85 ,,	0·15 ,,
02	,,	,,	,,	,,	3·90 ,,	0·10 ,,
01	,,	,,	,,	,,	3·95 ,,	0·05 ,,
1	,,	,,	,,	,,	4·00 ,,	
2	,,	,,	0·1 ,,	0·4 ,,		
3	,,	,,	0·05 ,,	0·45 ,,		
4	,,	,,	0·5 Al^2O^3	4 SiO^2		
5	,,	,,	0·5 ,,	5 ,,		
6	,,	,,	0·6 ,,	6 ,,		
7	,,	,,	0·7 ,,	7 ,,		
8	,,	,,	0·8 ,,	8 ,,		
9	,,	,,	0·9 ,,	9 ,,		
10	,,	,,	1·0 ,,	10 ,,		
11	,,	,,	1·2 ,,	12 ,,		
12	,,	,,	1·4 ,,	14 ,,		
13	,,	,,	1·6 ,,	16 ,,		
14	,,	,,	1·8 ,,	18 ,,		
15	,,	,,	2·1 ,,	21 ,,		
16	,,	,,	2·4 ,,	24 ,,		
17	,,	,,	2·7 ,,	27 ,,		
18	,,	,,	3·1 ,,	31 ,,		
19	,,	,,	3·5 ,,	35 ,,		
20	,,	,,	3·9 ,,	39 ,,		
21	,,	,,	4·4 ,,	44 ,,		
22	,,	,,	4·9 ,,	49 ,,		
23	,,	,,	5·4 ,,	54 ,,		
24	,,	,,	6·0 ,,	60 ,,		
25	,,	,,	6·6 ,,	66 ,,		
26	,,	,,	7·2 ,,	72 ,,		
27	,,	,,	20·0 ,,	200 ,,		
28	1 Al^2O^3	10 SiO^2				
29	,,	8 ,,				
30	,,	6 ,,				
31	,,	5 ,,				
32	,,	4 ,,				
33	,,	3 ,,				
34	,,	2·5 ,,				
35	,,	2 ,,	pure China clay with traces of alkali			
36	,,	2 ,,	pure clay			

[[1] In 1909 the composition of some of these mixtures (Nos. 015 to 6) was altered slightly and some (Nos. 21 and 25) were omitted from the series.—A. B. S.]

ing that is suitable has been reached, the number of the cone which has begun to bend over is observed, the following one being still unbent. This having been determined once for all, it is sufficient to use the three nearest cones to regulate the highest temperature in subsequent burnings. Cones can be prepared by following the compositions in the table, and afterwards comparing them with the normal tests by Seger, or they may (preferably) be purchased ready for use.

Pyrometers are much less frequently used in pottery than are cones and trials.

Wedgwood's pyrometer, based upon the shrinkage of the clay, is seldom used because of its lack of exactness.

The water pyrometer by de Saintignon consists entirely of an iron tube put in the kiln, through which a current of water, having sufficient velocity to prevent evaporation, flows. The difference in temperature between the water entering and coming out of the kiln, as measured by thermometers, indicates the temperature of the kiln. This apparatus when well regulated may be of service but is somewhat costly.

In the *actinometric pyrometer* by Latarche a mercurial thermometer outside the kiln receives the radiation of part of the interior. It is placed in a metallic tube surrounded by a reservoir of water which is kept boiling by the heat of the kiln. A certain ratio is said to exist between the temperature shown by the thermometer and that of the kiln.

Siemen's *electric pyrometer* is based upon the difference in resistance offered to an electric current by a platinum wire, this varying according to its temperature. This delicate apparatus, which is easily disarranged, is chiefly suitable for scientific researches on firing.[1]

In the *thermo-electric pyrometer* by Le Chatelier an electric current, varying in strength, which is produced by heating a couple formed of a platinum wire and a wire of an alloy of platinum with about 10 per cent of iridium or rhodium, is measured by an aperiodic galvanometer, the deviations of which are noted by means of a Poggendorf reflector. The couple must be fixed in that part of the kiln of which it is desired to measure the temperature, care being taken that there is no movement of air around the wires; the galvanometer must be put in an isolated position. This type of pyrometer gives most accurate results.[1]

The *pyrometric telescope* by Mesure and Nouel is a portable apparatus, shown in Fig. 177, with which an object placed in the kiln can be seen. It is based on the phenomena of rotatory polarization of light. The luminous ray entering by A, crosses two Nicol prisms, P and A, which are separated by a quartz disc, Q, before arriving at the observer's eye placed against the object glass, O. The colour seen varies according to the intensity of the luminous source; by turning the eye-piece in the direction of the graduation of the circle, C, a certain position of the prisms is found at which the colour passes rapidly from green to red, with an intermediate position at which there is a dirty citron shade. The measuring of the temperature is determined

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[[1] The use of electrical pyrometers in potteries has greatly increased during the past few years. Those made by the Cambridge Scientific Instrument Co. Ltd. are the most popular.—A. B. S.]

by the number of degrees that the eye-piece has been turned, starting with the zero of the apparatus until the moment when this shade disappears. This telescope may be put into the hands of a fireman and is of great use in regulating the upward rise of the temperature, the trials on the other hand showing when the maximum heat effect has been reached.

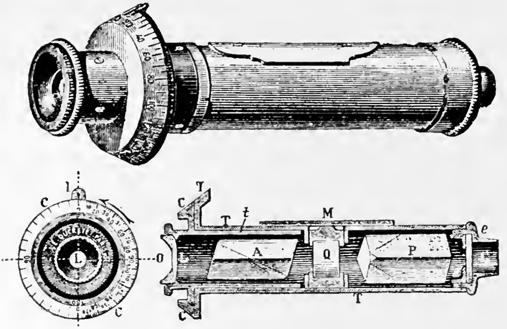


Fig. 177.—Pyroscope.

The *optical pyrometer* by Le Chatelier is based on the comparison of the light emitted by a definite part of the kiln with the flame of a standard lamp; Fig. 178 shows the arrangement. The lamp, L, gives out luminous rays which are reflected by the mirror, M, and perceived by the eye, placed at the eye-piece, O. On the other hand, the rays coming from the kiln through the opening, A, are also perceived there, the two images being side by side and thus easily compared. Their intensity is equalized by inserting darkened glasses, B, and by reducing the opening of the diaphragm, C. To make the observation easier, a red glass, D, is placed before the object in such a manner as to allow only monochromatic rays to pass. The apparatus is calibrated by aiming it at a small palladium globe, soldered on to a thermo-electric couple.

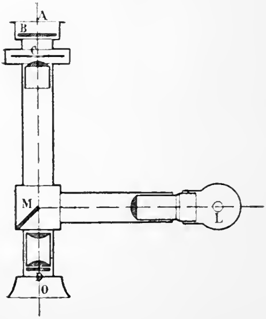


Fig. 178.—Le Chatelier pyroscope.

Optical pyrometers do not readily get out of order, and give results which are comparable; but the observer must be careful that the rays emitted by the object looked at in the interior of the kiln do not encounter gases or flames which would falsify the results.[1]

Cooling and Emptying.—When the maximum temperature has been reached and it has been kept up long enough to accomplish the annealing, the ware must be allowed to cool until the kiln can be emptied. If the cooling may be done in an oxidizing atmosphere it can be hastened by continually allowing a current of air to pass into the kiln. This air may be used for heating other ware, or may escape by the chimney or through openings in the top of the kiln.

If, on the contrary, the atmosphere must be kept reducing, all circulation is stopped and the cooling is only accomplished by radiation from the walls of the kiln. In this case it is sufficient to keep the kiln sealed up until the composition of the atmosphere will no longer affect the colouring, i.e. until the glazes have solidified or the bodies have a temperature below dark red. After this, the cooling may be hastened as in the preceding case. The same precautions must be taken as in heating, so as to avoid a too sudden or uneven cooling which would make the ware split. When the goods are nearly cold it is specially advisable to be prudent and to avoid undue haste in taking them out.

Emptying is the last operation in firing. It is a very simple one, although often very difficult because of the heat; it does not need any special description.

The thermic yield of a kiln is determined from the relation of the heat really used to burn the ware and that produced by the combustion. If c be the number of calories really used, and C the number of calories produced in the kilns, the relation $\frac{c}{C}$ represents the yield of the kiln, and $\frac{C - c}{C}$ the proportion of heat lost.

Although this definition is simple, the calculations and observations which have to be made to find the value of c and C are difficult. It is best first to try and find the value of c, and then to take account of all the loss of heat. The sum of all the amounts thus obtained gives the number of calories C, this being also determined independently by multiplying the weight of fuel used by its calorific power.

The number of calories theoretically necessary to burn a definite weight of pottery may be reckoned as follows. To the heat necessary for raising this weight of pottery to the maximum temperature T must be added that absorbed by the evaporation of moisture, by the decomposition of the hydrosilicate of alumina and the breaking up of the carbonates. On the other hand, the formation of silicates is accompanied by an evolution of heat. As the heat evolved or absorbed by the formation or decomposition of the silicates has not yet been determined, it may be assumed that these two phenomena counteract one another.

[[1] The Fery pyrometer is similar to that shown in Fig. 178, but instead of it being entirely optical, the heat rays are received on a thermo couple and the current produced is measured by a galvanometer. This instrument is quite satisfactory for most pottery purposes, but it is somewhat delicate.—A. B. S.]

The heat used to raise from 0° to T° 1 kilogramme of burned ware is equal to 0·2T assuming the specific heat of pottery to be 0·2. As T varies from 800 to 1375, the value of 0·2T is from 160 to 275 calories.

If the quantity of water contained in the *dry* body is a per cent, the heat necessary to evaporate it at 500° C. is

$$\frac{a}{100 - a}[606 \cdot 5 + (0 \cdot 305 \times 500)].$$

a, at its maximum, is equal to 13·9, which corresponds to 122·5 calories.

The moisture at b per cent gives about

$$\frac{b}{100 - b}[606 \cdot 5 + (0 \cdot 305 \times 100)] \text{ calories.}$$

If b varies from 4 to 6 per cent this gives 26·5 to 40·7 calories. Thus 1 kilogramme of burned ware needs, theoretically, a maximum of 445 calories for burning it, and this amount may be as low as 245 calories for fusible bodies. If carbonate of lime enters into the composition, it would be necessary to add to these numbers $\frac{21 \cdot 7 \times n}{100}$ calories, n being the proportion of carbonate in the body (Berthelot); but this amount, being small, may be neglected.

The causes of loss of heat may be divided into six parts :—

(1) Loss due to saggers, supports, etc., used in setting. The weight of the accessories thus used in setting 1 kilogramme of burned ware, multiplied by 0·2 × T, gives the number of calories lost. In certain kinds of ware, the weight set sometimes does not amount to a fifth part of the total weight of the contents of the kiln. This remark shows the advantage, which is considerable from a thermic point of view, of setting goods open, and of avoiding saggers when it is possible to do so.

(2) Loss due to the heating of the walls of the kiln. All the inside walls of the kiln have to be heated for a thickness of 15 to 25 centimetres, according to the temperature of the burning, to a temperature equal to that of the ware. This loss is found by multiplying, as before, the weight of the masonry heated by 0·2T. From this point of view the most economical kilns are those which offer the maximum space for goods for a minimum of walls. This condition is best fulfilled by round kilns and continuous kilns without partitions; but in continuous kilns with several chambers this loss may become large enough to outweigh the advantages gained by the continuity of the burning.

(3) Loss due to radiation from the outer walls of the kiln is most difficult to reckon and should be the subject of direct observation. In well-built kilns, with thick walls, it may not reach 10 per cent; in others it rises to 25 per cent. It increases with the exterior surface of the walls, and is produced particularly in the top part of the kilns, especially near the crowns.

(4) Heat lost in gases passing up the chimney can only be accurately determined by determining their volume and temperature

at frequent intervals by anemometers and thermometers. As the former work badly in hot gases containing coal dust it is preferable to calculate the volume of gases from the weight of fuel burnt and from their chemical analysis. When these gases have a temperature below 200° C. the heat in them is indispensable to the working of the kiln, so that it is only when their temperature rises above this that there is any real loss.

An oxidizing atmosphere, by increasing the volume of the circulating gases, also increases the loss of heat, especially in intermittent kilns, but it is often necessary to obtain certain characteristics in the ware to employ a large excess of air.

(5) Loss resulting from a reducing atmosphere. This may be calculated from the analysis of the gases and the fuel, and from the quantity of fuel burnt.

(6) Loss of heat in the fireholes due to imperfect combustion. It is determined by weighing the ashes and cinders, and by ascertaining the proportion of unburnt material they contain.

In the case of heating by gas, there is an additional loss due to the generation of gas in the producer.

When the heat contained in the burned ware can be partly utilized as in continuous kilns, this will reduce the foregoing losses.

The result of adding the number of heat units theoretically necessary for the burning of the goods to those from the different causes of loss just enumerated, gives the total heat evolved by the combustion. This may also be found by multiplying the weight of fuel used by its calorific power. By then drawing up a balance sheet showing the relation between the quantity of heat produced by the fuel and that used, the working of a kiln may be studied accurately. This problem requires for its solution men who are familiar with the subject of heating—and even then is difficult to solve.

CHAPTER IX.

DECORATION.

Colouring Materials.—In the term "colouring materials" are included only those fixed or developed by heat, i.e. the coloured mineral matters which resist the necessary temperatures. These owe their colouring to oxides and to the salts of one or more of the following metals: iron, copper, chromium, cobalt, manganese, nickel, uranium, titanium, antimony, gold, silver, platinum, and iridium, vanadium, molybdenum, and tungsten.

These colouring matters may be applied to the ware by five different methods:—

(1) They may be introduced into the body, which then becomes a *coloured body*, which may either remain unglazed or be covered with a transparent glaze.

(2) Coloured bodies can be used to cover another body with slip (p. 136), in which case they are called *coloured slips*, the ware thus decorated either remaining unglazed or being covered with a transparent glaze.

(3) The slipped body may be covered with a layer of colouring matter made adhesive by covering it with a transparent glaze (*under-glaze colouring*).

(4) The colour may be mixed with the glaze, which thus becomes a coloured glaze, being either transparent or opaque.

(5) Lastly, the colour may be mixed with a flux, i.e. made into *vitrifiable colour* and put on the surface of the glaze (*over-glaze colouring*).

Two or more of these methods of colouring may be used simultaneously.

When the colour is mixed with a body or a slip, it must resist the same temperature as that at which the body is burned; when it is placed under or mixed with the glaze it must bear the temperature at which that glaze vitrifies; but when it is put on the surface of the glaze which has been burned previously, it need only bear the temperature for vitrifying its own flux.

In this case, the colour is called *over-glaze* or *colour for muffle fire*, in all other cases it is *colour for hard fire.*

These names as commonly used have little value and cannot be used for classifying the colouring materials. The colouring materials and colours are best arranged under the names of the compounds or minerals to which they owe their colouring power.

The colour itself is influenced:—

(1) By the temperature of the kiln.

(2) By the atmosphere of the kilns being oxidizing, neutral or reducing.

(3) By certain colourless materials in the bodies, glazes or flux.

(4) By the reciprocal action that colours have on each other, the colour of a mixture not being necessarily a combination of the colour of the ingredients, e.g. the variable colours produced by oxide of iron in the body (p. 184) and the alkaline, boracic or plumbiferous nature of the glazes. Thus, it is impossible in pottery to give such a narrow classification of colours as in the dyeing industry. Colours cannot usually be made lighter or darker by simply adding white or black to them, but each must be considered separately in order to obtain the various tones obtainable by varying the proportion of colouring matter added to a definite quantity of body glaze or flux; or in some cases the thickness of the coloured layer may be increased or reduced.

Colouring Metals.—*Iron.*—The different colours given by oxide of iron to bodies has been described on page 184; its action in glazes is different. For relatively low temperatures (below 1000° C.) and in a slightly oxidizing atmosphere, iron oxide gives the colour of the peroxide, i.e. brown and red, which may become violet and approach black in consequence of the presence of monoxide. It is then suspended in the vitreous mass, with which it does not easily mix. At higher temperatures it may enter into combination and then gives unstable colours—a bluish-green in alkaline glazes, a brownish-yellow in boracic glazes, and a yellow in plumbiferous glazes. At very high temperatures ferrous oxide forms silicates which are scarcely coloured if it is only in a small proportion, and of a reddish- or blackish-brown if much of it is present. When mixed with certain other oxides it gives very stable colourings, which are much used.

Iron oxide is obtained in a pure state by heating sulphate of iron; it then forms a red powder or colcothar, of which the shade depends on the rapidity of heating and temperature. It may also be prepared by precipitating iron salts by ammonia or by alkalies. The tint in this case depends upon the salts employed.

Iron oxide is found in many earthy compounds, such as ochre, Sienna earth, Thiviers stone, Arminian earth, etc., but these are usually of very variable composition.

Copper oxides are only used in glazes which can be vitrified at a moderate temperature. At high temperatures they tend to be absorbed by the glaze and even to penetrate into the body itself. With an oxidizing atmosphere, copper in alkaline glazes gives a beautiful azure blue colour, known by the name of turquoise blue. It becomes intense green in boracic or plumbiferous glazes; with a strongly reducing atmosphere it forms the monoxide, and gives a beautiful purple-red in alkaline glazes, verging to orange or brown in others. Mixed with other colours, copper oxide makes greens.

It is especially used in the form of cupric oxide, a very dense black powder obtained by heating nitrate of copper, but copper carbonates are also used. "Blue Ashes" and other ores are impure and cannot be recommended.

Chromium oxides can only be used for colouring white bodies as the small quantity of iron contained in others always darkens and dirties the colours. In glazes, chromic oxide is generally used. The atmosphere of the kilns influences the colour, chromic acid being formed when the atmosphere is oxidizing, and chromic oxide when the atmosphere is a reducing one, though this action is much less marked than with iron or copper, and with a sufficient proportion of the colouring matter present it is only noticeable as a slight modification of the shades. Chromium oxide in alkaline glazes gives a bluish-green or a greenish-blue, which is little used; but in other glazes it produces a beautiful green colour which becomes yellowish with a small proportion of the oxide in an oxidizing atmosphere. Chromic acid produces intense yellows in alkaline or purely plumbiferous glazes, yellowish greens in boracic glazes, and in alkaline plumbiferous glazes, at a low temperature, an orange-red colour. By mixing stannic acid in a glaze containing lime and a small proportion of chromic acid, a red colour varying from rose to purple is obtained when the temperature is sufficiently high. This colour is not specially due to the chromic acid, because it can be obtained under the same conditions with other substances, but chromium gives the best results.

The compounds of chromium are also much used with other oxides to produce greens with copper, blacks with iron oxide, etc. Chromium oxide is prepared by heating mercury chromate, or by heating potassium chromate with sulphur. Chromic acid is used in the form of bichromate of potash. The use of chromium in pottery only dates from the beginning of the nineteenth century, so that its presence in ware may sometimes indicate its date of manufacture.

Cobalt oxide is a very powerful blue colour; it may be used for colouring either body or glaze and resists all temperatures. Added to a glaze it gives an intense blue colour inclining slightly to violet, but light shades cannot easily be obtained pure. When mixed with zinc oxide it gives ultramarine blue, and with aluminium compounds it produces a beautiful sky-blue colour.

It may be mixed with other colouring oxides to obtain various shades of blue.

In a small number of colour factories cobalt oxide is obtained direct from cobalt ores. It is sold in an almost pure state as cobaltous oxide (CoO), as a dark grey powder; but more usually cobalt oxide (Co_2O_3) is used which contains 85 to 90 per cent of oxide. For ordinary bodies it is more economical to use the rose-grey cobalt carbonate or the cobalt silicate called rose cobalt, which corresponds to only 40 to 50 per cent of the oxide. All these cobalt compounds contain some nickel oxide.

Manganese oxide is also a powerful colour which, when mixed with iron, gives a dark brown or black colour, resisting any temperature to bodies. In glazes it forms colours varying from brown to violet, according to the proportion of iron oxide and the composition of the glaze. In alkaline glazes it is more usually violet, and brown in the boracic ones; plumbiferous colours give intermediate colours; mixed with much iron oxide, manganese compounds make browns and enter into the composition of most "blacks".

Manganese oxide may be extracted in an almost pure state from its ores in the form of a black powder. For bodies and brown glazes the ores themselves are used, after having been sorted, washed and crushed.

Nickel oxide is scarcely ever used because it gives uncertain and spotted shades, varying from yellowish-green in alkaline glazes, dirty green in boracic ones, and brown-green in plumbiferous ones. It is used together with iron compounds to form shining browns, it also enters into the composition of certain "blacks". It is extracted, in the form of a green or grey oxide, from nickel ores.

Uranium oxide gives a yellow colour with an oxidizing firing and green or black in a reducing atmosphere. As it is costly it is scarcely used except in plumbiferous glazes, in which it gives, under moderately oxidizing conditions, a very bright orange yellow. It is extracted from pitch-blende ore.

Titanium in glazes only gives yellow tints, due partly to the iron always contained in commercial titanic acid.

Antimony oxide forms a compound of a yellow colour with lead. In all other cases it is colourless, but makes others opaque. It is usually mixed with oxide of iron, with which it forms a beautiful series of yellows. It is sold in the form of antimonic acid, as an antimoniate of potash, and as antimoniate of lead (Naples yellow).

Gold—specially prepared—may be used either as dull gold, which may be made brilliant by burnishing, or, directly, as brilliant gold. If introduced into glazes as a chloride, the colour varies from rose to purple, resists high temperatures, but is costly. By mixing chloride of gold with chloride of tin, a violet-purple precipitate is obtained (Cassius purple) which, in glazes, gives beautiful rose, purple, carmine, or violet colours, but when the temperature is raised above 1100° C. takes a bluish-violet tinge and often disappears.

Silver chloride is added to glazes, giving them a yellow colour, but is seldom used. It is occasionally used for silvering, because of the low temperature at which it fuses, and it is often added to Cassius purple.

Platinum may be used to cover the ware with a layer of dull platinum, made brilliant by burnishing. Added to glazes as a chloride, it gives a grey colour, which resists high temperatures, but is costly.

Iridium may be introduced into glazes as an oxide, and gives a colour varying from grey to black. It is but little used on account of its high price.

Preparation of the Colouring Materials is now done in special works as each of them requires special methods of manufacture, necessitating, sometimes, long preparation if they are to be obtained sufficiently pure. Their manufacture needs special knowledge, and it is considerably more economical to deal with a larger quantity of the raw materials than is used even in the largest pottery.

White Colours.—All the bodies which contain very little or no iron oxide are white, and may be used as white slip. Glazes can only be made white by destroying their transparency. All materials which cause opacity—oxide of zinc, lime, arsenious acid, alumina, etc.—are white.

Blacks can be obtained in different ways, though there is no true black in pottery.

(1) By using iridium oxide alone, or uranium oxide, also alone, but in a reducing atmosphere.

(2) By a mixture of two oxides, one of which must always be iron or manganese oxide and the other cobalt, chromium, or uranium oxide. The mixtures most used are those of iron and chromium, iron and cobalt, manganese and uranium.

(3) By the mixture of three or four oxides, always containing iron and manganese, to which are added cobalt, chromium, and copper.

In all these mixtures different shades are obtained by making one of the colouring materials predominate; thus, iron gives brown tints, cobalt blue tints, manganese violet tints, and chromium green tints. These colouring materials are used directly in the form of oxides; but sometimes iron chromate is used, being obtained by precipitating a solution of neutral chromate of potash by a solution of ferrous salt.

Greys are obtained by lessening the proportion of black colouring materials, but a mixture of iron and cobalt oxides is principally used. Grey is a more difficult colour to obtain than black, because the mixture of colouring matter must be very accurately adjusted so as not to give any yellowish, greenish, or bluish tints, which are very ugly. Platinum gives a beautiful grey of which the only disadvantage is its cost. For this purpose, the platinum is dissolved in *aqua regia*, precipitated by ammonia, and the liquid evaporated and then calcined so as to produce an extremely fine powder of platinum.

Blues are given by cobalt compounds, such as oxide, carbonate, silicate or phosphate. Alone, it gives a beautiful blue which is slightly violet, by mixing it with zinc oxide, or with alumina, ultramarine or sky-blue colours are obtained. Greenish-blue shades are obtained by adding a little chromium oxide, and violet by the addition of a small quantity of manganese oxide. Cobalt colours must be burned in an oxidizing or neutral atmosphere.

Copper oxide with an alkaline glaze, and burned with a decidedly oxidizing firing, gives a beautiful turquoise blue. Cupric oxide is black, and cuprous oxide red; only the cupric silicate is blue.

Greens are produced by means of chromium oxide. In alkaline glazes, the tint is changed from a bluish-green to green by adding copper oxide. Bluish-greens are obtained in all glazes from a mixture of chromium and cobalt oxides. The addition of a little iron makes them yellow or brown. A mixture of chromium and nickel oxides also gives a green similar to the greens furnished by copper alone; in boracic and alkaline glazes it is very little used.

Yellows are numerous, the most important being:—

(1) Pure iron oxide, specially used in bodies; at a high temperature turns brown.

(2) A mixture of antimony oxide and lead oxide to which is often added a little iron oxide.

(3) Pure uranium oxide, the tint of which becomes orange when lead is present.

(4) Titanium oxide mixed with zinc oxide.

(5) Chromic acid, but only in alkaline glazes.

At high temperatures, only uranium and titanium can be used.

Reds.—Rose, reds or purples are obtained from iron, chromium, copper or gold, according to circumstances.

(*a*) The red colour due to iron may only be obtained at a temperature below 1000° C., above this it becomes brown, then blackish. In glazes, its tint depends entirely on the way in which the iron oxide has been prepared.

(*b*) A mixture of zinc oxide, whiting or chalk and a small proportion of chromic acid gives a red colour—called carnation-red or pink—in an oxidizing atmosphere. First, the mixture of oxide and carbonate is finely powdered, a solution of bichromate of potash is added to it, then the mass is dried, calcined, powdered, washed and dried again. A certain quantity of quartz added to the mixture gives shades which are more decidedly red. (The success of the manufacture depends on the skill and thoroughness of the grinding plant.)

(*c*) By mixing gold chloride with a white, clayey body to which soda has been added, the mixture being first prepared as a liquid paste, and dried, a mass is obtained which has a beautiful purple colour and resists high temperatures, but is very costly.

(*d*) For low temperatures, gold is replaced by Cassius purple obtained in the following manner. A solution of gold in *aqua regia* is made and evaporated to remove the excess of acid, and the residue is dissolved in water. Tin is dissolved in concentrated hydrochloric acid, in a separate vessel, evaporated, and the salt allowed to crystallize. This salt is dissolved in water and half the solution is treated with a current of chlorine gas which changes the tin chloride into dichloride. The two solutions of chloride and dichloride are put together, much diluted with water, and the solution of gold chloride poured into it drop by drop. The precipitate is the colour of wine dregs, and is washed and dried. The method just described can be varied in several ways.

Sometimes, silver is added to gold chloride to make the Cassius purple redder, as it has a tendency to turn to violet.

(*e*) Copper oxide gives a beautiful red colour, but only in a decidedly reducing atmosphere; the employment of it is, therefore, limited to certain decorative effects.

Browns are made by iron oxide either alone or mixed with the manganese, chromium, cobalt or nickel oxide which give them the most varied shades.

Violets are made directly by manganese in alkaline glazes. A mixture of cobalt with one of the red colouring materials already described, specially with pink. Lastly, Cassius purple with a flux that is rather more alkaline than plumbiferous, and when silver chloride is not present, gives violet colour.

All the colouring materials ought to be very finely powdered and well mixed, in order to give a uniform colour and one that is regularly distributed. This grinding is done either by mortars for very small quantities, or by using the processes employed for powdering the glazes (p. 171).

Properties of the Colouring Materials.—At relatively low temperatures, the colouring materials may combine together to form salts, the colour of which is not related to the colours of the component substances. Thus, antimony oxide, and lead oxide, both of them white, form lead antimoniate which is yellow. In these combinations the oxides having the symbol MO (M being any kind of metal) act as a base, those with the formula MO_2, MO_3, or M_2O_7 are acids, while those having the symbol M_2O_3 act according to circumstances, as acids or bases.

Thus iron monoxide, manganese and cobalt and the red copper oxide are basic, while the compounds of antimony and chromium are acids. Among the salts which can be formed thus may be mentioned: iron chromate and antimoniate, the manganates of cobalt and chromium, manganese chromium, cobalt, etc., ferrates. By adding other colourless metallic oxides to the colouring matter properly so called, coloured salts are obtained. The colourless oxides which have been mentioned among the raw materials for the glazes, are the oxides of tin, zinc, and lead. The first, which is always acid, gives stannates, the second usually produces zincates, and the third in the form of monoxide makes bases, and plumbates when it is in the form of red lead. The stannate of chromium, the iron zincate, lead antimoniate and chromate, etc. are also used.

Among the alkaline earthy bases—which may also be found mixed in colours—lime, baryta and magnesia constantly act as bases, while alumina more often plays the part of an acid. Example: barium chromate and cobalt aluminate.

Alkalies (soda and potash) are always basic, while boracic acid and silica are always acid.

The number of combinations which may be formed explains the numerous variations in the shades of pottery colours, as well as the impossibility of mixing several colours in order to obtain a middle colour.

When the colouring matter has to be fixed to the surface of the glaze (over-glaze decoration) fluxes, i.e. materials which with the colouring matter form vitreous compounds, are added to it. It is then easy to give a vitrifiable colour the composition necessary to obtain the desired colour; this and the low temperature needed for baking them, explains why the series of vitrifiable colours sold by colour manufacturers is so large and comprises all imaginable shades.

When colouring materials are mixed with the body or glaze, the composition of the latter not being dictated solely by considerations of colour, they give a more limited range of colours, as the higher temperature needed for burning the body or maturing the glaze modifies the chemical affinities of the different substances present. For instance, the acid properties of silica develop as the temperature increases, so that silicates are progressively substituted for antimoniates, ferrates, zincates, stannates, manganates, plumbates, aluminates, and at the temperature used for burning porcelain the silica, together with boracic acid if present, is the only acid element in the material.

It is advisable to retard the action of silica by forming compounds that resist it as much as possible, between the colouring matter and the other elements of the body or glaze. The most stable combinations, from this point of view, are those with the composition of spinnelles, and are formed by the combination of a protoxide and a sesquioxide.

Some colouring materials, however, are not capable of combining with fluxes, glaze or body, but either make them opaque, as in the case of several colours for over-glaze painting, or remain unattacked at high temperatures, as gold and platinum.

The introduction of colouring matter into bodies or glazes usually increases the fusibility. Chromium oxide is the least fusible, then oxide of iron, manganese and uranium, and, lastly, the oxides of cobalt and copper. The composition of the body or glaze must, therefore, be modified so as to render it more refractory.

With the exception of copper oxide, all colouring oxides make compounds which expand less than that of lead oxide (p. 189). This property makes it difficult to obtain certain colours, especially turquoise blue, from copper.

Processes of Decoration.—By employing, separately or simultaneously, several decorative processes, most varied results can be obtained, thus allying the art of sculpture to that of painting.

Decorative Moulding of the Body.—In Chapter V. only the ordinary shaping was mentioned, the object being to produce a number of similar objects, without taking account of the purely decorative details of manufacture. To complete what has been already stated, from a decorative point of view, the moulding may have two objects: (1) The creation of a unique decorative object; (2) the decoration of objects manufactured by industrial moulding.

The moulding of an original decorative piece of pottery must naturally be modelled by hand, or by forming it on a potter's wheel, and finishing it by turning, the processes employed depending entirely on the nature of the material and on the form of the piece.

Modelling by hand needs somewhat plastic clays; this is always the case for terra-cottas and stoneware, and usually applies to faience; porcelain bodies are, however, much less plastic and present such difficulties that agglutinants (size, dextrine, etc.) must often be added to them.

It is often convenient, and sometimes necessary, to mould the parts in high relief separately, and to join them afterwards to the principal object. The ease with which this is done makes the modelling of very much under-cut objects and those with thin and delicate raised pieces possible.

The amount of moisture in the body is of great importance. During the whole of the modelling the body must be kept from drying by being surrounded with damp cloths or damped with sponges, but this inconvenience may be avoided when the body can be carved when it has been allowed to harden, as it then lends itself to exact working in which the joints can be lost, the thicknesses be lessened, and the contour be made accurate. In lean bodies, this carving replaces modelling to a great extent as the piece can only be formed more or less roughly in the first instance. In this way it is possible to attach very thin parts in high relief, which would get out of shape if they were put on when the ware is still plastic.

It is very important to notice that objects having thick massive parts with other parts that are much thinner, cannot be readily dried and fired, and it is then necessary to hollow out the more bulky parts inside. Sometimes, after the modelling is done, the part to be hollowed out must be taken off in two or more pieces by a metal wire, or with a thin blade. Each part is then hollowed out separately, the whole stuck together again, and the joints are cleaned off. An allowance must be made for the shrinkage all bodies undergo on drying and firing (about one-tenth in plastic bodies), the dimensions of the object being increased proportionately before modelling. It is often much easier to mould certain ornaments or certain parts that are much raised separately, and to join them or stick them on afterwards. This method of moulding is especially suitable for little figures in high relief, for wreaths and for medallions that are used for decorating the ware.

Decoration by hollow designs, frequently repeated, may be made with stamps having the design cut in relief. A slab of paste is prepared, the design is formed by the stamp, trimmed, and pressed against the body when it is slightly firm. When this decoration forms a band in which the same design is constantly repeated the stamp is replaced by a revolving wheel. These two processes in decoration are called stamping and beading. Engine-turning (or dicing) may also be used, as in other industries. Large plaques may be ornamented by a design repeated indefinitely, by passing them under an engraved cylinder.

When the body is nearly dry, the surface can be polished and its hardness increased by rubbing it with a horn.

In certain cases, the glaze may form part of the moulding of the body. Thus, it is possible to make plaited objects which would easily break if fired direct, but if dipped into a glaze before firing, are made strong, as this fastens the small pieces together. Small hollows may also be made in the body and afterwards filled with glaze, so as to form a special style of decoration.

Colouring the Body.—It has been shown in the chapter on firing that oxide of iron in the clay can give different colours to the body. By mixing other materials with it, coloured bodies of different shades may be obtained.

The colouring matter should be in the form of an extremely fine powder, and must be very carefully mixed with the body if a uniform colouring is desired. Sometimes, to economize the colour, only the surface of the body is impregnated with it, but this process seldom gives uniform colours.

In order that the colours may be stable and not removed by washing, it is necessary that the temperature at which they are burned should be sufficient to ensure their combining with the body, otherwise they are fritted beforehand.

Whites are obtained from bodies which do not contain oxide of iron. It is almost impossible to avoid its presence entirely, but, notwithstanding a small proportion, white bodies may be obtained at a moderate heat, but with vitrifiable bodies a reducing atmosphere in the kiln must be used, so as to obtain a slightly bluish-white.

Black is usually obtained from a mixture of iron oxide and manganese oxide. According as one or the other preponderates, the black approaches brown or violet. In ferruginous bodies it is sufficient to add manganese to them.

For fine wares, iron oxide, to which a small quantity of oxide of cobalt is added, is sometimes used; a mixture of the iron, manganese, cobalt and chromium may also be used.

A certain kind of black ware may also be produced by firing with a very reducing atmosphere so as to reduce the iron oxide and deposit particles of carbon in the pores of the terra-cotta. This carbon results from the decomposition of the hydrocarbons given off from the gases of the furnace.

Greys are obtained with a smaller proportion of the oxides of iron and manganese, but in order to obtain very light shades it is necessary for the body to be only very slightly ferruginous.

Beautiful shades are obtained by mixing iron oxide with a small quantity of cobalt oxide. For fine vitrifiable bodies, iridium oxide and platinum chloride may also be used, either separately or together.

Blues can only be produced with white bodies to which cobalt oxide is added. The shades thus obtained depend not only on the proportion of the colouring oxide, but also on the quantity of alumina in the body. If this is large, the colour is sky-blue, if the body is silicious, the shade approaches indigo. This latter colour (Persian blue) may be obtained in silicious bodies by first fritting cobalt oxide with its own weight of zinc oxide. Silicious bodies can be coloured sky-blue by first fritting cobalt oxide with alum.

Greens are obtained by mixing chromium oxide with a white body, as free from iron as possible. Various shades are obtained by altering the amount of colouring oxide, and by adding a little cobalt for bluish-greens. Sometimes, also, nickel oxide is used and, alone, gives a bright green, though it is a trifle uncertain; mixed with a little oxide of cobalt, it produces an olive-green.

Yellows, orange and yellow brown are produced in terra-cottas by iron oxide, using natural clays. In vitrified bodies iron oxide produces only a yellow body when the atmosphere is oxidizing. If it is a reducing one the colour changes to a greenish-grey.

Reds are also obtained from iron oxide, but they do not resist a high temperature. Intense yellows and reds are very difficult, if not impossible, to obtain in vitrified bodies, though if bichromate of potash be fritted with pure alumina and this frit, finely powdered, is added to the body, a rose-colour or pink is formed. The addition of a small proportion of cobalt oxide turns this rose-colour to lilac.

Browns are produced by iron oxide at a somewhat high temperature. For ferruginous bodies that only need a moderate heat, brown is easily produced by the addition of a little manganese oxide. In fine white bodies, a mixture of iron and chromium oxides or iron chromate is used. A mixture of manganese and chromium oxides can likewise be used, or a frit of zinc and chromium oxides obtained by heating zinc sulphate with chromium oxide.

Violets can be obtained only with difficulty, with manganese oxide or with chromium and cobalt.

Coloured Slips.—A slip is a body put on the surface of another body which has been previously moulded. Coloured bodies may naturally be used as slips to decorate objects made out of other bodies. This decorative process is used either for economy, by colouring only the surface, or for decorating the surface of the body with paintings and with reliefs in different colours.

In the first case, the slip should be spread over the whole surface, or else only on the inside or the outside of the piece, the ware being made of dry body or of biscuit. The methods employed for applying the coloured slip are those mentioned in Chapter V. for colourless slips, and need not be repeated.

In the second case, the slip is usually applied with a brush to the raw paste, or to biscuit, by employing the methods used for oil or water-colour paintings. This method of decoration has been called "*barbotine*". The decorated ware, when dry, may be baked if it is to be left rough, or it may be first coated over with a colourless glaze which must be transparent, and then burned. The background, or the painted parts only, may also be coated with glaze.

In "*barbotine*" it is wise to use only a small quantity of clear colours without giving too much modelling to the design, and without trying to imitate oil-painting. A dull or slightly monotonous look is avoided in this style of decoration by making the background more vivid than the painted parts, or vice versa.

By making the slip slightly stiffer, it is possible to apply relief decoration with a brush, and afterwards touching up the edges and the higher parts by carving with small tools.

The pasty slip may also be placed in a vessel with a very narrow spout and allowed to fall out, drop by drop, on to the ware, in such a way as to form round balls, or lines, or rosettes. This method of decoration is known as "*pastillage*".

By using a vessel with several compartments filled with slips of different colours, and a number of spouts side by side, a multi-coloured slip may be allowed to trickle on to the ware and thus produce *marbled effects*. By covering over the whole with a glaze, imitations of different marbles may be produced.

In certain cases, especially for paving tiles, cells which can be filled with slips of different shades are sometimes arranged during the moulding of the surface of the piece, the surface afterwards being levelled by means of a knife.

Slips may be used for decorative purposes by incrustation, formerly described (p. 137), small moulds, divided by partitions of thin tinplate which form the outlines of the design, being used, and filled with dried paste of various colours. After the separating partitions have been removed, the coloured slip is covered with a powder of the composition of the ordinary slip, and the whole joined together by great pressure. A fuller description of these last two processes will be found in the articles devoted to the manufacture of tiles (pp. 373, 415).

Under-glaze colouring consists in colouring the raw or burned bodies, with or without being covered with slip, the whole being covered with a colourless transparent glaze, which develops and fixes the colours. This must not be confused with under-glaze barbotine painting, in which the colouring matter is mixed with the slip, while in under-glaze painting it is the glaze into which the colours penetrate under the influence of heat.

When the whole article is to be uniform in colour, the method of applying it described in Chapter V. (p. 136) is used, the colouring matter, powdered very finely, being mixed with a sufficient quantity of water, to which a little gum arabic, treacle or glycerine has been added to make it more adhesive. When biscuit ware has to be decorated in this way, it is often best to make it less absorbent by soaking it in water or in a gummy or albuminous liquid, the article being heated sufficiently to make the body absorbent again before the glaze is applied.

Dipping may also be used to produce marble effects. The colours ground up with water or spirits are put in a bath of gum tragacanth dissolved in water and stirred. The warmed piece is then dipped into the bath and absorbs the colour.

If it is desired to use a pattern, the colours may be applied with a brush or by printing.

For under-glaze painting with a brush, the colours, ground to an impalpable powder, are mixed with gum arabic or spirits of turpentine on polished glass, either with a muller or with a pallet knife, and are applied with a brush as in oil painting. The shading is obtained by putting tints over one another. The ware thus decorated is afterwards dried, and coated by glaze by one of the methods already mentioned.

In decoration by printing, copper plates beaten out with a hammer are used and carry the design to be reproduced. The engraving on the plates should be done by stippling, using the graver as little as possible. The colouring materials, powdered very finely, are mixed very carefully with printing oil. This latter is made by heating linseed oil with a little resin, tar or gum. The mixing is done with a muller on an iron plate heated to 150° C. or in a special apparatus.

This mixture is spread over the engraved plate with a spatula, care being taken to force it into the hollows by means of a dabber; the excess of colour is then taken off and the plate cleaned. The plate being thus prepared, is covered over with a sheet of thin hemp paper, previously soaked in a solution of soft soap, and passed under a press to print. Then, after having placed it on a plate heated by steam, the paper is detached, and on it the colour remains; the part containing the design is cut off and applied to the pottery to be decorated, by rubbing it with a roller. At the end of several hours the decorated article is steeped in water and the paper detached with a sponge. The impression adheres to the ware, which is afterwards dried, heated to

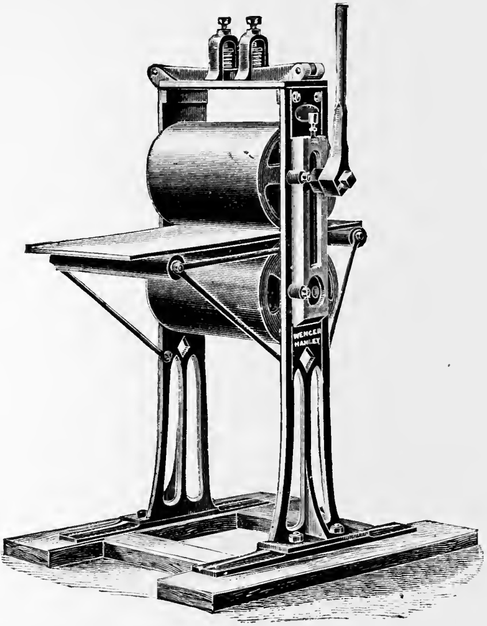


FIG. 179.—Printer's press.

150° C. or 200° C. to evaporate the oils, covered over with glaze and burned.

Only monochrome designs can be printed by this process, and the decoration may be completed by painting with a brush, or a process of chromo-lithographic printing may be used. This method of decoration is described on page 236.

In under-glaze work, the colours must resist the temperature used for burning the glazes in which they are vitrified. The colouring matter used has been described in the last chapter. The background colours must be somewhat liquid; they are used either for colouring the whole piece, taking the place of a slip, or else to colour only certain parts, such as the edges of plates, or for making bands. They are difficult to apply if a uniform tint is desired, as for deep colours it is necessary to make them very thick, and to run the risk of their not being entirely dissolved by the glaze, in which case they remain dull and are liable to be detached from the body.

The colours put on with a brush or printed are more numerous and need fewer precautions. Their composition depends on the temperature at which their glazes fuse; and they should have such compositions as are sufficiently stable to be able to resist the action of the silica as much as possible. They are often mixed with a certain proportion of the body, especially for porcelain.

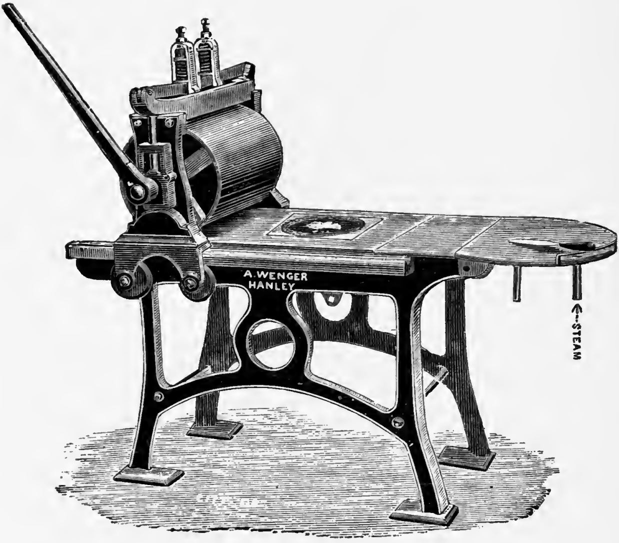


Fig. 180.—Steam-heated printer's table.

Coloured glazes are prepared like ordinary glazes, but with the colouring matter added to them. This method of colouring pottery gives most brilliant colours. According to the colour used they must be alkaline, boracic, or plumbiferous. After having been finely powdered, water is added to make a paste of the desired consistency. They are usually put on the burned body or on the biscuit.

If the whole ware is to receive a uniform layer of glaze, the latter is applied by one of the processes used for putting on colourless glazes (p. 173) either by dipping or dusting, the body having been first coated over with gum arabic or with some other viscous material.

When using these methods, certain parts intended to have a special decoration must be kept free by covering them by means of a brush, with a coating made of spirits or gum, then the whole piece is dipped into a coloured glaze, and heated sufficiently to make it adhesive. The painted parts which have not adhered to the body fall off themselves, leaving the *reserve* bare. When these reserves are to be ornamented with glazes of different colours from those of the background, they may be mixed with oil and applied with a brush ; at the time of dipping the glaze of the background, which is prepared with water, does not adhere to the greasy parts. When the glazes are transparent, it is sometimes difficult in dipping to get a perfectly regular thickness, though this is necessary to give the whole piece a uniform colour. In this case it is preferable, especially for large surfaces, to use the method described under spraying (p. 175).

At other times it is advisable to get different thicknesses in the glaze, so as to obtain darker or lighter shades. For this purpose, a hollow ornament is arranged in the moulding, or by engraving on the body. When the glaze is applied by spraying the thickness of the colour can also be varied.

Coloured glazes may also be applied with a brush on the burned body, but they tend to mix together when they are vitrified. To prevent this trouble, the edges of the design are drawn in fairly high relief with a black glaze that is less fusible. The cells thus made are afterwards filled with different colours. The ware decorated by this process has been called *cloisonné enamel* ware, in consequence of its likeness to certain enamels on metal.

Over-glaze colouring has the colour placed on the glaze, either before or after the latter has been burned. In the first case, the glaze is nearly always an opaque white enamel, which at the moment of its vitrification dissolves and fixes the colour, which must, naturally, be able to resist the temperature used for burning. In the second case, the colours ought to be added to fluxes, to form vitrifiable colours which change to glasses at a temperature for burning below that of the glaze to which they adhere.

The application of the colours to *raw enamel* can only be made with a brush and needs great skill, because of the thinness of the glaze. The colouring matter is diluted with water, to which glycerine may be added if they are absorbed too rapidly. The glaze being usually stanniferous or plumbiferous, it is wise to take account of the action that the oxides of tin and lead may have on the colouring matter. The reduction of the number of shades in consequence of this, added to the difficulties of application, make this kind of decoration unpopular in spite of its harmony and depth.

Over-glaze painting with vitrifiable colours is, on the contrary, a method of decoration which is very much used, not only in potteries but also by amateurs. Thanks to the low temperature at which the fluxes vitrify, an extremely rich pallet of colour is possible, and at the same time all the numerous difficulties presented by the other methods of colouring which have just been described are avoided. It is only fair to add that the colours are only dull, and that the decorative effect cannot be compared with that of the colouring used for hard-firing.

In order to manufacture *vitrifiable colours* a suitable mixture of the colouring materials must first be made. They are usually combined together by dissolving the colouring oxides in hydrochloric acid, and precipitating them with carbonate of soda. The precipitate is washed, dried, and then calcined at a red heat.

The flux is a compound of white sand, red lead, and borax in varying proportions, melted in a crucible and run off as soon as it is completely fused. When cooled, it is mixed in a suitable proportion with the colouring matter, and the whole powdered very finely. The most important pottery factories make their own vitrifiable colours, instead of buying them prepared for use.

For *over-glaze painting*, the vitrifiable colours are usually mixed with spirits of turpentine. They are applied with a brush, proceeding in flat layers over one another, as in water-colour work. To obtain dark colours, it is sometimes unavoidable to give to the layers thus put over one another such a thickness that the colour would scale off in firing. The article is put for the first time into the kiln and fired. Then it is repainted with the vitrified colour and burned again. This operation can be repeated several times, until the desired effect is obtained.

The backgrounds in a single shade can be painted in the same way, but with a badger brush, and the layer is afterwards stippled up with a short-haired or polecat brush. The piece can also be coated with boiled linseed oil, with the addition of a little resin, on which the dried and powdered colour is applied by dusting.

The merchants of vitrifiable colours sell these ready for use, so that it is easy for anybody to become a pottery painter, by buying a white plate or vase, painting it and having it burned.

For a large number of similar articles the design is printed either in monochrome, as already described, or by *chromo-lithographic printing*. For this, the original design in outline is traced with lithographic ink and transferred to stone, a sufficient number of copies being transferred to as many stones as there are different colours. The draughtsman then fills in the outlines thus produced with a brush in lithographic ink, each stone naturally being painted only on the parts corresponding to its colour, and the rest of the tracing being afterwards wiped off. The stones are then washed over with acidulated water, which fixes the ink and gives a slight relief to it. The surface of the stone is then passed over with a wooden roller covered with leather and soaked in varnish, the varnish being left on the parts covered in ink. A sheet of paper sized with gum arabic or dextrine is next spread on the stone, and the whole passed through a printing machine. From this the paper emerges decorated with the varnish ; it is raised, turned over and dusted with vitrifiable colour, any excess of colour being taken off with a soft brush after the varnish has been allowed to dry. The same process is repeated in printing the second and following colours, care being taken to fix the position of the sheet of paper, so that the different colours may occupy exactly their right places. Usually each design is reproduced several times on the same stone in such a way as to use all the surface. In some factories the lithographic stones are replaced by suitably prepared zinc plates.

The chromo-lithographic sheets thus manufactured are kept until wanted. They can also be bought.

The colour is transferred to the ware in a very simple way. The design having been covered over with copal varnish and resin dissolved in spirit, it is applied to the ware first with a roller, then by stippling, so as to remove any air bubbles. When the varnish is hard the pottery is plunged into water, which dissolves the gum or dextrine from the paper, so that the paper comes off by itself, leaving the colour adhering to the ware. The piece is washed, dried and heated in a stove to remove the varnish and is then put into the kiln.

This chromo-lithographic process is largely used for ornaments, flowers, animals and figures, though for the last named it is better to use *photo-lithography*, i.e. by using photographs in the place of original designs. A plate of bichromated gelatine is covered over with a negative of the photograph that it is desirable to reproduce and exposed to the light. When sufficiently exposed the surface of the gelatine plate is inked by a roller, then covered with a sheet of paper, the whole put in the press, and thus a reproduction of the photograph is obtained on the paper; this is afterwards transferred to stone and treated in the same way as in the ordinary process of chromo-lithography.

The colours thus obtained by printing on the glaze are rather dull on account of the small quantity of colour it is possible to apply by chromo-lithography. Sometimes they may be made more brilliant by burnishing them, after they are burned, with a stipple and very fine sand, or by a mechanical arrangement in which the ware is pressed against the rapidly rotating brushes, and adding emery powder to it.

Decoration with Metals.—Gold, platinum and silver are the only ones which, while being malleable, resist the action of oxidizing and heat and can be used in a metallic state.

Metallic *gold* can be used under glaze, a piece of gold thicker than those intended for gilding being cut to form a part of the decoration, and fastened to the burned body by means of resin or with a decoction of quince-pips. To brighten it, the body may be first covered with a thin glaze, dusted over with grains of sand, which, when burnt, is re-covered with gold leaf, and this is stippled with a short-haired brush, which gives it a granulated surface. The glaze is applied afterwards and burned in the ordinary way. The gold must not contain any copper, as this would oxidize and would colour the glaze green. The temperature for vitrifying the glaze must be below 1045° C., the temperature at which the gold fuses.

Platinum may be used in the same way. *Silver* being more easily oxidized and more fusible is more difficult to use.

The preceding method in decoration is only used in exceptional cases, but *over-glaze gilding* is very frequently used. In this process the gold is not in the form of leaf, but is an impalpable powder. For this purpose, the metal is dissolved in *aqua regia*, and precipitated either by a dilute solution of ferrous sulphate or of mercurous nitrate. In both cases a precipitate of metallic gold is formed, and this is separated from the liquid by decanting, washed several times in boiling water and dried at a temperature below 100° C. Gold powder prepared with mercury is more bulky, and consequently more economical and more used than that precipitated by the iron salt.

To fix the gold powder, thus obtained, to the ware, it must be mixed with a flux; a solution of bismuth nitrate in nitric acid being employed. This salt being precipitated by water, about half its weight of borax is added to it and the mixture dried, then it is added to the gold powder in the proportion of $\frac{1}{12}$th or $\frac{1}{15}$th. In certain cases, a little borate of lead is added to increase its fusibility.

After being burned the vitrified gold is dull, but may be brightened by burnishing it with burnishers, agate, hematite, or bloodstone, or with fine sand. It should always be rubbed in the same direction, so as not to scratch the gilding, and some liquid such as vinegar should be used to make the rubbing softer when burnishers are used. Certain parts may be burnished while others are left dull, so as to obtain contrasting effects.

Platinum may also be used over glaze in the same manner as gold, by dissolving it in *aqua regia*, and precipitating it by means of carbonate of potash and sugar, or by caustic potash and alcohol. The black precipitate of platinum is dried, calcined at a dull red heat and used like gold. *Silver* is obtained in the form of a powder by precipitating the chloride with zinc in the presence of sulphuric acid or by decomposing silver nitrate with copper wire. The precipitated silver is dried and used in powder in the same manner as gold.

The preceding metals may also be mechanically reduced to a powder by grinding them on glass with honey, but this process is very troublesome and is now seldom used.

Decoration with Metallic Lustres.—The lustres are formed of a very thin layer of very finely divided metal which shines with iridescent effects when it has been heated at a rather low temperature, or has been burnished. The metals used are gold, platinum, silver, copper, iron and lead. Lustres are always applied over glaze, and the more brilliant the latter, the more the lustres shine. Numerous recipes for obtaining lustres cheaply exist; those that are most used are *bright gold* or *Meissen gilding* which, when burned, has a metallic brightness, but does not wear so well as dull gold made bright by burnishing as just described. The ware is treated by liquids sold by certain colour merchants who carefully keep their recipes as manufacturer's secrets. The prices are so reasonable that potters do better to buy the lustres than to try to manufacture them for themselves.

Fulminating gold, obtained by precipitating chloride of gold with ammonia, may also be used. The precipitate is ground, while still damp, with essential oil of turpentine or spirits of lavender. The liquid is applied directly to the ware, no flux being used. The precipitate must be prevented from drying at all costs, or it would explode violently with the least touch.

Burgos lustre only differs from the preceding ones in the larger quantity of spirit and the less gold used; 20 per cent of metallic tin is often present.

Platinum Lustre.—A concentrated solution of platinum chloride is mixed with essential oil (spirits of lavender) and the liquid is spread on the ware with a brush. The lustre obtained has a steely appearance but is nearly opaque.

The preceding lustres may be burned with an oxidizing fire, but the following ones must be placed in a distinctly reducing atmosphere.

Silver lustre is made by fusing silver chloride with a plumbiferous flux; the yellowish glass is powdered; and after the addition of spirit, and sometimes bismuth, it is applied with a brush. When burned it gives the ware a metallic appearance with yellow sheen or a rich iridescence, which has given it the name of *cantharides lustre.*

Various lustres may be manufactured containing salts of silver, copper, iron, and lead. Copper gives a golden colour, silver a steely tinge, iron produces red. The metals are usually in the form of sulphides; sometimes a little lampblack is added to help in reducing them. The colours are thinned with vinegar or with spirit, and applied with a brush. Lustres having the most varied reflections may be purchased ready for use.

Various methods of decoration used, but which cannot be classified, are the following:—

Crazing is ordinarily a defect which arises from excessive contraction of the glaze, but may be used as a means of decoration. The difference in contraction between the body and glaze must be fairly great, so that the latter may be cracked in a large number of little lines, forming a regular network. The ware may be covered with a second more fusible coloured glaze which penetrates into the cracks and makes them stand out by their different colouring. The Chinese excel in this method of decoration.

Streaks are produced by too long a heating or too high a temperature, which causes the glaze to run down. This defect has been used as a means of decoration, glazes being used which have been made very fusible by the addition of borax; they are usually coloured and applied to biscuit or to another more refractory glaze. Marbled effects are thus obtained.

Flamed ware is produced by the intentional use of a defect. Certain colouring materials change colour according as they are burned in an oxidising or reducing atmosphere. This is especially the case with copper oxide which under oxidizing conditions has a green colour in boracic and plumbiferous glazes, and blue in alkaline glazes, but in a reducing atmosphere gives a red colour. By alternating the composition of the atmosphere, a succession of oxidizing and reducing effects may be produced, and changing capricious colours, which are quite unforeseen, especially if the temperature is rather high, are given to the ware. In the latter case the copper oxide may partially volatilize and let the body showing through the glaze appear uncovered.

Flowing Colours.—If the wares, decorated with a design in certain colours, are heated in an atmosphere containing volatile chlorides, the latter may attack the colour and change it into a volatile chloride. This chloride spreads on to the surrounding white body and is decomposed there by contact with the silica, giving a light graduated tint, darker in the neighbourhood of the design and forming a sort of halo round it. The chlorinated atmosphere is usually produced by putting on the top of the pile of saggers a vessel containing a small quantity of lead chloride obtained by dissolving white lead in hydrochloric acid. With the paste thus obtained, little balls, about ½ inch in diameter, are formed, dried and placed in the vessels which have been first coated with flint to prevent their fusing by contact with the lead. When the gases employed are very rich in lead and it would be inadvisable to increase the amount of lead in them, a mixture of six parts of sea salt and four parts of saltpetre may be used, as this gives off alkaline chlorides.

The principal colours which thus form volatile chlorides are cobalt oxide which produces a blue, nickel oxide yields a brown, copper oxide with a low temperature produces green, and iron oxide gives a disagreeable yellow. This process of decoration is used chiefly for earthenware. For success, the saggers must be carefully luted.

When a coloured glaze has been applied and is dry it may be removed in places, or it may be engraved so as to allow the body or glaze underneath to show. The friability of the raw glaze makes this operation easy, but it requires a certain amount of dexterity.

An effect of *being covered with pearls* on the surface of a piece of pottery may be obtained by first covering it with a thin layer of a colourless glaze, over which, while still damp, grains of sand or of burned ware coarsely powdered may be dusted. When burned, the surface is again coated with another glaze which forms around each grain a little vitreous drop, resembling a pearl. By replacing the sand by some of the more finely granulated body a decorative effect is obtained which has been called *moss.*

Small glass objects—*pearls, spangles, jewels,* etc.—may be fixed to the body or to a first glaze, by means of resin dissolved in spirit, with some flux added to it.

The burned bodies may be decorated with *vitrifiable crayons* made of vitrifiable colours enclosed in wood, which are used like ordinary pencils. They are sharpened by rubbing them on glass paper.

Ceramic photography, which must not be confounded with photolithography (p. 264), lends itself to reproduction. A sheet of ground glass is covered with bichromate of potash, dextrine and grape sugar dissolved in water, and exposed to the light under a positive. If a negative is used, the sheet of glass must be covered with an aqueous solution of perchloride of iron and tartaric acid. The surface is dusted over with a vitrifiable colour. The developing finished, the excess of colour is removed, the glass coated with a layer of normal collodion, and plunged into some slightly acidulated water. The collodion comes off, taking with it the vitrifiable colour, which is applied to the ware. If the collodion is placed underneath, it need only be dried and burned, if, on the contrary, it has been applied to the ware on the side where the colour is, the collodion must be dissolved off with a solution of alcohol, ether, and spirits of lavender.

There is a series of processes for decorating pottery without using heat, called *cold decoration.* Pottery may be coated with ordinary paint, varnish, lacquer, etc., but such work does not belong to ceramics, and need not be described.

Burning Colours.—What has already been said in relation to bodies and glazes will naturally apply to burning colours. As with colourless glazes, the agreement between the body and the glaze must first be studied and the directions previously given must be followed. The maximum temperature for burning as well as the working of the fire require most minute attention. The colours must not be exposed too long to the temperature for fusing the glaze or flux, because of the ease with which some of them volatilize. This volatilization is increased when the wares are placed in the kiln by the side of unglazed bodies, being greater with over-glaze colours and coloured glazes than for under-glaze colours. The metallic oxides on a piece of ware may stain a neighbouring piece when they are too close together in the kiln or when they are of different colours.

When the burning temperature is very high the goods are placed in saggers in ordinary kilns; in all other cases muffle kilns are used, the goods being placed on slabs. For burning vitrifiable colours at a relatively low temperature the fireclay slabs may be replaced by iron plates. In addition to the methods for measuring temperature already described (p. 239), *tests for gold* are often used for burning vitrifiable colours. These tests consist of a piece of body covered fairly thickly with a gold colour. The tint varies with the temperature as shown by the following table :—

Colour of the Test.	Approximate Temperature.	Observations.
	Degrees C.	
Red-brown	650	For burning lustres.
Red	800	,, ,,
Rose-purple	900	For burning vitrifiable colours.
Rose-violet	920	,, ,, ,,
Violet	950	,, ,, ,,
Pale Violet	980	,, ,, ,,
Colourless or only slightly Violet	1000	For burning dull gold.

The atmosphere in muffles used for burning colours should usually be oxidizing, and there should be no cracks through which the gases from the fire can enter. For copper-reds and certain lustres, on the contrary, a decidedly reducing atmosphere is necessary, and a small ordinary kiln is then preferable, the ware being set in open-work saggers.

CHAPTER X.

TERRA-COTTAS.

Bricks: (*a*) Plain Ordinary Bricks.

Forms and Dimensions.—The bricks used by the Egyptians, Assyrians and Romans were noticeably larger than those manufactured at the present time, and were usually in the form of slabs. The following table shows the dimensions of some of the best-known types of bricks.

Ancient Bricks.	Dimensions in Inches.		
Roman	23·5	23·5	2·2
,,	17·5	17·5	2
,,	8·4	8·4	1·6
Languedoc (11th and 15th century)	1·3	9·9	2·4
Modern Bricks.			
France, Burgundy	8·8	4·4	2·2
,, Marseilles	8·8	4·4	2
,, ,,	8·8	4·4	2·8
,, Paris (Vaugirard)	8·8	4·4	2·4
,, ,,	8·8	4·4	2·6
,, largest	9·1	4·4	2·8
,, smallest	7·9	4	2
,, type proposed by the Pottery Union	8·8	4·2	2·2
,, type proposed by the Architects of the North	8·8	4·2	2·4
Germany	9·8	4·9	2·6
England, largest	10	5	3
,, smallest	9	4·5	2
Austria, largest	11·6	6	2·6
,, normal	9·8	4·9	2·6
Belgium, smallest	7	3·4	1·8
United States	7·8	3·9	2
Mexico	10·2	5·1	2·6
Netherlands	10·2	4·8	2 2
Switzerland, largest	10·8	5·5	2·6
,, normal	9·8	4·9	2·6

All the bricks are parallelopiped in form, though some Roman bricks were triangular.

At the present time in all countries there is a general opinion that the volume of bricks should vary between 130 and 59 cubic inches, the length double the width, with an allowance of 0·39 to 0·24 inch for a joint. The width is seldom more than 5 inches, so that a bricklayer may easily take the brick between his fingers when it is lying flat. Hence the length ought to be at the most equal to 10 inches. The thickness should not be more than 3 inches, so that the drying does not take too long; nor less than 2 inches, if the price of brickwork is not to be increased. The normal German type, on the one hand, and the type proposed by the Pottery Union of France, on the other, may be taken as the two limits for the most convenient measurements.

Moulding by hand is used for many ordinary bricks, but is rapidly being replaced by machinery. Sandy bodies should be used so that they may not adhere too closely to the moulds, on account of their softness.

The preparation of the bodies usually consists of a simple mixing together (p. 84). Treading with the feet or by animals ought not to be used. As in "hand" brickfields there is usually no motive power, the mixers are worked by a rod fastened directly on to the vertical bar and rotated by hand or horse power (Fig. 181).

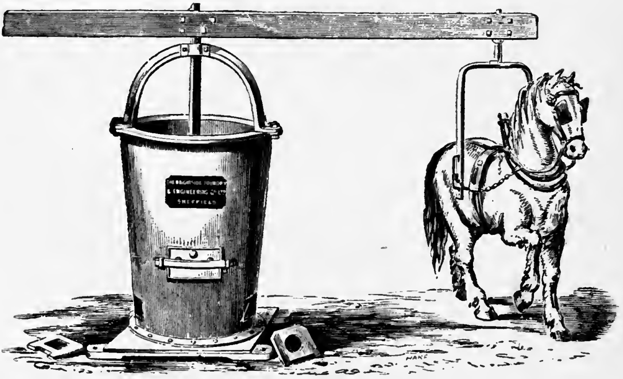


Fig. 181.—Horse-driven pug-mill.

The clay should be made of the required consistency by moistening it either in a heap or a pit (p. 83). If a sandy substance is to be added it should be fed into the mouth of the mixer. The output of these horse-driven mixers varies from 26½ to 53 cubic feet an hour.

The moulding is done on a table before which the moulder stands. A wooden brick-mould is shown in Fig. 77. Iron moulds or wooden ones strengthened by iron bands, may also be used. In some localities two moulds, fitting together, are employed; in others the mould instead of being a simple framework has a bottom to it.

To prevent the body sticking to it, the mould is first dipped in a bucket of water, or well dusted over with sand. The former method gives the bricks a more pleasing appearance, but they are more liable to split in drying.

The moulder takes up a slightly larger quantity of the body than is necessary, throws it sharply into the mould and afterwards levels the upper surface with a scraper. When the mould has no bottom, it is drawn to the edge of the table, then, by putting the hand underneath,[1] it is turned over in such a way as to set it on edge. It is then carried to the floor where it is turned over again, so that the face which was uppermost at first is placed on the ground. The slight shock given while putting the mould on the floor loosens the brick, so that it readily falls out of the mould when the latter is raised vertically. In some localities the mould instead of being carried, is emptied on to a little board, a second board is then laid on the brick, and the whole is taken up to the floor, the brick being then held vertically between the boards and deposited by drawing them away. If the mould has a bottom to it it is turned over, so as to discharge the brick on to the floor.

Moulders of different nationalities each have their special methods.

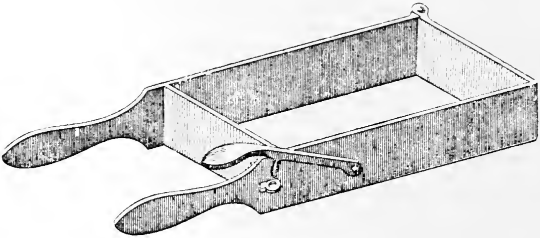


FIG. 182.—Mould which can be opened.

They usually work in gangs composed of the moulder and one, two or three women and children, who help to carry the bricks and take them out of the moulds. Under the most favourable circumstances a moulding gang may make 600 to 700 bricks an hour, but there will be many defective ones, because the body used is too soft. The stiffer the body the better the quality, but the lower the output. To make bricks of good appearance and of best quality, it is necessary to use a body of such a stiffness that it is not easy to take them out of the moulds just mentioned. Those which can be taken to pieces (open moulds) are preferable and may be constructed in various ways, the most usual type being shown in Fig. 182. In this case the quantity produced is reduced to 150 or 200 bricks an hour.

Moulding by Machinery.—In the first machines used for making bricks, the hand moulding was naturally imitated, the idea being to introduce an excess of body which was rather soft into a series of moulds, and to compress by passing these moulds under a rotatory cylinder.

[[1] Skilled moulders can turn the mould without placing their hand underneath it.—A. B. S.]

The bodies were propelled by paddles or screws in a pug-mill; sometimes the bottom of the mould was movable, and by raising it the pressure was increased.

These machines are no longer used, except to a very limited extent, as with a soft body moulding by hand is the best and the most economical method of working. It has the disadvantage of producing bricks which cannot be handled, and require considerable space for drying, shrink much, and being very porous have little power of resistance. If, then, in making by machinery, a body as soft as that for hand moulding is used the same disadvantages are experienced, so that machine moulding is useless if stiffer bodies cannot be used, so as to make goods which can more easily be handled, piled up, and dried. *Soft-mud* machines are much used in the United States. They consist of six wooden moulds joined together, strengthened by iron facings, similar to those shown in Fig. 183; they are placed under the press, which fills them, compresses the body and pushes them on to a board from which they are taken off, while a new group of moulds is put in their place. Fig. 184 represents the whole machine, comprising a vertical pug-mill; in Fig. 185 a horizontal pug-mill is used. The output of these machines is 2500 to 3000 bricks an hour. The direct expenses of working are always higher if machines are used. [In England the machines shown, which imitate hand moulding, are successfully used, and in America they are very popular, though the number of materials for which they are suitable is very limited.—A. B. S.]

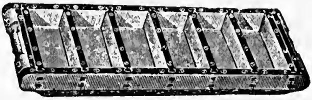


FIG. 183.—Multiple mould.

At the present time there are two chief methods for machine moulding plain bricks: (1) expression from half-soft or half-stiff bodies, and (2) moulding in a press.

In some cases the bricks made, either by hand or by expression, may be repressed to improve their appearance.

Manufacture by Expression.—When being made by expression, the stiffer body must necessarily be more plastic than for hand moulding. It is prepared as described in Chapter IV. (p. 143 *et seq.*), being usually rolled and then mixed.

The dies (p. 110) are usually lubricated with water. The bar of clay produced corresponds in width and depth to the length and breadth of the brick, and it is cut in pieces the size desired for the bricks. Dies of this kind, called *cross cut,* make bricks which are smooth on all the visible surfaces, while the two large surfaces which receive the mortar are rougher by being cut with a metal wire. In some cases, the bar of clay corresponds to the breadth and thickness of the brick, the cutting then being done at intervals equal to the length. With a large machine a greater breadth can be given to the bar of clay, and it can be cut as it comes out of the die by means of several wires stretched across, as shown in Fig. 186. The space between these wires is equal to the thickness of the brick, the height of the die equal to the breadth of the brick, so that it is necessary to cut the parallel bars into pieces equal to the length of a brick. With this die, termed *longitudinal cut*, only the two long surfaces are smooth, all the others—being cut by wires—are rough. Among the five classes of *propellers* used in pottery (p. 112) those with pistons are not used for making plain bricks, on account of their small

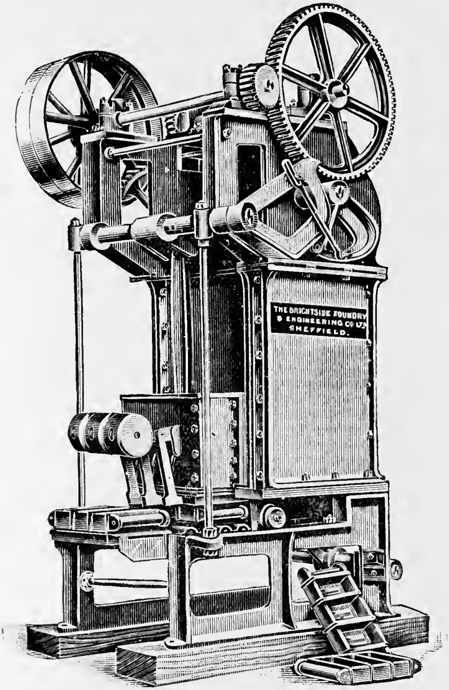


Fig. 184.—Machine for sand-stock bricks.

delivery. An arrangement of *propellers with blades*, or *pug-mill*, is generally used.

Screw propellers are chiefly used, and their invention has made a great advance in the making of plain bricks. The screw is seldom used for the propeller alone, but generally serves at the same time as an horizontal mixer, the hinder part of it being composed of movable and fixed paddles, a description of which has been given on

FIG. 185.—"Monarch" brick-machine.

page 87; these act as a mixer, while the front part has a regular helix form (Fig. 69), and serves as a propeller.

The dimensions of these different parts, the inclination of the passage, and the speed of rotation, must be adjusted to the stiffness and plasticity of the body. The most suitable consistency is that which allows of five to ten rows of bricks to be piled up on coming out of the machine. If it is softer, it has the disadvantage of bricks moulded by hand, and if stiffer, the power expended becomes very considerable. The plasticity of the material should be sufficient for it to take a regular shape, without being torn when it comes out of the die; but a too plastic body should be avoided as it has the same disadvantages as too stiff an one, that is, an abnormal increase of power is required or the output is greatly reduced.

When the body does not contain gravel or stones, it may be put direct into the pug-mill; in other cases it must first be passed through a pair of rollers or otherwise crushed.

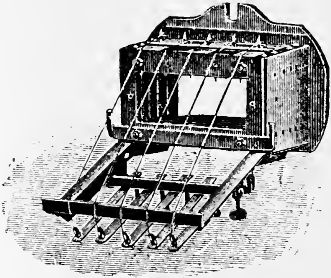


Fig. 186.—Die for plain bricks.

Figure 187 shows a machine much used to work up the more difficult bodies. It has two sets of rollers, placed immediately over the pug-mill to push the body against the blades, which rotate in an opposite direction to that of the screw. The output of these machines varies from 1000 to 4000 bricks an hour, using 10 to 30 horse-power.

Figure 188 represents a machine of the same kind, in which only one pair of rollers is used. This is placed directly over the pug-mill so as to push the body into it. These machines produce 500 to 2000 bricks an hour, for an expenditure of 4 to 10 horse-power.

A large number of machine manufacturers make similar machines differing from each other chiefly in the structure of the details, thus, some machines, instead of having only one die plate, have two placed side by side and inclined to the axis of the screw. This arrangement —by making the passage of the body more difficult—greatly increases the power expended, and it is not to be recommended.

A screw machine constructed by Messrs. Chamber Brothers & Co., of Philadelphia, shown in Fig. 189, differs from the preceding ones and has some interesting features. The rolling is done, if required, by crushing rolls placed on the ground, and joined to a high hopper over the mixer by an endless belt.

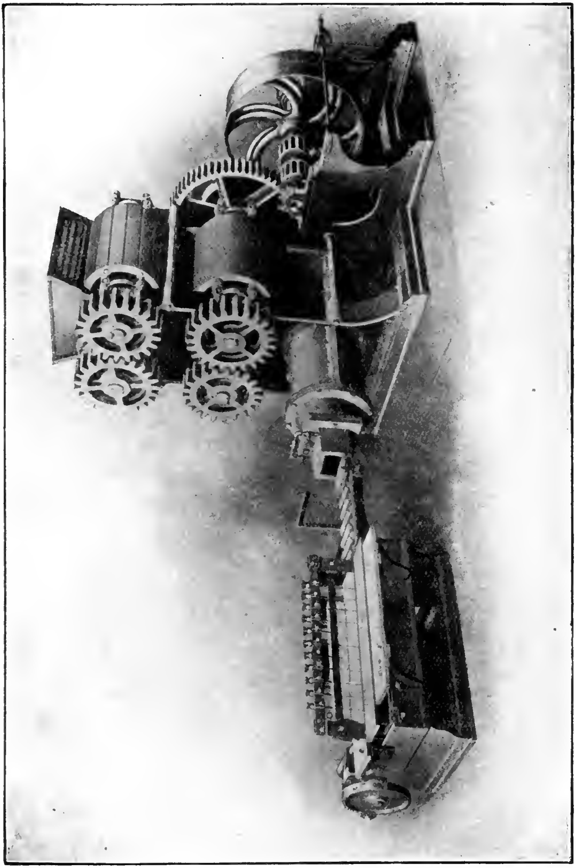


Fig. 187.—Brick machine for tough clays.

A small cylinder with a rectangular section forces the clay against the blades of the screw. This is composed of two quite distinct parts.

One in the cylindrical body is a mixer with blades; the other is a truncated helix propeller. The bar of clay has for its width and height the width and thickness of a brick. The clay comes out of a die, the walls of which are heated with steam. A hopper, placed above the outlet, contains sand, which is dusted on to the bar of body by a separate mechanism. A safety valve, kept in place by a counter-weight, prevents the pressure on the body from exceeding a certain limit. The output of this machine may reach 4000 bricks an hour.

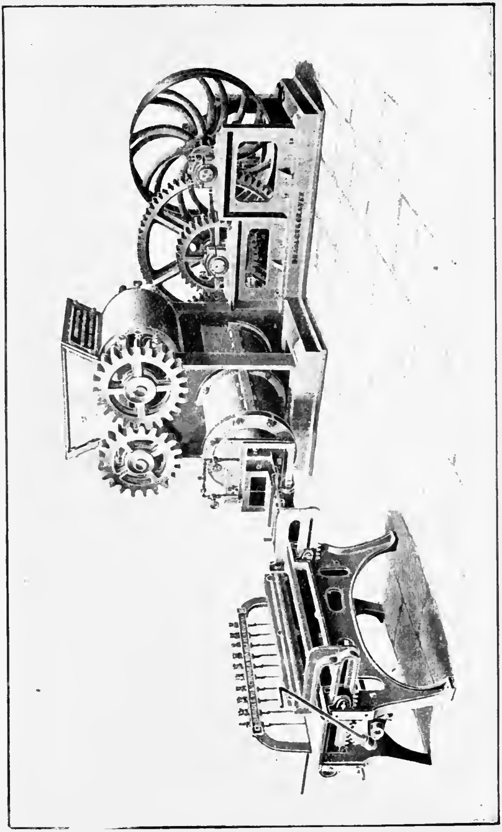


FIG. 188. Brick machine.

In all these machines movable *cutting apparatus* ought to be used (p. 116) such as those shown in Figs. 187 and 188. In these, the wire after cutting the clay tends to tear the edges as it goes out. This may be remedied by using movable frames which cut in a downward direction.

The cut bricks are raised from the board with the hands or by boards. The cutting table limits the output of the machines to 2500 or 3000 bricks an hour.

Automatic cutters have been tried, but for the most part without any satisfactory result, the machine invented by Chamber Brothers & Co., notwithstanding its complication, being one of the best solutions of the problem. As shown in Fig. 190, which is a continuation of Fig. 189, the bar of clay is received on an endless band which moves with a speed equal to that of the body and is regulated by a sloping lever. At the end of this endless band a vertical wheel turns with a speed corresponding to that of the band, and is furnished with seven arms carrying wires, which, by their circular movement, cut off the bricks to the desired length. The bricks, when thus cut off, are pushed on to a second endless band, moving more rapidly, so that they are separated from one another, and can afterwards be taken up separately by a series of workmen, who stand by the table on which this second endless band runs. By this process 200 bricks a minute can be made.

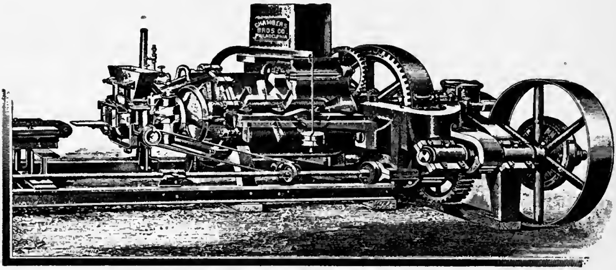


Fig. 189.—Chambers' brick machine.

The *propellers with two screws* mentioned on page 115 are often used in the manufacture of plain bricks. Two tangential screws are not very good for pugging, and the goods when they come out of the die are sometimes unsound. These machines are always surmounted by a pair of rollers, to crush the body. They resemble machines with one screw. Their output varies, according to size, from 160 to 1500 bricks an hour for an expenditure of from three to ten horse-power.

Propellers with cylinders, though more logical than the preceding ones, do not give good results in the manufacture of plain bricks except when using soft bodies. It can easily be understood that the passing from a large and very thin section, like that which exists between the cylinder propellers, to a section that is almost square in the die for plain bricks, will only work when the body is a plastic one, and not stiff.

Manufacture with a press involves the use of a dry or semi-dry body. That is to say, the raw materials must be in a state of a more or less damp dust, and not pasty. The goods thus obtained have a granular appearance and need more burning to replace, by vitrification, the absence of cohesion in the body possessed by plastic bricks. This process is used for rocky or sandy materials, the pressure used partly making up for the lack of plasticity; its chief advantage being cheap manufacture, simplified preparation of the body and avoidance of drying. The body is usually a sandy clay or shale, and is simply reduced to a homogeneous powder which is given as much dampness as corresponds to the pressure which can be saved. For large quantities, either granulators or mixers are used.

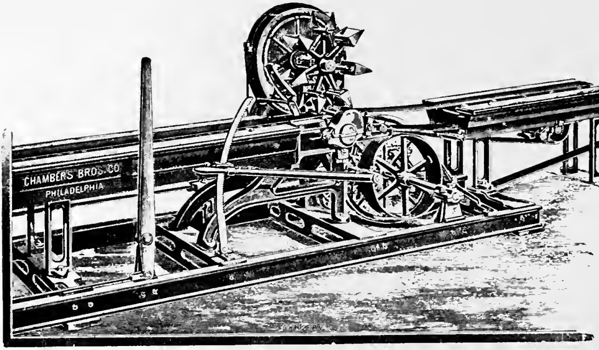


FIG. 190.—Chambers' cutting appliance.

As there is a very large number of presses on very different systems, a complete description of them would only have a slight interest; the following are the chief types.

Moulds are always filled by pressure and are usually arranged as described on page 128.

For small quantities, a pressure by shock may be made use of, of which an example is given in Fig. 92. Fig. 191 shows a machine of the same kind which is much used in small brick-fields. The two moulds, which are usually of bronze, have movable bottoms and a cover with hinges, which is closed by means of a hook, after the moulds have been filled by hand with the dry body. By using a double lever, a pressure is exerted on the bottom, then the cover is opened, and by means of a pedal the bottom is raised up so that the brick may be easily taken out. A moulder with two helpers can thus make about 300 bricks an hour.

For larger quantities and for goods of a better quality power-driven presses with a continuous motion are used. The presses constructed by MM. Boulet et Cie., shown in Fig. 97, is an example of this kind of machine. It can produce 800 to 1000 bricks an hour, with an expenditure of about three horse-power.

[In the machine shown in Fig. 192 the two moulds are filled with clay dust, the plunger is lowered first rapidly, then after a short time of stopping, it gives a second pressure more firmly, after which the bottoms of the moulds are raised in their turn to exert a third pressure. The bricks are taken out of the moulds as in the preceding presses by raising the bottoms. A screw placed in front acting on one corner allows the thickness of the brick and the pressure to be regulated. The moulds and pipes are heated by steam to prevent the clay from sticking to them.

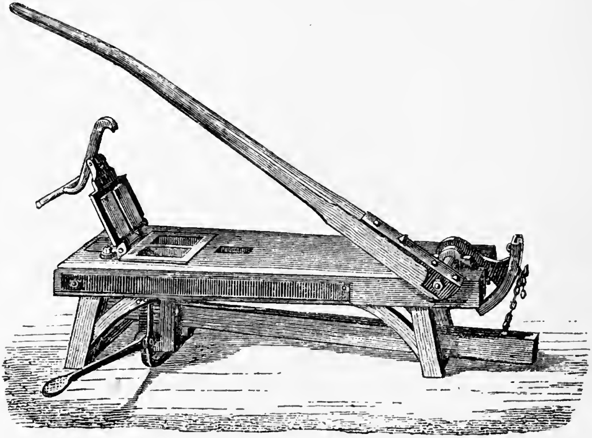


FIG. 191.—Hand-power lever-press (old type).

Hydraulic presses are not used for making plain bricks because of their small output.

By using damper bodies, less powerful machines may be employed with good result. In all the preceding machines the shape of the moulds is the same, and the pressure is always exerted by the plunger and also by the bottom plate. This arrangement is not, however, obligatory, and some presses are differently constructed.

In Fig. 193 the clay is put into a pug-mill with a shaft, which pushes the clay into a mould, on the circumference of a drum which carries eight moulds. This drum makes an eighth turn each time and then stops. In the first position they are filled with the body; in the third the rough brick is pushed out of the mould on to the table of the repress, and is automatically lubricated. The yield of this machine is 1200 bricks an hour.

Many other types of press not mentioned by Bourry are now at work and are regarded as standard machines. The publishers of this treatise will be pleased to supply further information on request, and to suggest more recent books in which these machines are described.—A. B. S.]

Repressing.—Bricks may be manufactured in two separate operations. In the first, the bricks are fashioned of plastic body by one of the methods already described; then when they have been dried and are of a leathery consistency they are pressed so as to give them a true parallelopipedal form, with hollows ("frogs") on the two large faces. The object of these frogs is to force the body to push towards the edge when pressed, and to diminish the thickness of the joints by leaving a place for the mortar.

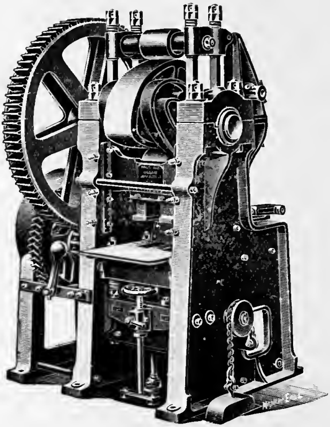


FIG. 192.—Nuneaton press.

Represses are similar to ordinary presses and may work either by a lever or by other mechanical pressure. Generally the represses worked by hand have a lever; they are portable, so that they may be moved about the drying ground or dryer and thus avoid the unnecessary carriage of the bricks. Fig. 194 shows the ordinary type of lever repress. The brick is placed on the bottom of the die by an assistant, then the workman standing on the platform shown in front, seizes the lever and throws it violently down, leaning on it to make it bear the weight of his body. By this movement the bottom of the mould is lifted, the brick is forced into the die, then the plunger presses on to the brick. The lever is raised after the stroke, and the workman then takes the brick out of the mould, and it is carried away by the labourer and replaced by another. In this way 350 to 400 bricks an hour can be repressed.

If the goods, though of a suitable consistency for repressing, are not sufficiently plastic for pressing by hand, they may be treated to a much greater pressure in a power press, and would stick to the walls if the latter were not carefully lubricated with vegetable or mineral oils diluted with water, or else with an emulsion of soap.

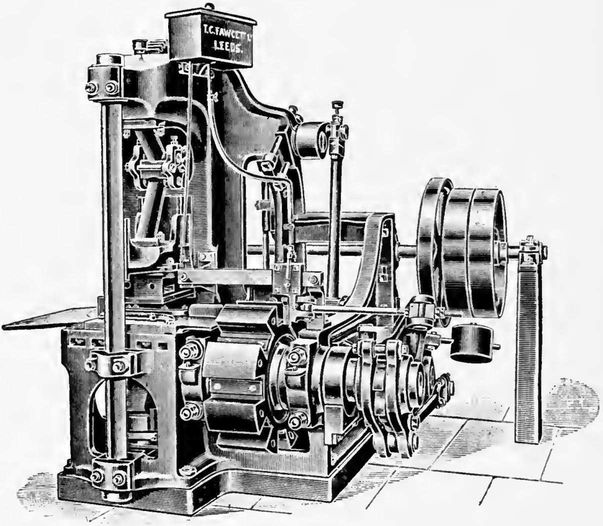


Fig. 193.—Fawcett's brick machine.

When the clay contains lime the lubricant may become saponified, forming calcareous salts which are destroyed in burning, but which leave a residue of lime on the surfaces of the brick and thus produces whitish blotches which it is impossible to remove. To avoid this inconvenience, which is often very injurious, oils which do not contain fatty acids must be used.

A less powerful repress is shown in Fig. 195. It carries three moulds on a turn-table, which allows of one brick being taken out and another being ready for lubricating and being ready for putting in the die. Fig. 196 shows a third arrangement, in which the stroke is produced by the great power accumulated in a very heavy fly-wheel.

Repressing may also be done in a machine worked by an engine, which then works continuously. The larger output of these machines, which are necessarily fixed ones, does not often make up for the increased expense caused by carrying the bricks. The patterns of repressing machines of this kind are numerous; the following are typical examples.

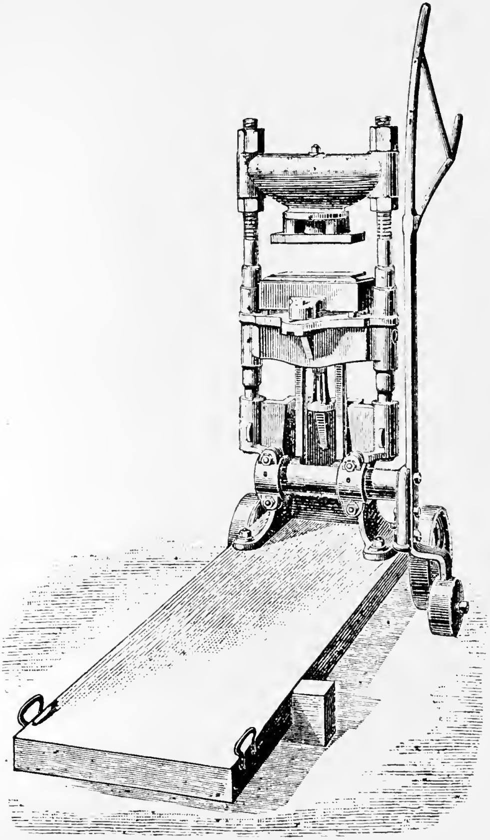


FIG. 194.—Portable lever-press.

The repress, Fig. 197, constructed by Clayton, resembles the one

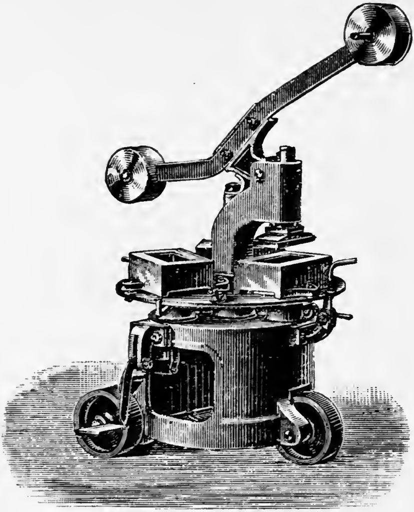


FIG. 195.—Portable repress (French type).

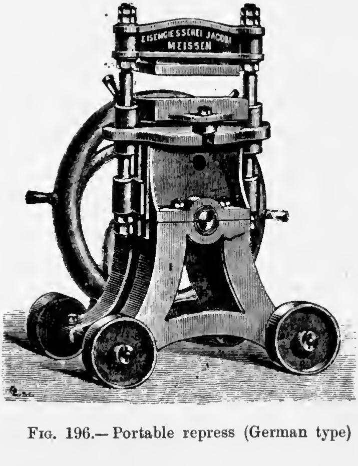


FIG. 196.—Portable repress (German type)

just described. Two eccentric wheels mounted on the drying shaft move the bottom of the die and the plunger. On the other hand, the machine (Fig. 198) by Pinette is arranged horizontally. The bricks are put on to a travelling slide in front of the machine which carries them opposite the die where a plunger pushes them in and presses them. The bottom of the die is pushed up in its turn, and puts the repressed brick back on the slide, which carries the finished brick to the other side, whence it is removed. This machine is said to repress 1000 bricks an hour. Fig. 199 shows a repress constructed by Frey, in which the bricks are placed on an endless band which carries them into the machine, where they are pressed laterally by a cam, and pass out on the other side on to the same endless band. Two rollers automatically lubricate the bricks as they enter. The output is a little larger than that of the preceding machine.

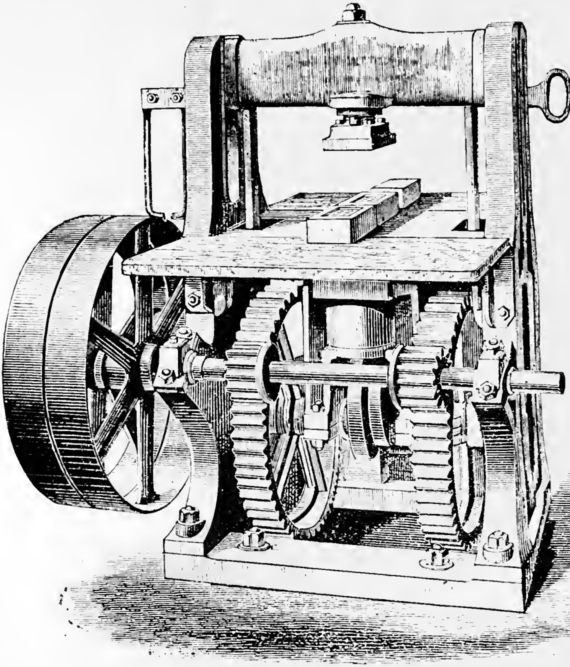


FIG. 197.—Clayton's repress.

[Power-driven represses used in Great Britain are of entirely different appearance though similar in principle.—A. B. S.]

Repressing only improves the appearance of bricks and not their

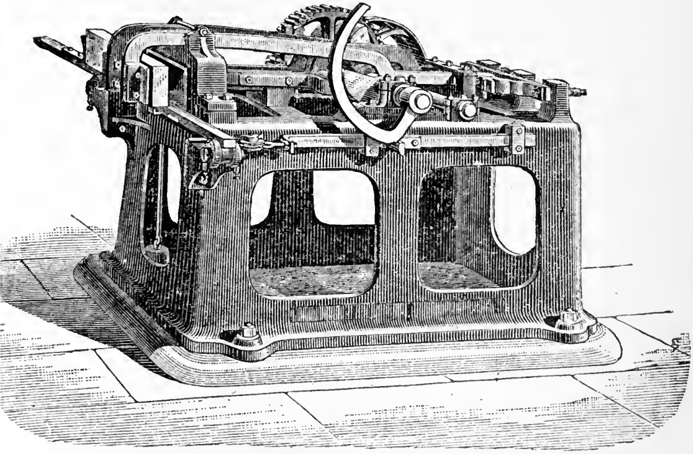


FIG. 198.—Pinette's repress.

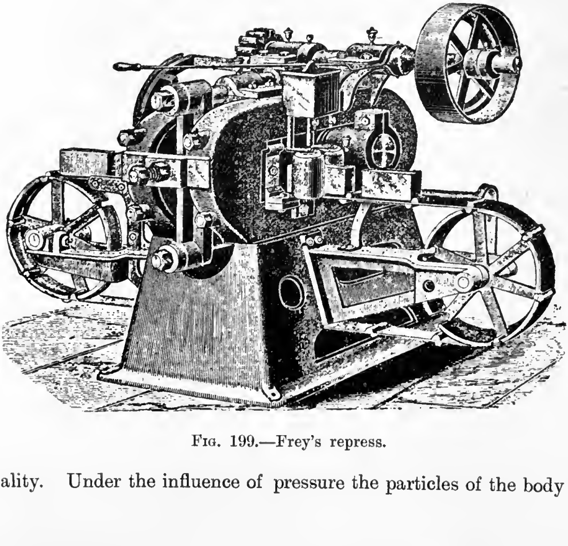
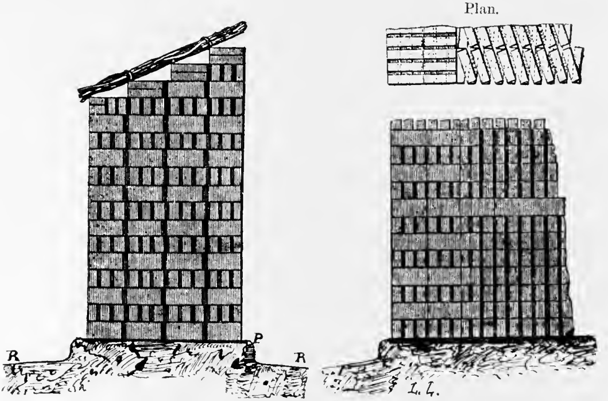


FIG. 199.—Frey's repress.

quality. Under the influence of pressure the particles of the body are put out of place and to a certain extent pressed together; but as their plasticity is very weak, they blend very badly together, and cracks are left in the goods which lessen the resistance to crushing.

Drying bricks is a difficult operation, on account of the large quantity of water which has to be evaporated. Thus, bricks, when moulded, may contain about 25 per cent of water if made by hand; or 15 to 20 per cent when made by the wire-cut process. When moulded of dry body this proportion is reduced to 5 or 10 per cent, the water present is 20 per cent, 17·28 ozs. of water per brick must be evaporated, or 1102 lb. per thousand.

Bricks are dried by one of four processes: (1) drying in the open air; (2) drying on shelves which are either isolated or grouped together in a building; (3) drying in ventilated drying sheds, using the waste heat of the kilns; (4) drying in warmed and ventilated drying sheds.



End View. Part of Side.

Fig. 200.—Hacks (French method).

Drying in the open air is only used when the bricks are moulded by hand. On large surfaces of prepared ground, slightly sloping so that the water drains off naturally, the bricks are placed as they come out of the mould, flat down, side by side. When they have hardened sufficiently they are spread out, then after drying again for a time, they are piled up into a heap—in *hacks*. [In England the bricks are so arranged that the hacks are formed at first and not at a later stage as described.—A. B. S.] These hacks are placed on the higher parts of the ground, the lower row often being of burned bricks, to avoid damp. When there is any fear of rain, the hacks are covered over with straw matting, planks, or other light movable coverings. Sometimes one side of them is covered as well, to prevent the rain being blown on them by the wind. In these hacks the bricks finish drying.

Drying on shelves is done either in little separate sheds, or in sheds that contain several rows of stages, or even in buildings constructed over the kilns. Figs. 106, 107 and 109 show the different arrangements in general use. When the bricks are made of soft body, they should be put on little boards, but if the body is stiff or dry they are at once placed on two strips fixed to the upright of the stages. Fig. 201 shows both these arrangements.

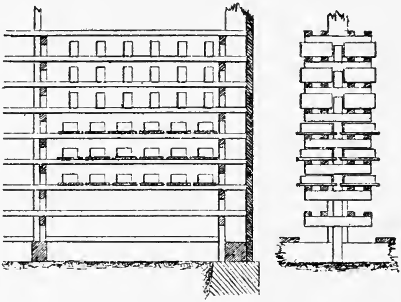


FIG. 201.—Drying racks.

Bricks are sometimes put on boards, about 4 to 5 feet long, directly they are made, and these boards are carried to the shelves, where they take the place of the strips in Fig. 201. In some cases, movable shelves are formed of planks with "legs" at their ends so that they may be piled up, as shown in Fig. 202.

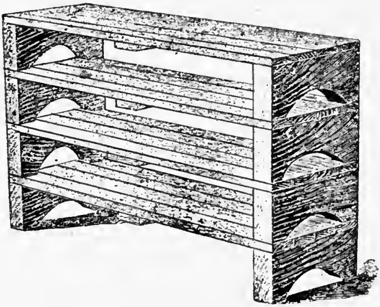


FIG. 202.—Drying stools.

Wheelbarrows are chiefly used to carry the bricks from one place to another because they can easily be moved about between the rows of the shelves. Those used for carrying green bricks are flat in form, as shown in Fig. 203, and should have good springs. For transporting dry bricks, simple flat wheelbarrows, with backs, are used. When it is necessary to raise the bricks on to the shelves the barrows may be pushed up inclined planes, or they may be raised by a lift.

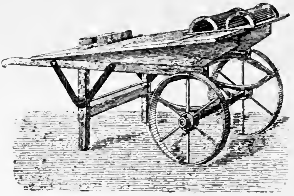


FIG. 203.—Off-bearing barrow.

Wagons are only used in larger works, because they need a considerable amount of rails to be laid if they are to be carried along between the stages. For green bricks, the wagons shown in Figs. 204 and 205 are used, and for dry bricks wagons of the usual flat shape. In some cases, wagons suspended from an overhead railway are used. This method, when the arrangement of the works permits of it, is often more practicable than the preceding one.

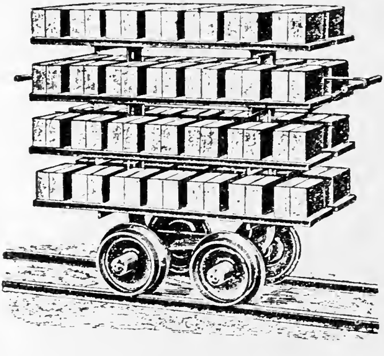


FIG. 204.—Brick wagon or car.

When the making is done in a building which contains the drying sheds, elevators may be arranged by the side of the machines, and the bricks, being placed in them, can at once be taken to the different floors, put on wheelbarrows and then spread on the shelves. Fig. 206 represents an elevator of this kind, composed of two double pulleys on which turns a chain, carrying boards used for receiving the goods which are suspended in such a way as to remain horizontal while being raised.

The length of time needed for drying on the shelves depends on the arrangement of them and on the weather. On the ground it varies from two to five weeks in favourable seasons. It can be reduced when shelves are used, and under better conditions to ten or even eight days. The speed of drying at a height of 10 feet is double that on the ground itself, and is treble at the height of 20 feet.

By arranging drying sheds over the kilns as shown in Fig. 109 the bricks can be dried at any season if the building is well closed and the weather not too severe. The length of drying, nevertheless, depends largely on the season, even with the best of such arrangements. It is double, or even treble, in winter what it is in summer.

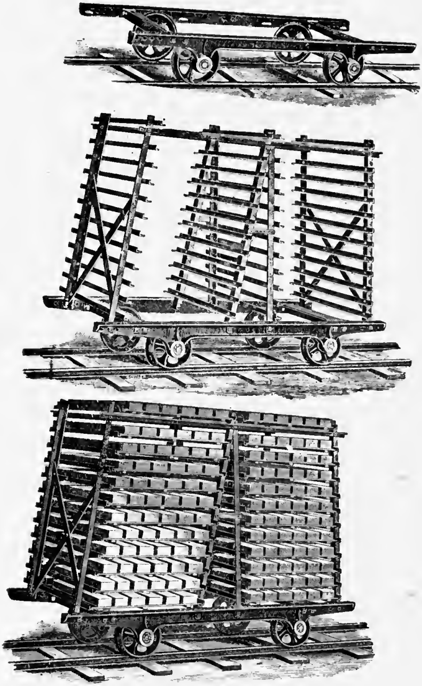


Fig. 205.—Brick wagons.

The drying can be noticeably improved by arranging fans in suitable places, which may be used in calm weather, when the natural draught is insufficient.

Ventilated drying sheds, using waste heat from the kilns, may also be employed (Fig. 110). The kilns are always those with continuous firing, and the ventilation is done by chimneys or fans. Several

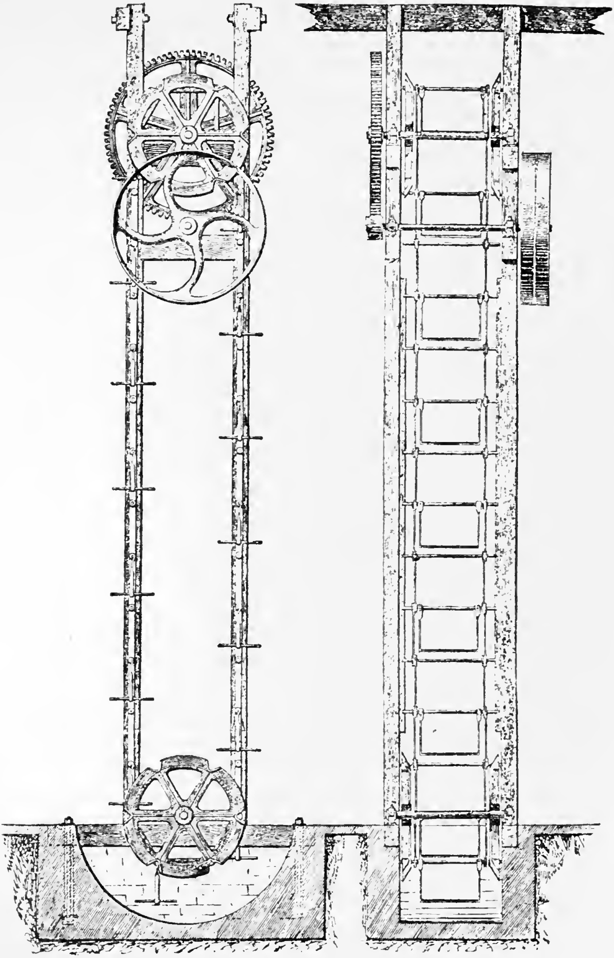


Fig. 206.—Brick elevator.

arrangements have been proposed by Ohle (Fig. 110), Cohr, Ruhme, Hoffmann, etc., but they are no better than drying by ventilation in a building over the kilns, especially when a fan is used for the latter.[1]

The heat necessary for evaporating one kilogramme of water contained in the body is (p. 146)

$$C = \frac{1000\,(T - \theta)\,c}{E\,(T - t)}$$

with the condition

$$E\,(T - t) \overline{<} P - p.$$

If the outside temperature (θ) is equal to 0° and $T = 20°$, the heat expended is at a minimum for $t = 11°$, in which case $C = 1360$ calories (p. 150). This number must be increased from 50 to 100 per cent according to the installation, and becomes, under the most favourable conditions, equal to 2000 calories.

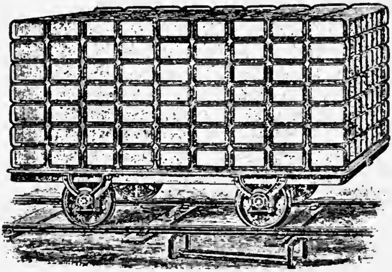


Fig. 207.—Brick wagon.

If, on the other hand, a body has 10 per cent of water to be evaporated, 1 kilogramme of burned brick will contain 150 gr. in all, thus needing 300 calories. But the quantity of heat a continuous kiln can furnish while burning bricks will scarcely exceed more than 200 calories per kilogramme of burned body, so that it is impossible to dry bricks solely by the waste heat of the continuous kilns, though this is often the only heat available in brickfields which are worked economically. It is this fact which has caused heated and ventilated drying-sheds to be used (Figs. 113, 114, 115, 116, 117 and 118). When the shelves are fixed, the bricks are placed as already described. Otherwise, wagons are used which carry fixed shelves on movable iron supports, as shown in Fig. 207. These wagons, loaded with bricks, are then put in the drying-sheds.

There are several other kinds of drying-sheds; Fig. 208 shows one

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[[1] Few clay-working experts in Great Britain would agree with this statement as applied to the British Isles.—A. B. S.]

built by Chamber Brothers & Co. It is of type C (p. 156, Fig. 114), in which the bricks are not moved while being dried, and is composed of a series of separate tunnels, heated at one end and furnished with a chimney at the other.

Figure 209*a* shows a different type, in which the goods are moved in the same direction as the air, the latter being heated progressively by a subterranean set of pipes containing steam. It is constructed by Wolff & Co.

Lastly, Fig. 209*b* represents Moeller and Pfeiffer's drying-shed, the plan of which is given in Fig. 118.

In order to calculate the dimensions for drying-sheds and the number of wagons, the time needed for drying must be known or calculated. Under favourable conditions this time can be reduced to twenty or twenty-four hours, but it is often much longer.

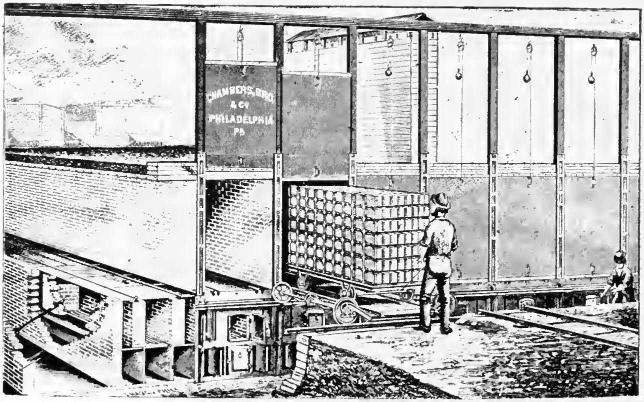
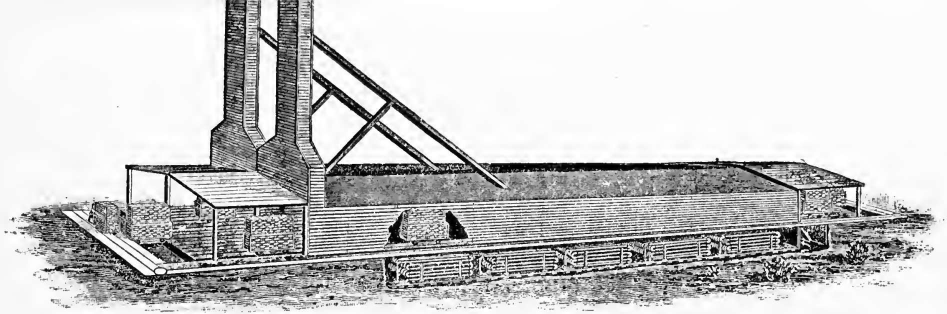


FIG. 208.—Tunnel dryer.

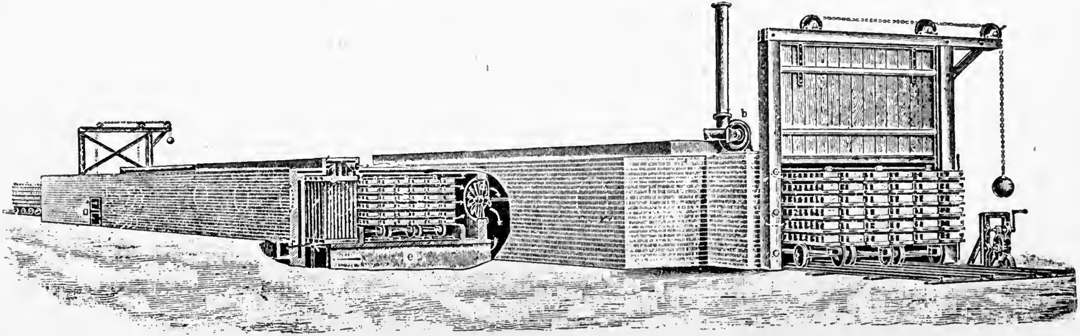
Chapter VI. allows of the value being compared and of the consumption of fuel being estimated for the different drying-sheds. Heated drying-sheds are suitable for countries with a cold or damp climate, as in Great Britain. It seems hardly likely under the present condition of the brick industry that it would be advantageous to use these processes where, as is usual in France, bricks can be dried in winter on shelves suitably arranged above the kilns.

Burning ordinary plain bricks is sometimes done in open kilns, or *clamps*. This process usually accompanies moulding by hand, and as it requires special workmen it need not be described in detail.

The site for the kiln should be away from water and close to the drying bricks. A first layer of burned bricks is made as a square founda-



(a)



(b)

tion (Fig. 210), measuring 11 to 16 yards a side. On this is put a second layer, the burned bricks being placed perpendicularly to the first ones, and also separated.

The third layer is also made of bricks laid down edgeways, but with a space of $\frac{3}{4}$ to $1\frac{1}{8}$ inches between them. Having reached this height, the channels that cross the kiln are filled with wood and shavings, then the fourth layer, composed of two courses of bricks flat down, separated from one another as in the preceding case, is put on. At the fifth layer, the channels are covered over with flat bricks, the others being placed edgewise at intervals like those already mentioned. The sixth layer is put perpendicularly to the fifth, then the seventh like the fifth, the eighth like the sixth, and so on. The bricks at the edges are closer together, put more carefully, and placed in such a way as to give a slight roughness to the faces, which are covered over with a layer of clay.

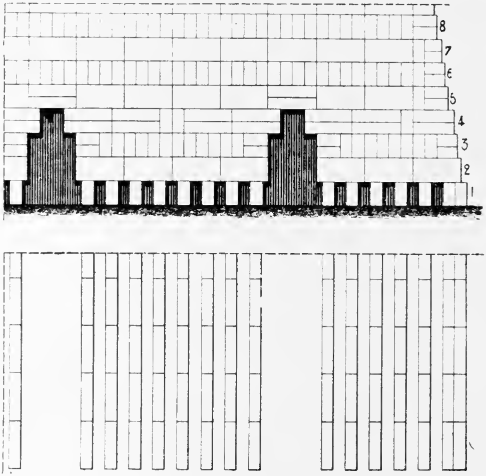


Fig. 210.—Clamp.

Between the sixth and seventh layer, coal is spread evenly about,[1] and the same is done every three layers. The first seven or nine layers are of burned bricks, as they form the foot of the kiln, the others are green bricks. When the foot is finished, which will take a gang of ten to fifteen men a whole day, in the evening the wood put in the channels is lighted, and the fire is fed with faggots, blocks of wood and coal. The next day the setting is continued so as to put on three or four layers.

When the fire has well caught the first layer of coal, which can be told by the smoke, which ought to come evenly out of the whole surface

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[1] [In Southern England this fuel is mixed with the clay.—A.B.S.]

of the clamp, the speed of the combustion is regulated by lessening the size of the openings which let the air in. Each day the setting ought to follow the process of combustion, which has a tendency to become quicker, so that towards the end of the burning as many as four to six layers are put on. The men usually stop when the kiln is about 8 feet high, and the last layer is put on closer together than the others.

With such a primitive method of burning it is natural that accidents should be frequent. If the fuel is not spread evenly, the entrance for the air is lessened on one side where it is too thick, and any "chimneys" that may occur are stopped up from above by putting fuel into them. In the same way the fire is quickened in the parts where it is too slow, by unstopping the air entrances. As the centre is necessarily more burned than the edges, it sinks more, and the difference in level is put right by placing a layer in which the bricks are edgeways in the centre, and sloping or flat down at the edges. But the most serious accident that can happen is rain, from which it is difficult to protect such a kiln, even with movable coverings. Hence burning in the open can only be done in the summer.

These clamps contain 200,000 to 1,000,000 bricks. Those most used are for 500,000, of which about a sixth are waste or under-burned. The consumption of fuel varies from 63 to 81 lb. of coal per 1000 bricks, according to the quality of the coal and to the size of the kiln.

Burning in the open is used in the North of France, in Belgium and in England, when the body is sandy. Its chief value is for small temporary brickfields, formed near to and in view of a particular building-site [but it is also regarded as essential for "London stocks"].

For small works in the Colonies, *intermittent kilns with ascending flames* of the type shown in Fig. 148 may be used, the heating being either with coal, wood, grass, straw or any other fuel.

Besides the two methods just described, bricks are burned in continuous kilns with one gallery; it is only in very small brickfields created for local needs that use is made of semi-continuous kilns.

Kilns with continuous firing have already been described (p 219), and instead of their primitive round or oval form a rectangular form (Fig. 158) is used.

Fig. 211 represents a kiln of this kind specially intended for burning ordinary bricks. Each of the two parallel galleries is divided into six, seven, or eight compartments, each having a door for filling, a damper and an arch making a projection in the walls of the burning gallery ("drop-arch") against which the dampers are arranged. These dampers were formerly of iron plates in two or three pieces, to allow of their being put through the doors. Now they are made of paper fastened with mortar to the arch. When they need to be removed the lower part of them is simply torn away, so as to let the gaseous current pass, the paper naturally being destroyed during the burning. The openings in the walls at the side of each archway are intended specially for this operation.

The paper is bought in rolls about 40 to 56 inches wide; it is cut

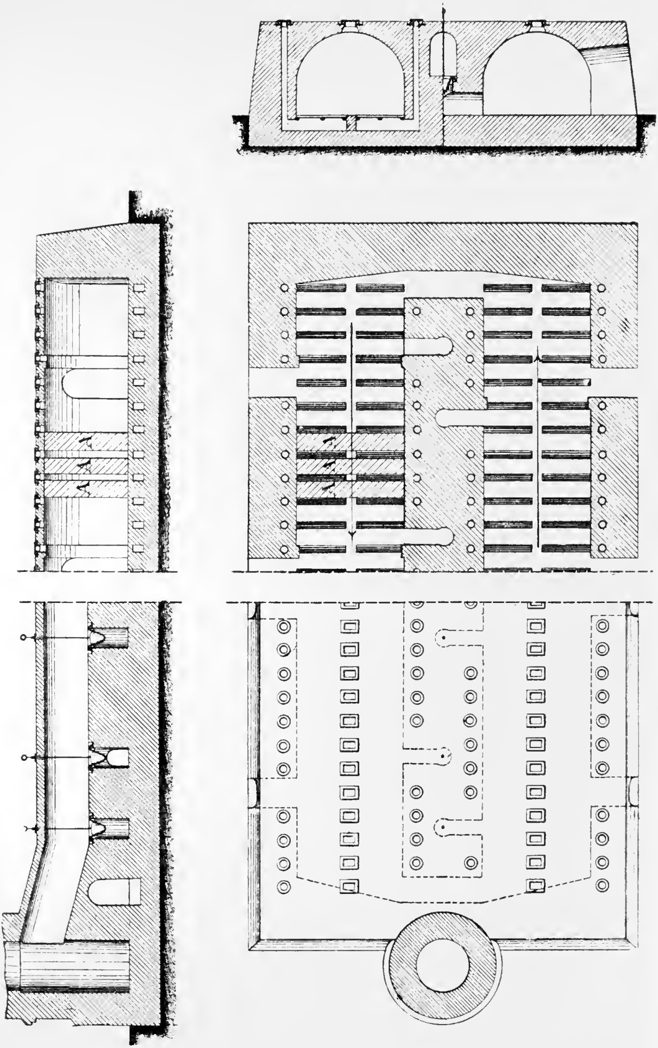

Fig. 211.—Continuous kiln.

and pasted in such a way as to be identical in shape with the opening between the chambers.

The heating is done with coal, lignite or turf, the fuel being put in through a series of openings formed in the crown about 40 inches apart and closed by cast-iron covers. The setting is arranged as shown in Fig. 133.

With a normal working, the fire advances 10 to 24 feet in twenty-four hours. For a daily yield of about 25,000 to 30,000 it is sometimes better to employ two distinct kilns.

The construction of kiln shown in Fig. 211 may be varied in several ways:—

(1) The chimney may be quite away from the kiln and either at the end or at the side (Fig. 158), though the position shown in Fig. 211 gives the best draught.

(2) The flues for carrying off the gases, instead of being placed laterally in the central wall, may be built in the outer wall or under the hearth, though these arrangements, which seem theoretically better, are [according to Bourry] of no practical advantage in spreading the heat and are more complicated in construction.

(3) The gases may also be carried off through the openings for putting in the fuel by making the latter communicate with the smoke flue by means of movable sheet-iron pipes which are displaced as the fire advances. Fig. 212 shows this arrangement in section (Siehmon & Rost), which is simple in construction, and when the goods are damp lets off the steam better and prevents it from accumulating under the crown. On the other hand, the moving of the pipes is a much longer operation than the simple raising of a valve. It is generally preferable to carry off the hot gases through special, lower flues, and when the raw goods are very damp to carry off the steam by means of upper pipes as suggested.

(4) The warming of the bricks freshly placed in the kiln sometimes needs special arrangements, and small movable fireplaces, heated with coke, are fitted to the chamber that is being warmed, a large quantity of air being also allowed to enter at a low temperature rather than a small quantity of very hot gas. These fireplaces are placed in the doorways, fixed into the outside walls or in the feedholes on top of the kiln. The warm air from the chambers which are cooling down may be carried through a special system of flues into a chamber just starting, but this does not give all the heat needed for damp goods and must be supplemented.

(5) For temporary works, the construction of the kiln may be simplified by putting part of it in the ground, and replacing the greater part of the masonry by embankments of earth, as in Fig. 213. Owing to the low cost of this construction, burning in this kiln, including the money sunk, is cheaper than in clamp or open kilns when the total number of bricks to be made is 2,000,000.

The kiln shown in Fig. 211 is intended for coal or lignite. Wood can also be used, but for heating with small wood, faggots, straw, etc., the kiln shown in Fig. 161 should be adopted. The average consumption of fuel is from 77 to 110 lb. of medium quality coal per ton of burned bricks (or 3 to 4 cwt. per 1000 bricks), according to the height of the temperature and the nature of the body.

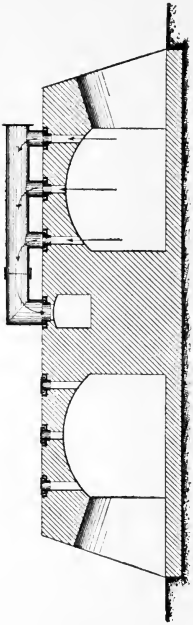

Fig. 212.—Movable flue on kiln.

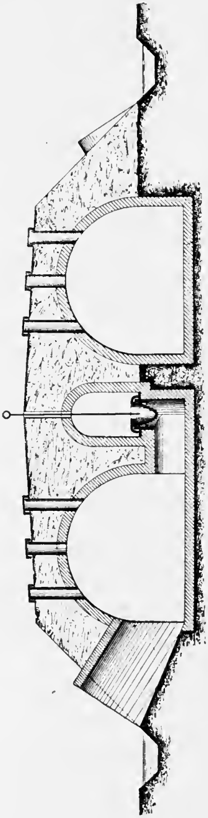

Fig. 213.—Temporary continuous kiln.

The thermic yield of continuous kilns for burning bricks can be calculated as follows:—

Heat produced by the fuel	100	Heat that is theoretically of use	90
Heat collected from cooling goods	40	Heat lost by heating the walls	20
		Heat lost by radiation	25
		Heat lost by the chimney	5
	140		140

The air is generally 1½ times that theoretically necessary. If this proportion were increased, a larger proportion of heat could be recovered and consequently the consumption of fuel could be lessened. To completely recover this heat it would be necessary to employ from 2½ to 3½ times as much air as the theoretical proportion. But this would lower the temperature so much that it limits the amount of draught. In practice, a double volume of air must not be exceeded for the lower temperatures and not more than 1½ times the theoretical quantity should be ordinarily used.

General Arrangements.—Brickworks are essentially local factories, because of the large number of deposits of clay suitable for making bricks occurring in all countries, and also the great weight of the goods in comparison to their value. The cost price of making bricks varies, except in extraordinary cases, from 12s. 6d. to 24s. 6d. per thousand, to which must be added from 20 to 50 per cent for general expenses. Any reduction in cost price due to a large output is rapidly balanced by the cost of transport, so that important brickfields are only found near large centres of consumption. [It is only fair to state that since Bourry first published this treatise the machinery used in brickmaking has been greatly improved and the cost of the manufacture is now two-thirds of the foregoing figures in up-to-date yards.—A. B. S.]

Brickworks can be divided into three classes. (1) Those using moulding by hand and burning in intermittent kilns. (2) Those using hand moulding, but burning in continuous kilns. (3) Those moulding by machinery and using continuous kilns.

When the output is below 600,000 or 1,000,000 bricks per annum the first is preferable, as there is a limit below which it is not economical to use continuous kilns. As a rule, also, the use of mechanical power is only advantageous when more than 10,000 bricks per day are made.

The maximum output of a continuous kiln is 25,000 to 30,000 bricks in twenty-four hours, which, allowing for stoppages, holidays, etc., is equal to a machine production of 30,000 to 40,000 bricks a day. For a larger output two kilns are arranged side by side in two buildings, 40 or 50 feet from one another, the making machines being between the two.[1] For more than twenty million bricks a year, two or more independent works must be built.

In all brickworks the cost of transport must be kept as low as possible, and all unnecessary handling of the goods must be avoided.

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[1] [Buhrer has conclusively shown that suitably arranged kilns can work at double the rates mentioned above if the materials are right.—A. B. S.]

(*b*) Hollow Bricks.

The manufacture of hollow bricks as an industry only dates back to 1855, but the use of them has developed considerably since then. They are principally used for the construction of partitions, light walls, and for filling in the intervals between the girders in floors.

Fig. 214 shows a number of designs of these bricks, generally used for partitions; they are from 8 to 14 inches long, 4 to 7 inches wide, and 1 to 4 inches thick.

Fig. 215 shows examples of flooring bricks. Type I. is used for light floors, and is from 15½ to 22½ inches long, 8 to 9¾ wide, and 2 to 2¾ inches thick. When the bricks rest on the lower wing of the girders of the floor it is advisable to cut them as shown in the drawing so as to make a place for the wing. Type II. is meant for solid floors with a space between the girders of 2 to 3 inches. The bricks are usually from 8½ to 11¾ inches long by 4 to 5 inches thick. Type III. is used for very strong floors intended to bear great weights.

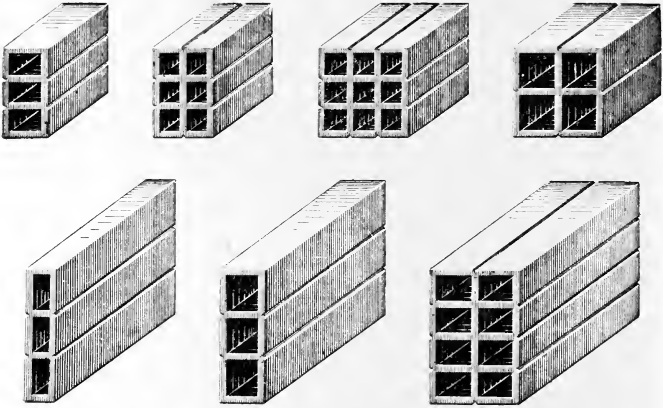

Fig. 214.—Hollow blocks.

Hollow bricks may be made in various other shapes, but to secure regular and economical working, the following dimensions should not be exceeded: 18 inches long, 10 inches wide, and 6 inches thick.

The bodies used for moulding hollow bricks should be more plastic than those for making plain bricks. They are always made by expression; the dies used for this purpose have been described in Chapter V. For small goods piston propellers ("stupids") are used (Fig. 67).

For hollow bricks with larger dimensions than those already mentioned a stiffer body must be used, as then there is less shrinkage and loss of shape.

The *drying* of hollow bricks presents no special difficulty. It is much quicker than that of plain bricks, and the goods have much less tendency to get out of shape.

The *setting* is also easy; they are put in the kiln close to one another, the internal holes being sufficient to secure the circulation of the gases and flames. The *burning* is also more rapid than that of plain bricks, and it is easier to spread the heat uniformly over the kiln.

(*c*) **Ornamental Bricks.**

When the bricks used in special buildings are to be neither painted nor covered with stucco, the bricks called ornamental bricks are often used. These are distinguished from ordinary bricks by their more regular shape, the uniformity of their colouring, their finer grain, and their great resistance to the changes of weather. The body must be better prepared and more carefully mixed than is usual for ordinary bricks, and it must, after baking, have the desired shade (p. 184).

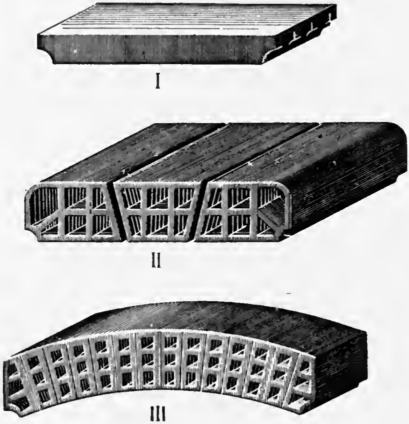

FIG. 215.—Flooring blocks.

Ornamental bricks moulded by hand are not satisfactory, but must be repressed. The brick at the left of Fig. 216 shows the type of repressed brick most used. The dimensions are those of ordinary bricks, the width and thickness, however, are slightly increased, as the joint of ·4 inch of brickwork is reduced to ·2 to ·3 inch for masonry that is to show (*facing bricks*).

Figured bricks may also be obtained by repressing (Fig. 216); a copper plate with the pattern intended for the brick hollowed on it being fitted in the ordinary mould. The pressure forces the body into the hollows of this plate, and it is taken out of the mould together with the brick, removed afterwards and replaced in the mould after it has been oiled.

When pressed out of dry body, ornamental bricks may be made of accurate dimensions, and when well burned resist the inclemency of the weather, but it is costly to make the mould for use in this method.

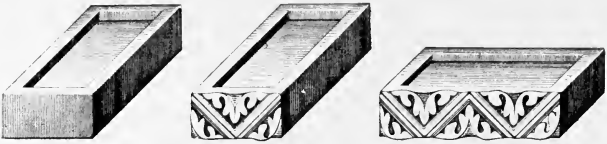

Fig. 216.—Repressed fancy bricks.

Shaping by expression is the best and most economical method of manufacture for ornamental bricks when it can be used, as the surfaces which have been in contact with the die plates have a regular grain of agreeable appearance, and a better colour than repressed bricks. Such bricks are sometimes repressed, but this should be avoided, because, with a little more care, better goods can be obtained direct from the mouthpiece. Bricks for mouldings (Fig. 217) are easily fashioned by fixing on the outer edge of the mouthpiece or die a small steel templet, with its edge turned towards the inside of the shape of the profile desired (Fig. 218). The part of the body cut off by the templet remains on the brick, and is taken away when the latter is dry and before it is placed in the kiln.

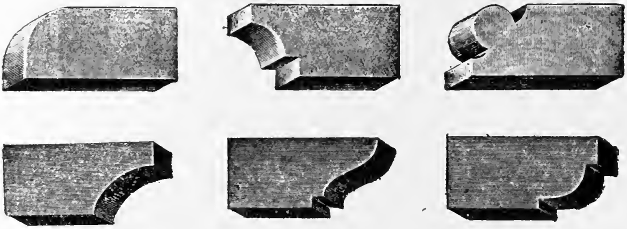

Fig. 217.—Fancy bricks for mouldings, plinths, etc.

When very regular ornamental bricks are required, and it is at the same time desirable to economize the raw material, it is better to use hollow bricks, as they are less liable to get out of shape while drying (Fig. 219).

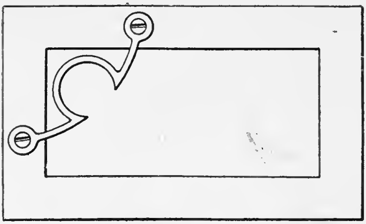

FIG. 218.—Die for plinth bricks.

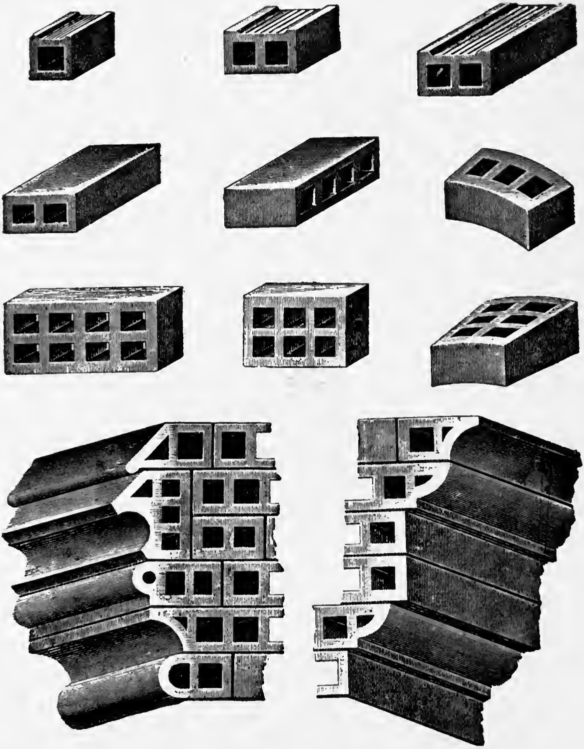

FIG. 219.—Hollow blocks.

Figs. 220, 221 and 222 show the mouthpieces used for expressing hollow bricks. The propellers have a single screw. To prevent the surface of the bricks from getting out of shape or being spoilt, they are taken from the cutting table with wooden forks which are put into the holes.

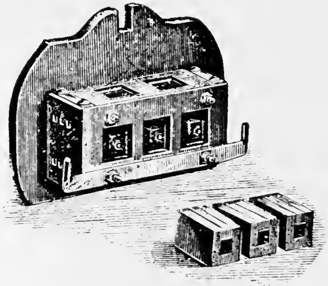

Fig. 220.—Die for hollow blocks.

Ornamental bricks which are to resist the weather must be burned at a temperature high enough for them to be scratched by iron only with difficulty. They must be made of a body containing sufficient fluxes to vitrify slightly, and enough refractory materials to prevent it from getting out of shape. Certain natural clays (terra-cotta clays) fulfil the requisite conditions; when none such are available they must be made by mixing others. To obtain clear colours, the goods must not come in contact with ashes or flame. With this object, either gas-fired continuous kilns or continuous kilns with solid fuel are used, but certain precautions, which are mentioned later, must be taken.

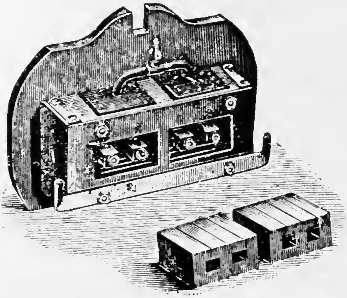

Fig. 221.—Die for hollow blocks.

When the body is not of a sufficiently uniform tint, or when the colour is unsatisfactory, the surfaces of the ornamental bricks can be covered with slip, but it is seldom that really good results can be obtained from this method.

(*d*) **Vitrified Bricks.**

Vitrified bricks cannot be scratched by iron, and only with great difficulty by steel. They form the transition between terra-cotta and stoneware. They show, at least on the surface, the beginning of vitrification; their colour is light or dark reddish-brown—sometimes even almost black—or a brownish-yellow. In the first case, the body is ferruginous, and in the second calcareous.

Vitrified bricks are used for ornamentation, but chiefly in masonry which has to bear great pressure, hence they are often called *Engineering bricks.*

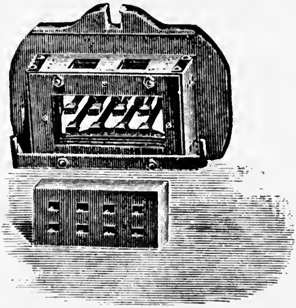

FIG. 222.—Die for hollow blocks.

They should contain a large proportion of fluxes, and also a considerable amount of crystalline silica in relatively large grains, so that while the bricks are being heated at a temperature high enough to vitrify the fluxes, the silica may remain uncombined and form a firm skeleton which prevents the mass from losing its shape. Many natural clays fulfil these conditions; to others, quartzose sand or fusible clays must be added.

Vitrified bricks are made by the same methods as the ordinary bricks, but the burning must be done at a higher temperature. They should not, however, be moulded by hand as that makes them too porous. They are best burned in continuous kilns, but are chiefly fired in single kilns (Figs. 150 and 223), as the output is limited. In some countries, such as the Netherlands and the United States, these bricks are much used for paving streets.

When wood is used as fuel, the ashes are carried along by the draught and are deposited on the surface of the bricks, forming, when the temperature is high enough, fusible alkaline silicates which cover the bricks with a thin vitreous layer.

Attempts have been made to obtain a similar effect in kilns using coal by throwing salt into them and by feeding the kilns so as to produce a reducing atmosphere. If the body is decidedly ferruginous, black bricks may be obtained with a certain metallic sheen, to which the name of *iron bricks* or *blue bricks* has been given.

(*e*) **Light Bricks.**

Light bricks are distinguished from ordinary bricks by their apparently small density and their great porosity. In America they are termed "Terra-cotta Lumber". They are made by adding combustible materials to the body; these are consumed in the burning and leave spaces (see p. 36).

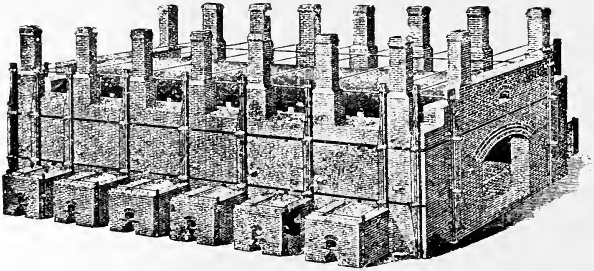

FIG. 223.—Kiln for paving bricks.

Many manufacturers of ordinary bricks add some powdered coke, coal, cinders, saw-dust, etc., to their clay, and thus obtain lighter goods, but these should hardly be reckoned as a variety of light bricks. The reduction in weight thus obtained is never very great and is less important than the other advantages obtained, viz., more rapid drying, less shrinkage, more economical burning, etc.

If sufficient coal is added to a body to make it lighter, the heat produced in burning would melt the clay, so that light bricks can only be obtained with vegetable matter of a small calorific power. The substances most used for these purposes are wood, sawdust and chopped straw. The clay must be very plastic, so as to bind together a very large quantity of organic substances, as under some conditions one-third clay must be mixed with two-thirds of sawdust. The proportion of clay may even be reduced to one-fourth of the mixture by adding straw chopped up into pieces one and a half to two inches long.

The body thus obtained must be worked in a pasty state either by hand in a mould with hinges or by forcing it through a mouthpiece, though as it cannot be cut by metallic wire the cutting tables must be replaced by circular saws. The die must be of small section, compared to the diameter of the screw, so as to thoroughly compress the body.

The drying is the same as for ordinary bricks. The burning can only be done in continuous kilns if the proportion of organic materials is adapted to the clay; beyond this amount, the heat would be too great. The burning must then be in intermittent kilns, preferably with up-draught and with a current of air strong enough to keep the temperature of the kiln low. In all these cases, only enough fuel to start the fire and to produce an even distribution of the temperature should be added.

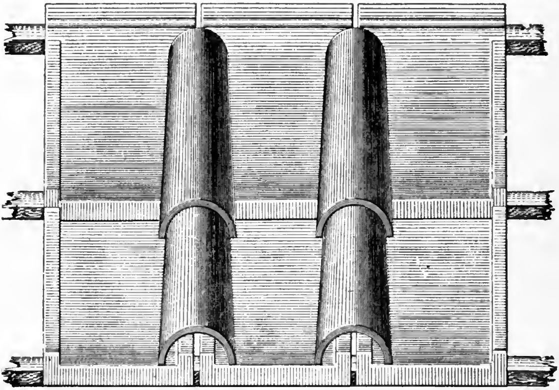

FIG. 224.—"Roman" tiles.

The light bricks thus obtained can be sawn, turned, and even planed with tools similar to those used for working in wood. This kind of pottery is chiefly used in the United States as a light fireproof material for buildings.

The Romans manufactured bricks so light that they floated on water. They made use of volcanic silicious tufa, with the addition of a small proportion of clay. Infusorial earth can also be used.

Tiles: (*a*) Ordinary Tiles.

The use of tiles dates from very ancient times. The Romans imitated the Greeks in this kind of covering, and the shapes used by these nations are wrongly called *Roman tiles* (Fig. 224), as this same pattern was used by the Chinese several centuries before our era, and since then by other nations of the Far East.

Two moulds are used, one to form a fairly thick slab, with two side ridges, and the other a slightly conical semi-cylinder. The slab is $15\frac{3}{4}$ to $31\frac{1}{2}$ inches long, $9\frac{3}{4}$ to $20\frac{3}{4}$ inches wide, and 1 to $1\frac{1}{2}$ inches thick. The lap is about $3\frac{1}{8}$ inches. This is possible by pressing down the edges to the same depth at the back of the tile. Lastly, a little fillet projecting from the upper face of the tile corresponds to a hollow in the lower face which is put over the other, for the purpose of ensuring the gaps being filled.

This tile is pleasing architecturally, and, in this respect, is superior to most modern tiles, but it is very heavy. In the Far East these round covering tiles are often decorated with flowers, which gives the roof a rich ornamental appearance.

It was in general use up to the tenth century, when it was modified to the type shown in Fig. 225, in which the slabs are of a shape which allows of their being covered without necessitating the pressing down of part of the mouldings. This modification involves an enlarging of the covering tile, and a widening of the flat tile. The arrangement shown in Fig. 226 consists of round tiles somewhat conical in shape and overlapping each other,[1] the greatest diameter being towards the top of the roof. These tiles are afterwards covered with similar tiles, arranged in exactly the opposite direction. The length varies from $16\frac{1}{2}$ to $19\frac{1}{2}$ inches, and the greatest width from 7 to 9 inches. It makes a heavy roof, but protects the buildings well from heat and is popular in South Europe.

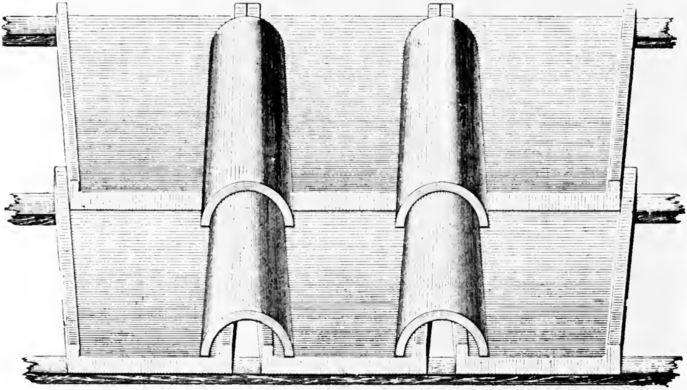

Fig. 225.—Mediæval tiles.

Rib tiles (Fig. 227), having the shape of an elongated S, are evidently derived from the round tiles, but differ from them in form, and

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[1] These are often called hollow tiles, but this name ought not to be used.

by the addition of a small projecting piece to the lower face of the tile. This "hook" is used to fix the tiles to the laths and allows of a steeply sloping roof.

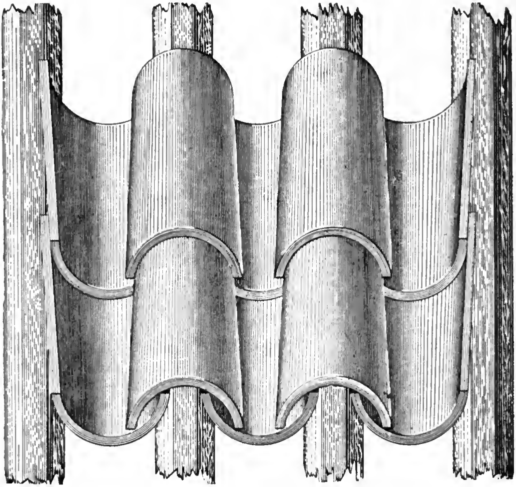

FIG. 226.—Round tiles.

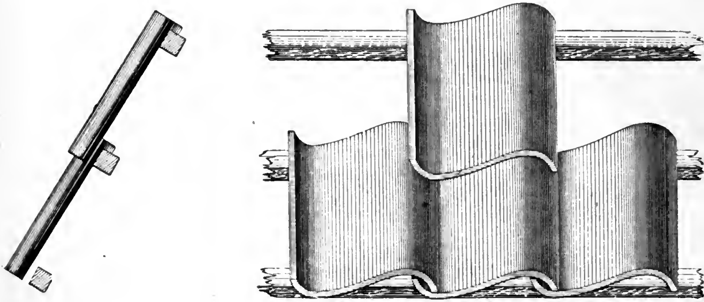

FIG. 227.—Rib tiles.

Flat tiles (Fig. 228) are rectangular in shape, $11\frac{3}{4}$ to $13\frac{3}{4}$ inches long, by $7\frac{3}{4}$ to $10\frac{3}{4}$ inches wide, and $\frac{1}{4}$ to $\frac{3}{4}$ inches thick. A hook fastens them to the laths, and two-thirds of the surface is covered over by the upper tiles. Sometimes holes are pierced in the tiles, which are then nailed to the laths.

By rounding the bottoms of flat tiles, *scale tiles* (Fig. 229) are obtained, the average size being 10 inches by 6 inches.

In Germany the upper surface is usually grooved as shown in Fig. 230.

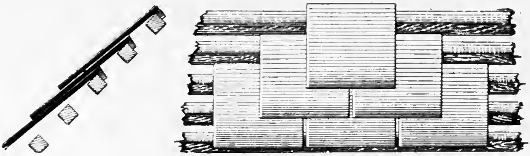

Fig. 228.—Plain tiles.

Interlocking tiles are supplanting those already mentioned. There are many patterns, the following being typical:—

The *lozenge tile*, shown in Fig. 231, is 15¾ by 8¼ inches.

The Marseillaise tile (Fig. 232) is 16½ by 9⅞ inches.

The mountain tiles (Fig. 233) are extensively used in Switzerland. They are 15 by 8¼ inches.

Tiles somewhat similar to the preceding type, but hollow, are shown in Fig. 234, and so give a good insulation against variations in temperature. They are of various dimensions.

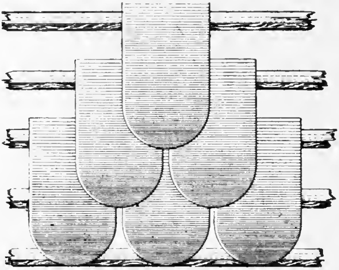

Fig. 229.—Scale tiles.

In addition to ordinary tiles, there are also used in roofing: *ridge tiles*, used for covering the ridge of the roofs; *cat hole tiles*, with an opening for ventilation; *tiles with windows*, for lighting; *tiles with pipes*, used for passing ventilation or draught pipes through. *Finials, king-posts, borders, ends of borders, frontals*, etc., etc.

Designs for these different parts of the roof will be found in the catalogues of the principal manufacturers and need not be described here.

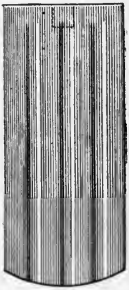

FIG. 230.—Ribbed scale tile.

The moulding of tiles needs much more plastic bodies than those used in the manufacture of bricks; the porosity of the body must also be considered, as it is necessary that the proportion of real clay should be sufficient to fill all the spaces between the grains of non-plastic material. It is true that the porosity of tiles is only a temporary defect, as the pores are quickly sealed up by dust in the air. But this sealing may cause the growth of vegetation on the tiles, and a great porosity, even though temporary, also makes the tiles of less value commercially.

Hence it is advisable to avoid the use of too soft bodies, which become more porous when dried. This is the chief defect in all tiles moulded by hand, though attempts have been made to lessen it by a great thickness of body and the use of glazes. Machine-made tiles of a stiffer body are therefore preferable, providing that this stiffness is not excessive, or a more serious defect, viz., puffing-up or cracking, results.

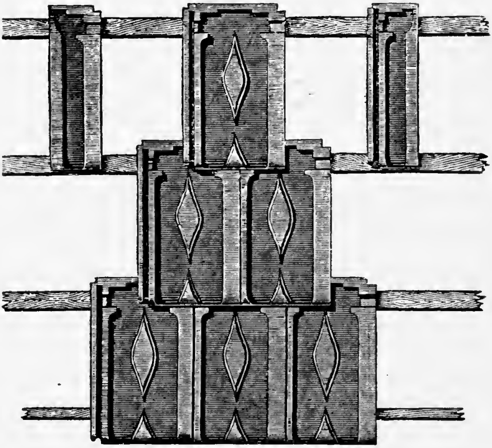

FIG. 231.—" Lozenge " tiles.

The bodies must be carefully prepared and must be absolutely homogeneous.

Moulding by hand was formerly the only method of making tiles.

For round tiles, a flat cake is first moulded, and placed on a piece of wood the shape of the tile. The body, being plastic, takes the desired curve, the surplus body is cut away, and the tile is raised when the body has sufficiently hardened. The same process is used in making

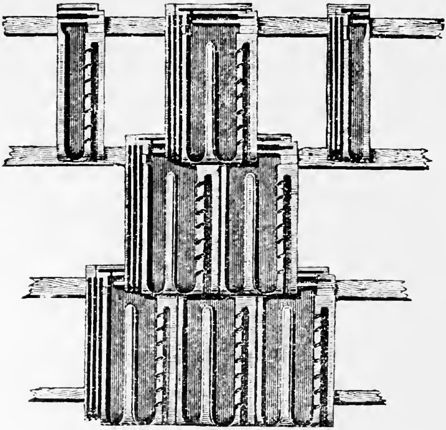

Fig. 232.—Marseillaise tiles.

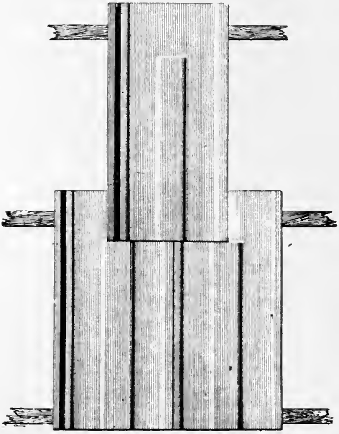

Fig. 233.—" Mountain " tiles.

ribbed tiles. The hook is fastened to the body after moulding. Interlocking tiles can also be moulded by hand by using two plaster moulds bearing the imprint of the upper and lower faces. But on account of its high cost this method is only used for the manufacture of finials, etc., which it would not pay to manufacture by machinery.

Flat or round tiles and those of the type of "mountain" tiles are usually made by expression through a mouthpiece, while interlocking tiles are moulded in a press, in a soft, stiff plastic or semi-dry state (see below).

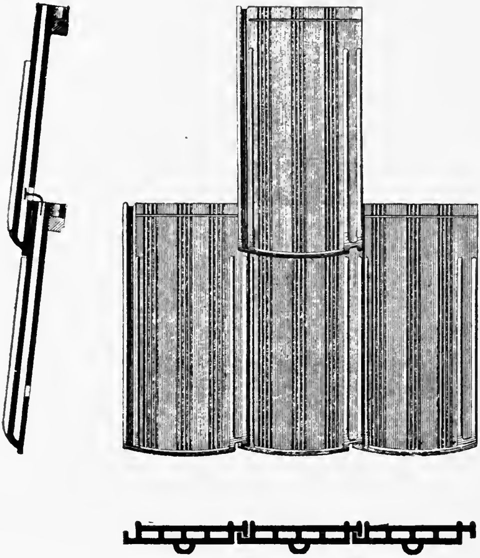

Fig. 234.—Hollow tiles.

Manufacture by Expression.—The body is made into a stiff plastic or soft paste; and it must be well mixed before it is put into the pug-mill. The die plates are usually of the form shown in Fig. 64, the construction of them offering few difficulties. All the interest in this method of manufacture is centred in the cutting apparatus, which differs for each type of tile.

For flat, rectangular and thin tiles the hook may be formed by folding back the body. The clay paste forced out of the pug-mill is passed between two rollers which are turned round by it. The lower one has a projection which corresponds to a hollow on the upper roller, so as to press out the paste at regular intervals and to form a hook. A blade connected to the upper roller cuts the tile to the right length, after which it is put on to a frame by a workman and carried into a drying-shed.

For thicker, flat tiles this method is not applicable and a piece is cut out of the mouthpiece, the same size as the section of the hook, so that the body issuing from the machine is given the shape shown in Fig. 235, and the roll thus formed is cut by a wire, *a*, *b*, except the part which is to form the hook. Fig. 236 shows an apparatus of this kind constructed by Schlickeysen, in which the tile is cut in one operation to the shape and length shown in Fig. 230. When the cut tile reaches the end of the hinged board it is covered with a wooden frame, and the whole turned over by holding it in the frame with the hand, and carried to the drying-shed, while the hinged board is put back into its original position ready for another tile. In this way 600 to 700 tiles an hour can be made.

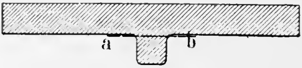

Fig. 235.

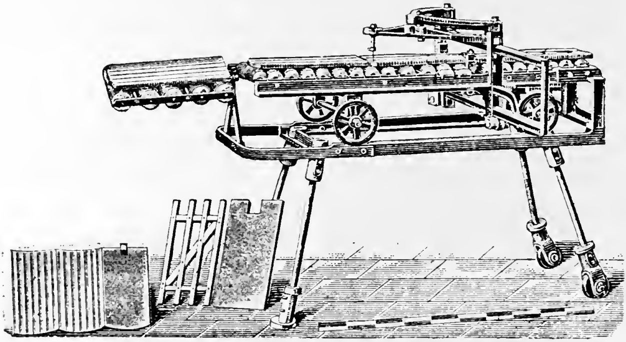

Fig. 236.—Cutting table for tiles.

Diesener makes several flat tiles of the preceding type simultaneously by using a mouthpiece giving a body having a sectional shape shown in Fig. 237, which is cut to the length of the tile by a first cutting apparatus. The bundle of tiles is then pushed by hand into a second apparatus in which a series of horizontal wires divide it up into four tiles, missing the parts of the fillets, *a*, which are to form the hook.

The whole is then put into the drying-sheds, and the tiles are separated when dry by taking away the small pieces *a* and *b*. About 1200 tiles are made per hour in this manner.

The "mountain" tile already described (Fig. 233) is made by a cutting apparatus in the same way as for the preceding flat tiles; the body must be cut to the desired length and a part of the fillet be raised to form a hook. It is also necessary to press down a length equal to the projection of the mid-rib on the covering tile. These various operations are easily done by one workman. The tile arrives at the end of the board quite finished, is covered over by a frame and taken to be dried, about 500 tiles an hour being made.

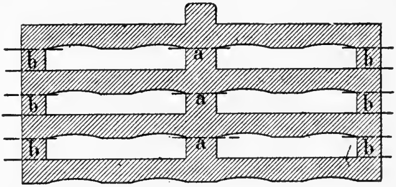

Fig. 237.

Cutting appliances furnished with punches have been made in Germany by which projections which it is impossible to get with a mouthpiece can be given to tiles.

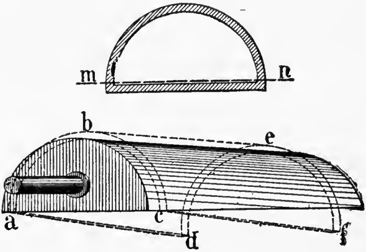

Fig. 238.

Various very ingenious machines have been made for forming round tiles which are of partially conical form. The following is the simplest. A length of body is passed out of the die of the shape shown in Fig. 238, and is at once divided by a horizontal fixed wire, *mn*. Then the tile having been cut to a desired length on a cutting board, the upper curved part is lifted by a wooden conical block (Fig. 238) of the same shape as the interior of the tile. The sheet of clay, being plastic, fits the block following the dotted lines *abc*, *def*, and is cut with an iron wire and placed on a board. This process allows 250 round tiles to be made in an hour. They can be made equally well by a press.

Manufacture in a Press with Soft or Stiff Plastic Body.—The body, suitably prepared, is put into a mill from which it comes out in the form of several strips approximately of the length of the tile. Fig. 239 represents an example of a machine of this kind, with expression rolls surmounted by two pairs of crushing rollers, which will manufacture about 1000 slabs an hour.

The strips of body are cut to the size desired, with an ordinary cutting machine; the *bats* thus obtained are then put into a heap and damped for twenty-four or forty-eight hours and are afterwards separated from one another and placed in a press (p. 128). The metallic moulds are covered with plaster previously cast into shape by means of two patterns made of polished cast iron, which are a reproduction of the upper and lower faces of the tile. When the pattern has been removed the plaster is soaked in water for an hour. The mould is then ready for use.

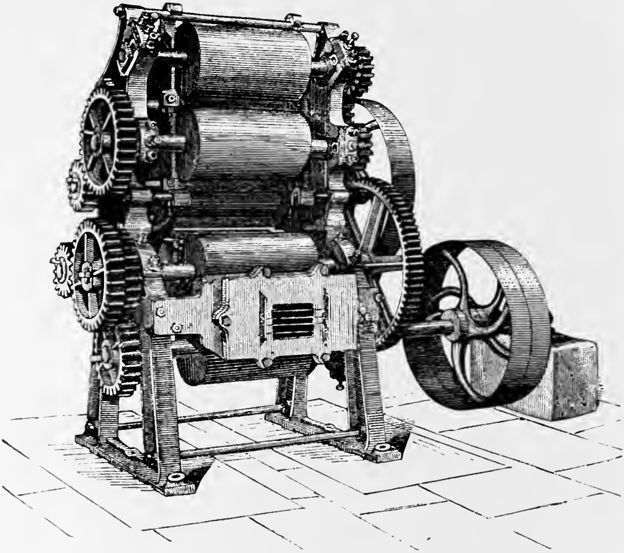

Fig. 239.—Bat-making machine.

Fig. 240 represents, at the upper part, the two moulds, and at the lower part the two patterns of a Marseillaise tile. and Fig. 241 the press used in making the moulds.

The presses used for making tiles of soft or stiff plastic paste are driven by tappets or eccentrics, and act by steady pressure. Fig. 242 represents a machine of this kind made by Chavassieux Long, with two lower moulds and an upper one. Each lower mould is slipped in turn under the upper one which rises and falls alternately. The tiles are taken out of the mould by placing a framework on them; this adheres to the lower mould, and by holding the board with the hand and turning the mould over on to it the tile is released. With this machine one man can produce about 250 tiles an hour; the output may reach 400 tiles an hour with two moulders.

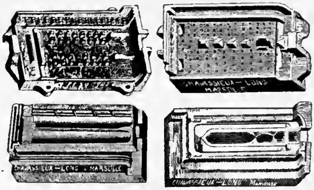

Fig. 240.—Patterns and moulds for tiles.

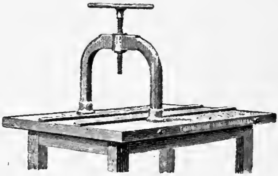

Fig.241.—Mould-press.

For larger quantities "five piece" presses are used (Schmerber), an example of which was given (Fig. 96) on page 133. With this machine, made by Boulet et Cie., one man produces about 500 tiles an hour.

The tiles, when thus pressed and placed on boards, are carried to the drying-sheds, where, after having been dried for some time, and having acquired the consistency of stiff body, they are cleaned from arris, caused by the body oozing out between the parts of the moulds.

Manufacture in a Press with Stiff Body.—The moulding of tiles in stiff body is done in the same manner as moulding in soft or stiff plastic body; but other machines must be employed, because of the greater pressure required. The body must be prepared as was described on page 89.

Screw propellers cannot be used, and it is necessary for the making of the slabs to use piston propellers ("stupids") (Fig. 243).

The machines used for hollow blocks are specially suitable for this style of manufacture.

Fig. 244 shows a machine constructed by Boulet et Cie. for making slabs, in which the body on coming out of the die is forced to pass between the two rollers, one of which has an edge to cut the body into pieces corresponding to the length of the slabs.

The moulds used for hard paste cannot be of plaster as that would be broken; polished cast-iron moulds which are oiled to prevent them sticking are therefore employed. The cake itself may be greased before it is put into the press. Screw presses are principally used (Figs. 93 and 94). In the latter, the cake is put into the lower mould, which is in the position shown in the engraving, and it is then pushed under the upper mould. By working the side lever one of the vertical discs presses the upper horizontal fly-wheel and causes the screw to rotate. The pressure exerted is in proportion to the actual force accumulated in the fly-wheel. By a second movement of the lever the other disc is made to move the screw up again. The lower mould is then brought forward and turned over. This type of press can make to 350 roofing tiles an hour.

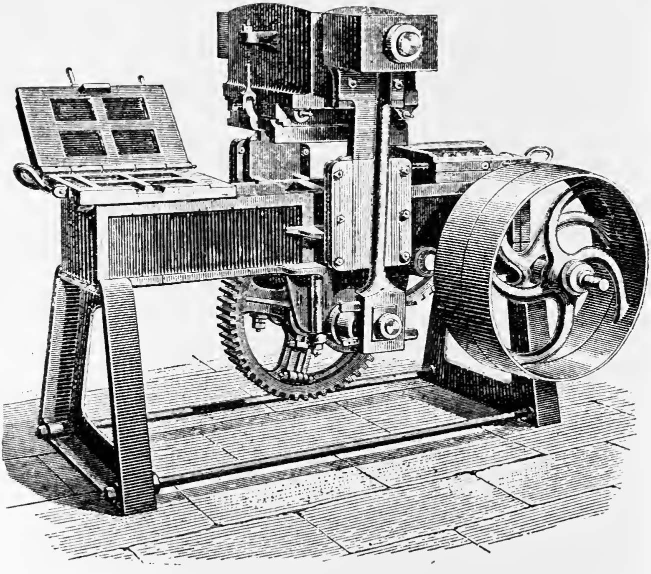

Fig. 242.—Tile-press.

Eccentric presses are also used, but they give a definite pressure and are less useful than the preceding friction-press which allows the pressure to be graduated by the motion given to the screw, and by exerting two or more successive pressures. When the tiles come out of the press they are placed on a turn-table and trimmed by hand. The use of a clipping machine has not proved satisfactory.

Drying.—Only when the tiles are made of very stiff body can they be carried and put on the shelves without being supported by wooden frames. The shape and dimensions of the frames or laths depend on the type of tile. Fig. 245 shows the usual arrangement, viz., three wooden strips nailed on two cross-pieces. As the drying on these frames lasts from ten to twenty days, if artificial drying is not employed, the number of frames used, even in small tile works, is considerable. They must be made of good, dry wood which will not easily warp by the damp of the body when fresh moulded, as the warping of the frame naturally involves that of the tile as well.

The tiles are carried into the drying-sheds in the same manner as bricks. Wagons are seldom employed, and the wheelbarrows instead of being flat are usually of the kind shown in Fig. 246.

The tiles are generally dried in large ventilated buildings over the kilns, the waste heat from which is thus used. The different types of drying-sheds formerly described can also be used.

As tiles weigh 4½ lb. to 7 lb. each, the amount of heat and volume of air required for drying them are about the same as for plain bricks, and the same calculations may be made. The duration of the drying is, however, much shorter, on account of their small thickness.

The burning of tiles ought to be done in continuous kilns, except for small quantities, in which case single (Fig. 148) or semi-continuous kilns must be used.

The fuel and ashes must be

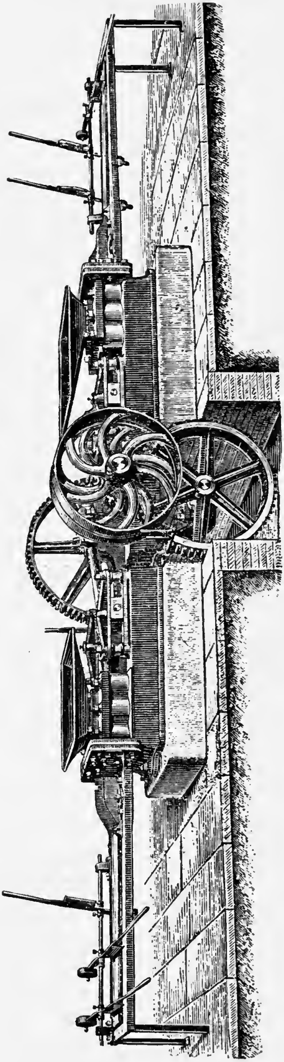

Fig. 243.—Slab-making machine.

kept from contact with the goods. When, as is usual, plain or hollow bricks or tiles are made at the same time, it is wise to use the kiln shown in Fig. 211, the bricks being used to form the heating shafts

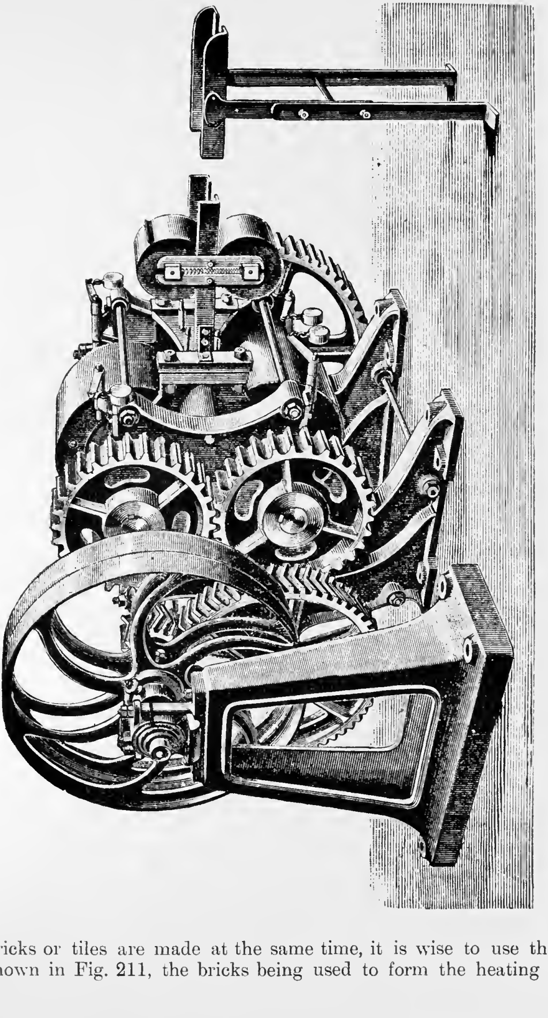

Fig. 244.—Slab- or cake-making machine.

and to cover the bottom of the kiln. This method of setting, which needs 40 per cent to 69 per cent of bricks, is shown in Fig. 247.

The manner in which the tiles are placed in the kiln depends on their shape. The tiles are usually placed in pairs, being leaned against each other so as to take as little room as possible, and to protect the projecting parts.

Interlocking tiles are packed close together, sufficient spaces being left between them to ensure the circulation of the gases and flames.

Fig. 245.—Drying lath for tile.

Round tiles are placed upright on one another. Flat tiles are not so easy to set with sufficient spaces. When they are thin they cannot be set in bulk, but must be put in slips, using bricks or special pieces when necessary, to form cases for them. This method of setting should be used for other tiles as well. Tiles are burned at a temperature approaching that of vitrification, but not so high that they will get out of shape. The simultaneous burning of hollow bricks and tiles gives excellent results. Owing to their slight thickness the burning can be very rapid, and the thermic yield of the kiln is above that when plain bricks are burned. By admitting a proportion of air double that theoretically necessary, the kiln can be made to work with the following thermic conditions:—

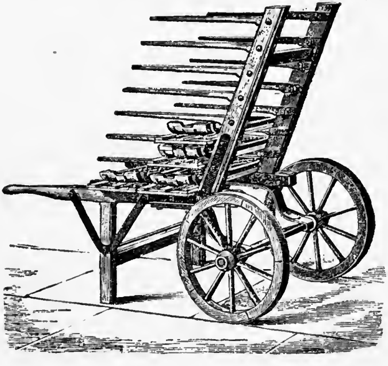

Fig. 246.—Tile-barrow.

Heat produced by combustion	100	Heat theoretically necessary	100
Heat regained from cooling goods	50	Heat lost by heating the walls	20
		Heat lost by radiation	25
		Heat lost through the chimney	5
	150		150

Thus the yield of the kiln may reach 100 per cent, the heat regained compensating the heat lost.

When it is necessary to make tiles exclusively, the heating shafts may be replaced by a kind of fixed furnace of firebricks, about $6\frac{1}{2}$ feet apart. Fig. 247*a* shows an arrangement in which the fuel thrown in through a central opening falls on the bricks put in steps between two walls, half a brick thick, the air following the path shown by the arrows. The ashes remain between the walls. This arrangement makes it much more difficult to look after the kiln, much space being lost in setting, and the furnaces must frequently be repaired. Hence it is better to use gas. Fig. 248 shows a suitable gas-fired kiln in which the gas coming from the producers through two lateral flues is carried to the burners by movable iron pipes. The setting is done in the chambers (A), leaving between them a space in which are the burners and where the combustion takes place; the gas passes out

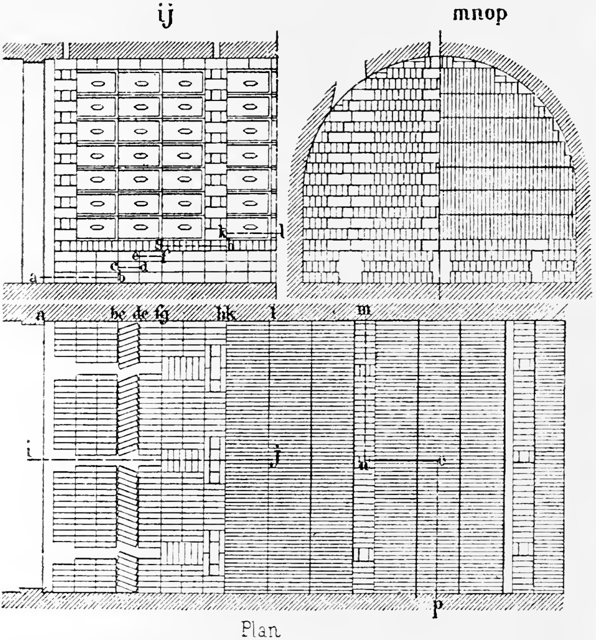

FIG. 247.—Arrangement of tiles in continuous kiln.

perpendicularly to the circulation of the air. The working of this kiln is the same as that of the kiln shown in Fig. 211.

Gas firing does away with the defects due to the contact of the fuel, the heating is more rapid, and the temperature more easily regulated. On the other hand, it is more costly to instal and the thermic yield of the kiln is lessened by the loss due to the gasification of the fuel.

Continuous kilns with fire-boxes, p. 222, also solve the problem of the exclusive burning of tiles. Fig. 249 shows a kiln of this kind.

In these kilns the air necessary for combustion is passed directly under the fire-grates and cannot be collected unless, as is usually the case, the kiln works with an excess of air. This excess of air may be made to come from the back as in the kilns just described, and a certain amount can be collected.

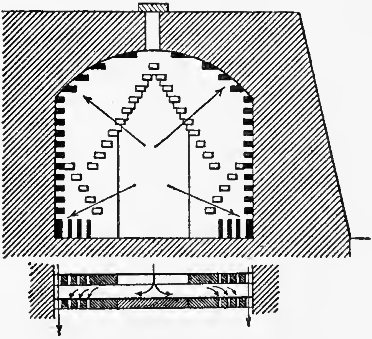

FIG. 247*a*.—Haedrich's fireplace.

The thermic balance of these kilns is approximately :—

Heat produced by combustion	100	Heat theoretically necessary	60
Heat regained	15	Heat lost by heating the walls	20
		Heat lost by radiation	25
		Heat lost through the chimney	5
		Heat lost through incomplete combustion	5
	115		115

The yield is reduced to 60 per cent, as so much less heat is recovered.

General Arrangements of Roof Tile Works.—The value of roofing tiles is 2½ to 3 times as great, in proportion to the weight, as that of plain bricks, but clays suitable for the manufacture of tiles are less widespread, so that tile works are factories less local than brickfields.

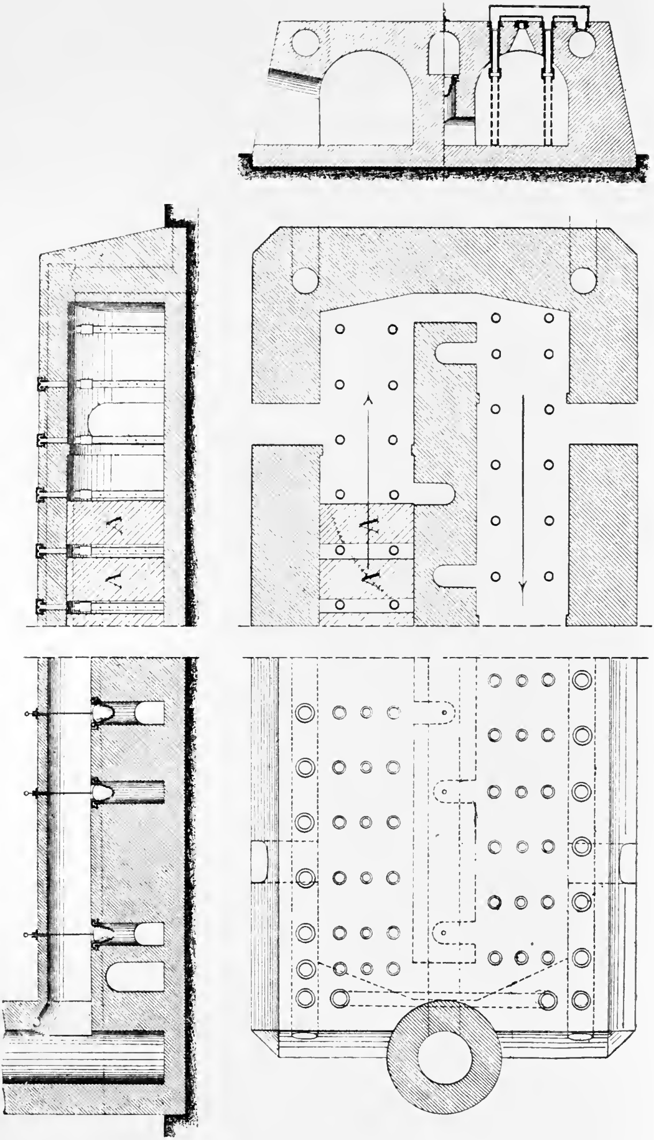

FIG. 248.—Gas-fired continuous kiln.

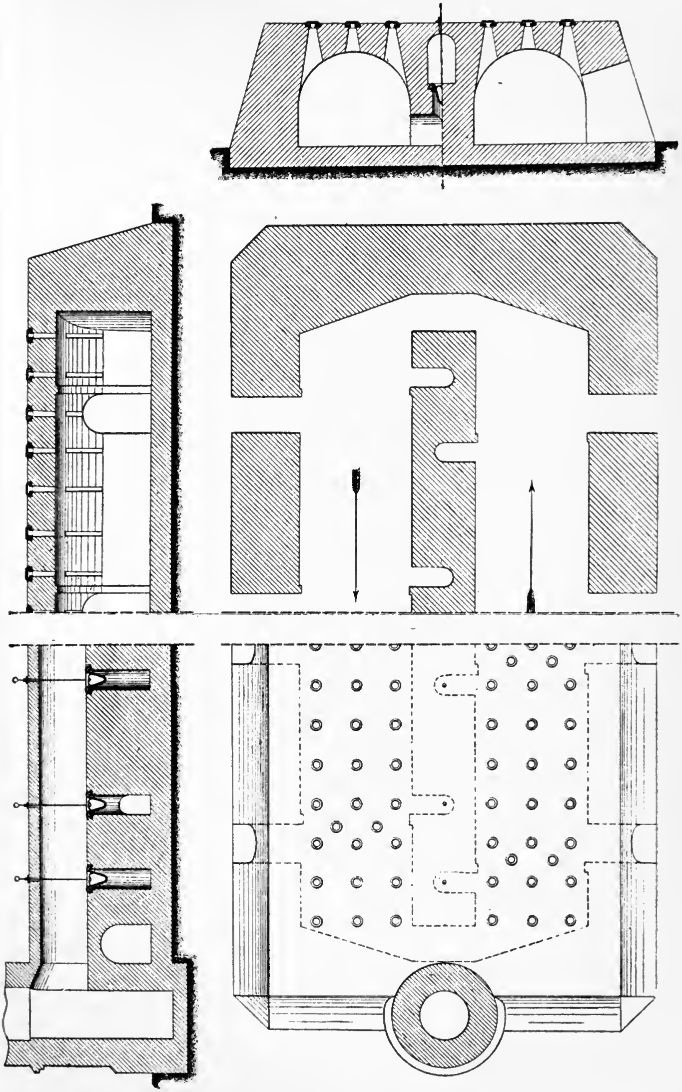

Fig. 249.—Continuous kiln with fire-troughs.

The cost of transport is also very high compared to the value of the goods, but factories, when well placed, can send such tiles over a fairly large radius, and even sell them for export. Small tile works which cannot use continuous kilns are rare,[1] and can only succeed under favourable local circumstances, especially as tiles moulded by hand are usually inferior, and manufacturing them by machinery and preparing the body well can only be done by using power. Apart from the small factories, most tile works are placed by the side of clay pits; it is only in very exceptional cases that the raw materials are transported and used near the larger centres of consumption.

The differences in methods of manufacture employed in the tile works are not sufficient to make variations in their general arrangements important. All the tile works recently constructed [on the Continent] consist of large buildings over the kilns, containing rooms for preparing bodies and for making tiles on the ground floor, while the upper floors are used as drying-sheds.

(*b*) **Black Tiles and Blue Bricks.**

The black colour of unglazed terra-cotta may be obtained by five methods. (1) Colouring the body by means of manganese oxide. (2) By an application of a black slip to the body. (3) By dipping in tar. (4) By burning in a reducing atmosphere charged with hydrocarbons. (5) By burning in saggers containing powdered carbon.

The first two methods have already been described, but are costly and are seldom used for ordinary terra-cottas.

Tarring or dipping the goods in liquid tar is principally used for tiles. For this purpose the tar must be sufficiently fluid to penetrate the pores of the terra-cotta; so that it must be used hot. If cold terra-cottas are dipped in tar they absorb it only on the surface, and the black colour quickly disappears under the action of rain, but by heating them first to 50° or 60° C., the tar penetrates to a depth of $\frac{1}{8}$ inch and gives a dull unglazed black colour. Tarring does not appreciably help the terra-cottas to resist the weather but rather the opposite, as will be seen at the end of this chapter, in the tests for building terra-cottas.

The process for colouring terra-cotta black, by means of a special kind of burning, is technically known as "blueing," because the black colour has a bluish metallic sheen. The kilns for blueing (on account of the extremely reducing atmosphere used for cooling) are necessarily intermittent,[2] and may be built in different ways.

Fig. 250 shows a popular one (O. Bock) in which series of horizontal kilns placed side by side communicate with a chimney through a central underground flue. The heating is by two fireplaces at the

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[1] [On the Continent, works which make tiles exclusively are common. In Great Britain, small tile-works—usually associated with brickyards—are more usual.—A. B. S.]

[2] [Blueing can now be equally well done in a suitable continuous kiln, such as Barnett & Hadlington's or Dean Hetherington's patents, with a great saving in fuel. —A. B. S.]

ends. Two shafts (funnels) are used for pouring in the oil. As the cooling lasts seven to ten days, not more than two burnings a month can be done. The filling, warming and burning are done in the same way as for ordinary terra-cottas, and only when the maximum temperature has been reached the special operation of blueing commences. Formerly, green wood was used for this purpose, the furnace being charged and all the openings of the kilns shut, and it was then allowed to cool slowly, entirely by radiation. Now the burning space is entirely isolated and the liquid hydrocarbons, such as tar or the oils arising from distillation of petroleum, are poured through special shafts.[1] Under the influence of heat, these bodies are decomposed, and the deposit of graphite formed in the interior of the pores of the terra-cottas colours the whole mass. If the bodies do not contain iron, or if the latter is combined with the lime in them, the colour is a dirty greyish-black. If, on the contrary, the body is ferruginous, a ferrous oxide or even metallic iron is formed and gives a very beautiful blue metallic sheen to the terra-cotta. From 17½ to 55 lb. of oil are needed for a thousand tiles, this oil being added in two or three portions at intervals of one or two hours.

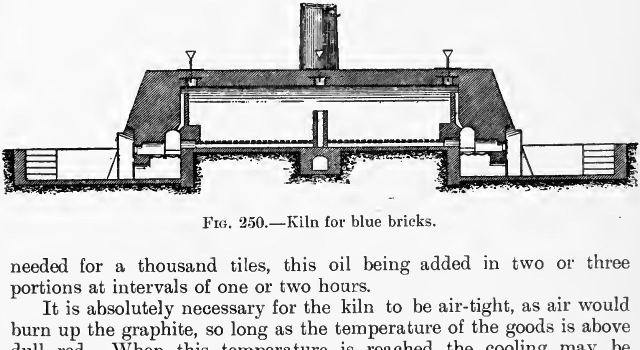

FIG. 250.—Kiln for blue bricks.

It is absolutely necessary for the kiln to be air-tight, as air would burn up the graphite, so long as the temperature of the goods is above dull red. When this temperature is reached the cooling may be hastened, without disadvantage, by an opening in the top of the kiln or by raising the chimney damper. Too many precautions cannot be taken to keep the kiln closed and prevent air from getting in.

A black colour may be given to tiles by putting them with powdered coal or carbon into saggers or in a box formed of bricks or terra-cotta slabs. There is thus formed in the saggers or boxes an extremely reducing atmosphere, which acts in the same way as that of the blueing kilns. Although this method has the advantage of not needing special kilns, the difficulties of filling them are great, so that it is scarcely used except for paving tiles and ornamental pottery.

[1 In England, the blue colour is produced by regulating the air supply and not by the use of oils.—A. B. S.]

Paving Bricks and Tiles.

Paving tiles are used either for paving or for walling. In the first case, they are either of terra-cotta or stoneware; in the second case, they are of glazed terra-cotta, faience, stoneware or porcelain.

Terra-cotta paving tiles are usually square or hexagonal; the side of each varies from 4 to 12 inches, the most usual size being 6 inches. The thickness depends on the other dimensions, on the method of making and on the nature of the body, and varies from $\frac{1}{4}$ to 3 inches.

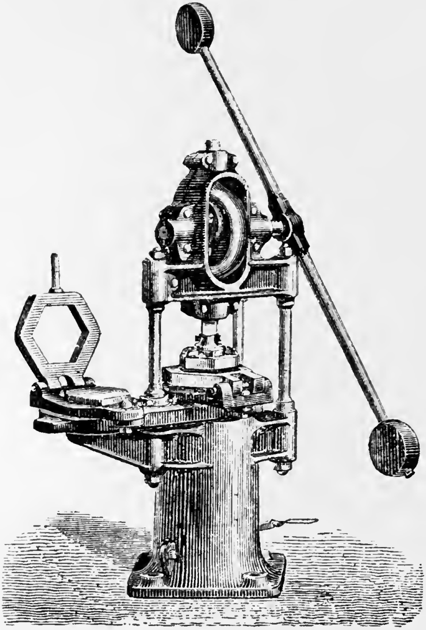

Fig. 251.—Press for paving tiles.

The body used for paving bricks and tiles is the same as that for making other bricks and tiles, and the methods of moulding by hand or producing by machinery are identical.

Ordinary paving bricks are laid in a bed of mortar for use, and have the disadvantage of showing the joints all round them. This defect may be remedied by giving the paving tiles the shape of a truncated pyramid, the larger base of which is at the top and forms the face. When they are laid the sides of this face touch and do not let the joints show, the mortar settling in the triangular space formed between the two bricks.

The repress shown in Fig. 251 is excellent for making hexagonal tiles of this kind. Its chief disadvantage is that there is more pressure on the lower face of the paving tile, while the opposite would be better. Care must be taken to put the rough slab on the mould in such a way that no air bubbles can remain under it, as these would cause defects on the face. The same moulds can readily be adapted to all the presses already described.

Paving tiles are generally stacked two and two, with the visible faces in contact, and are thus placed in the drying-sheds. When they are thin ones it is necessary to dry them in piles, the upper tile being covered with a burned one on which rests a brick or other weight. This makes the drying very slow, but it must be employed in order to obtain straight goods.

Paving tiles may be burned in any kilns used for tiles. Thick pavers may be set in pairs by putting them in flat so as to leave spaces. Thin paving tiles should be piled to prevent them warping, and the other goods set at the same time should be placed so as to prevent these piles from falling. The tiles must be "smoked" very slowly and carefully before the burning. If at the commencement of the firing any traces of damp remain in the piles, ugly whitish blotches are formed on the tiles. The precautions which must be taken during the drying and burning make the manufacture of paving tiles more difficult than that of any other terra-cotta for building purposes. Ordinary pavers are usually made in tile works, and do not need any special arrangements, other than those just mentioned.

Pipes.

Pipes for gas flues (Fig. 252) are used as chimneys and ventilators. They are of varied shapes, the description of which belongs rather to the art of building than of pottery, because, whatever the arrangement employed, the methods of manufacture are the same.

Type I. are round pipes, with a spigot at one end, from 5 to 10 inches in diameter and 11 to 20 inches in height.

Type II. are rectangular with rounded corners, the interior dimensions varying from 5 by 7 inches to 10 by 12 inches with a height of 12 to 20 inches.

Type III. is built into walls and is made straight or sloping, or with projections to keep the pieces together better. In some cases the walls are made hollow (Type IV.).

The body used for these pipes is the same as that used for hollow bricks. Pipes are made by squeezing out soft body, with piston propellers, generally worked by power. Fig. 67 shows a machine of this kind. A metal cylinder is filled with body pressed together as much as possible so as to prevent empty spaces being left, then the piston (being set in motion by a crank) descends and forces the body to pass out through a die below (Fig. 61). The pipe thus formed, rests on a balanced platform, which descends with it. When the desired length is reached, the workman stops turning the crank but keeps it in position, and a second workman slips a metal wire along the frame, and cuts off the pipe. The platform is pushed a little lower and the moulded pipe is taken away on a board to the drying-shed. By means of a pedal the platform is raised again ready to make a second pipe. This is continued until there is no more body in the machine. The piston is then raised and, after refilling, the process is again continued. During the time of stopping for cutting the pipes it is necessary to keep the crank in place as the compressed air in the body of the cylinder would otherwise raise the piston and produce inequalities in the pressure, which would cause defects in the pipes.

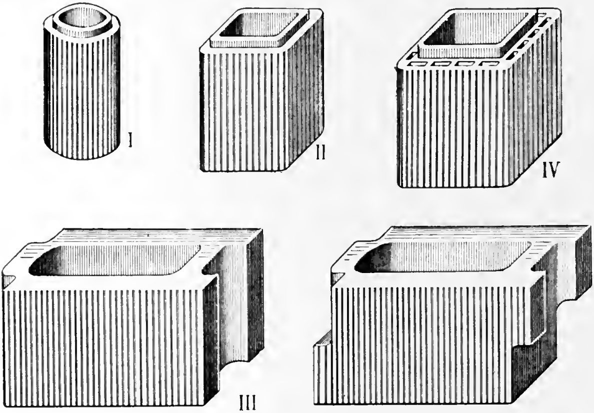

Fig. 252.—Patterns of gas-pipes.

These machines make forty to eighty pipes an hour. In larger factories continuous machines are used and are described later.

When pipes with sloping ends are to be made, it is sufficient to incline the pipe on the platform, and to place the cutting frame parallel to this inclination. The body is then allowed to become hard, a strip of the outside body is taken off by hand, with a small cutting instrument passed round the pipe so as to form the spigot or socket. Some time afterwards the pipe is turned over, and the same thing is done on the inside.

The baking of these pipes is done in brick or tile kilns. In filling the kiln they are arranged vertically, two pipes of different sizes being placed inside one another.

Pipes for water made of terra-cotta were formerly much used, but are now replaced by stoneware pipes. The burning of them is done in the same way as for the preceding pipes. Terra-cotta pipes are often glazed inside to make them water-tight; the methods used for this purpose are described in Chapter XII.

Land or agricultural drain-pipes cannot be made in stoneware. They are simple cylinders of about 2½ inches to 8 inches in diameter inside, and are joined by placing their ends in a piece of pipe of a larger size. They are pressed out of machines similar to those used for hollow bricks. For this purpose dies similar to those shown in Fig. 253 are used. For the large diameters only one pipe is made at a time, while for small sizes, two, three, or even four can be made simultaneously, and are cut with the same apparatus as is used for bricks. The burning is done in brick or tile kilns, by putting the smaller pipes in the larger ones.

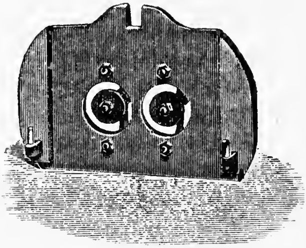

Fig. 253.—Mouthpiece for small pipes.

Architectural Terra-cottas.

Numerous kinds of terra-cottas are used in building that do not belong to the foregoing classes. Most of them are decorative and made either from patterns belonging to the manufacturers, or according to the original designs of the architect or the decorator.

The bodies used in the manufacture of these architectural terra-cottas should be plastic enough to lend themselves to hand moulding. The preparation must be very carefully done. The body should be somewhat fine, or the ware would have a rough surface which would catch impurities in the air and would quickly look dirty.

In some cases, making by expression or turning may be employed, but hand moulding in plaster moulds is largely used. If the number of pieces is very few, the expense of the moulds may considerably increase the cost of these terra-cottas. It is difficult in terra-cotta to obtain long straight pieces such as handrails or balustrades; hence it is better to make smaller pieces with more joints.

The drying is done in the moulding shop or in an adjoining shed, so that it can easily be watched by the moulder.

The burning is done in the kilns of the type used for tiles or pavers, the architectural terra-cottas being protected from the flames by means of less delicate goods. Muffle kilns are sometimes used, but there is a danger that the temperature will not be high enough. In most factories devoted entirely to making architectural terra-cotta it seems best to use round down-draught kilns.

The use of fluxes is indispensable, in order to lower the temperature at which they are burned and to obtain goods which will resist the weather. The proportion of fluxes must be such that a hard well-burned body may be obtained between 1000° and 1200° C.; below that the carbonate of lime may not be entirely decomposed. Bodies of a grey or black colour may be obtained by burning them in a very reducing atmosphere, using the methods already described à propos of black tiles (p. 328).

When the cost is not against it, colouring oxides may be added. The only oxides used are those of iron and manganese; the former in the form of earthy ochres or certain iron ores, the latter of washed manganese ores.

When, for reasons of economy, or on account of certain difficulties of manufacture, the desired colour cannot be given to the body, then slips must be used. The composition and application of these have already been discussed (pp. 136 and 258). To obtain a perfect agreement between the body and the slip, the latter must contain as large a proportion as possible of the body itself. The light shades, and white in particular, are difficult of application.

The application of these slips is either with a brush on the ware when nearly dry, or by "incrustation" (described on p. 137). The processes of drying and burning have been already described. White slips must not be placed by the side of coloured bodies or slips, as there is always a certain volatilization of the oxide of iron, which would soil the former.

Architectural terra-cottas, instead of a uniform colour, may have different shades, by using slips of different colours, but, except for certain wares with distinctly marked different reliefs, this method of decoration gives hard tones which are not very satisfactory. It is usually better not to put different colours side by side, but only to shade the natural colour of the body. For this decoration, spraying may be used advantageously (p. 175), by using either a light slip, or some of the colouring matter diluted with water. The colour may also be applied with a brush in successive layers. This method can produce very remarkable effects, for example, by lightening the parts in relief and by darkening the sunken parts.

Vases, Statues and Decorative Objects.

At the present time vases, statues, *jardinières*, flowerpot-stands and all other terra-cotta objects used for decoration are manufactured by processes similar to those just described for architectural terra-cottas. The bodies employed are, however, finer, the clays are almost always washed, and the sands used to open them must be very fine, so as to give the ware a smooth and even polished appearance. The articles are made by turning or by moulding in plaster moulds. Statues must necessarily be moulded in several pieces, which are afterwards joined together. All the thicker parts, such as the head, the trunk, etc., ought to be hollow. The joining of the parts is a delicate operation if the model is to be reproduced exactly. It very often happens that the position of certain parts, such as arms or legs, is not exactly correct, a defect which takes away a good deal from the artistic value of these goods. Moulders frequently have a bad habit of "touching up," which results in the reproductions being finished in undecided forms, with rounded contours which have lost all the character of the original.

The drying is done in the moulding shop, and the burning usually in a muffle or in saggers.

Such terra-cotta wares are usually made in tile works or potteries, but there are also some special works for them, particularly in large centres of consumption.

The uniformity of tint generally demanded needs a careful manufacture, and a specially regular burning. It frequently happens that, in order to give these terra-cottas a beautiful shade, they can only be burned at a very low temperature. This is not a disadvantage if the goods are kept inside buildings, but they cannot be exposed out of doors without being quickly spoilt.

It is easier to get this uniform tint by putting over the ware, when made, a slight slip, made of the body diluted with water. Some manufacturers simply paint the burned ware with water-colours or with size. This process takes away all ceramic value from the ware, and is easily recognized by the colour, which comes off when rubbed by the finger or with a damp cloth.

Ware of many colours is easily obtained by means of coloured slips which can be thick enough to allow of different designs being made with a brush; for example, ornaments, flowers, figures standing out in white on a coloured ground. This is the process known as barbotine painting (p. 258). Very dilute slips may also be used; these are also put on with a brush, in successive layers, so as to form shades. Thus, more relief can be given to the model by darkening the lower parts and lightening the projections, or even by covering the various parts of the ware with different light tints. This latter method has, latterly, been much used for decorating statues.

Common Pottery.

Until the Middle Ages, common pottery was almost exclusively used for all domestic purposes. Glazed ware, then faience with lead glazes, and finally faience of a fine body, stoneware and porcelain have completely taken its place, except for some special purposes, and it is becoming obsolete.

The body formerly used was a fine fusible clay mixed, when necessary, with an equally fine sand. The preparation consisted in treading and kneading. The body, which was always rather soft, was built up either by hand, without moulds, or by throwing; the last finishing consisting of cutting the ware by means of a templet. The burning was done in horizontal kilns with a single fireplace or in square up-draught kilns heated by wood.

The moulding of these ancient objects was very remarkable on account of the considerable size of the pieces, but the burning left much to be desired, as the ancient potters found serious difficulties in obtaining a high temperature, and in addition they used very fusible, especially calcareous, clays.

At the present time, the bodies employed are the same as those that are used for making tiles, and after being pugged into a paste are kept in a heap in the moulding shops.

Household utensils, which are usually round, are thrown; this is sometimes made more accurate by means of a templet; the handles, spouts and feet are put on by sticking (p. 135). Flower-pots are usually thrown, but can also be moulded on a jolley (Fig. 88)—though this method needs a considerable number of moulds—or in a press. In the latter case it is wise, before taking them out of the mould, to give a certain rotary motion to the chuck, so that it will spring away from the piece, which ought to remain in the mould. With a suitable press, fifteen pots of medium size can be made per minute.

The wares being always thin and relatively light, are easily dried in the moulding shop or on the shelves placed near it.

If the factory has continuous kilns, the burning can be done without any difficulty; but the goods must be protected from contact with the flames or ashes by means of coarser ware. If a special kiln is desirable where the output is small, a small, round, down-draught kiln may be used.

When the ware is to be exposed to the weather, it should be burned at a higher temperature and allowed to become partly vitrified.

Pottery for Water and Filters.—Pottery has been made for a very long time in all southern countries for cooling liquids. On account of its porosity, the liquid oozes out on to the surface, and if carefully put in a current of air, a quick evaporation takes place, which lowers the temperature 5° to 6° C. Such pottery is also used in filters.

The body is the same as that used for ordinary ware, but special methods are used to render it more porous. If the clay used is sufficiently plastic, sand or, better, some grog or burned clay may be added. The method described for making light bricks (p. 308) can also be used, but the combustible materials added must be reduced to a powder, or the air-holes produced would be too large, and the liquid would run and not ooze out. Sometimes salt is added to the body. At the low temperature at which this pottery is burned this salt remains undecomposed, and is dissolved out afterwards by putting the pottery into water.

The same porous body can be employed as a filter for clarifying liquids, especially water. For this purpose, white, china clay bodies, similar to porcelain, have also been used. These bodies, being burned at a very low temperature, are really terra-cottas. The manufacture of these wares presents no special difficulties.

Tobacco Pipes.

There are two kinds of tobacco pipes: (*a*) those made in a single piece used in Northern and Western Europe; and (*b*) those in two pieces, the bowl only being of terra-cotta—used in the countries bordering on the Danube and in the East.

For the first kind, pure clays or fire-clays which contain so little iron oxide that when slightly burned they are of a white colour are used. In some factories, the colour of the iron is discharged by a certain quantity of lime. These clays are fine enough not to require washing. They are sorted by hand and made into a paste, usually by hand, this being carefully done so as to make a very homogeneous mass.

Tobacco pipes are moulded by hand, a little roll of body being made and a little lump of body being attached to one end. By means of a wire terminating in a small ball, a hole is pierced down the middle of the roll, then, when this rough model is stiffened, the whole is placed in a copper mould in two parts (Fig. 254) which are pressed together by a screw. To form the bowl a plug is put in with a rotary motion as shown in Fig. 254. After the plug has been taken out, the piercing of the communication between the bowl and the pipe must be finished by means of a wire put in through the bowl; the pipe is then taken out of the mould and laid aside to dry. This moulding, which is very simple, is usually done by women or children, who become very quick at it. Any ornamentation desired can be placed in the mould, provided it will prove no hindrance to the pipe being taken out. If such is not the case it must be stuck on afterwards. Superior pipes are afterwards polished on the outer surface.

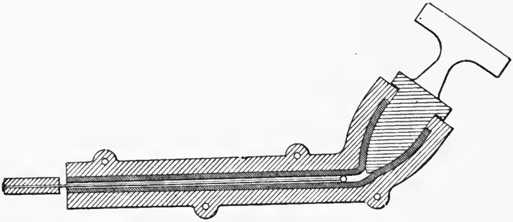

FIG. 254.—Tobacco-pipe mould.

Pipes must be dried very slowly on account of the plasticity of the body, but there are no special difficulties connected with it. They are burned either in small square or round up-draught kilns in saggers, or in muffle kilns. Fig. 255 shows an arrangement of this description, with the special method of setting the pipes in the kiln.

In pipes made in two pieces the bowl is made of a plastic ferruginous clay, similar to that used for making fine red paving tiles. When necessary it is thinned with grog made by heating the same clay.

The bowls are shaped by throwing on wheels and are finished by turning. The part for fixing the pipe in is then stuck on as it has been turned separately. They are burned in saggers, but on account of the similar shape of the pieces do not need a special method of setting.

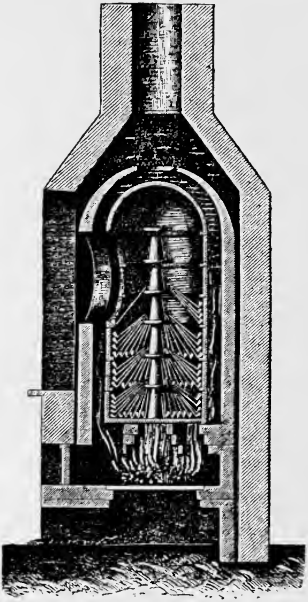

FIG. 255.—Tobacco-pipe kiln.

To finish tobacco pipes needs a number of different operations, intended to make the end put between the lips less porous, to polish them, or to ornament them; these operations are of no interest from a potter's point of view, but are much appreciated by smokers. On account of the dexterity required for making tobacco pipes, which can only be acquired by a long apprenticeship, their manufacture is localized in places where there is a population accustomed from childhood to this work. The most important centres of this manufacture in England, are London, Broseley and North Derbyshire.

Lustre Ware.[1]

Lustre ware was manufactured by the Egyptians, the Greeks and the Romans, from the sixth century before our era till towards the year 300, at which time it fell completely into oblivion and was only revived in the course of the nineteenth century.

The body is made of a clay sometimes moderately plastic and ferrugino-calcareous (Greeks and Romans), sometimes decidedly silicious (Egyptians). The ware is turned and finished. The burning, which is usually at a low temperature, is sometimes oxidizing, giving products of a colour varying from yellow to bright red, sometimes reducing, giving the body a grey tint. The composition of the lustres used for covering these wares remained a secret for a long time, and even now the problem cannot be considered to be entirely solved.

The Greeks understood slips, which allowed them to make white, yellow, or deep red ornament by means of mixtures of white clay and ochres. They frequently used to polish the ware before it was burned, an operation which gives the surfaces a particular brightness after burning. These methods of decoration, added to the action of fusible ashes from the wood used as fuel, have often led people to think that some of their wares were covered over with a glaze.

Certain red, black, or grey parts in the Greek ware and the greenish parts in the Egyptian ware must have been decorated by means of a thin layer of a somewhat vitrifiable material, probably put on with a brush. According to Brongniart's analysis, this lustre is an alkaline silicate, the very thin layer of which, when burning, combines with the elements of the body. When it was red it contained oxide of iron, from which the colour was added to the body. The green shades of Egyptian pottery were produced by oxide of copper. The analysis of black lustre has only shown iron oxide, sometimes mixed with a little manganese oxide in a proportion quite insufficient to produce a black colour. This lustre when heated in an oxidizing atmosphere becomes red. This experiment shows that the black colour must be attributed only to being burned in a decidedly reducing fire. In wares where the background is black, while the places where the ornaments come off are red, either spaces have been left or the black lustre has been scraped off afterwards.

On account of the soft nature of the body, it could be polished, carved and even painted or varnished.

The composition of the lustres is still doubtful, on account of their uniting with the body, which prevents them from being taken off and analysed separately. According to Salvetat black lustre consists of 15 per cent of sand, 25 per cent of lime and of alkalies, furnished either by the ashes or by volcanic products, and 60 per cent of a ferruginous

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[[1] The ware known by this name in France must not be confused with the pottery having a metallic sheen of broken lustrous colours seen elsewhere.—A. B. S.]

earth. Only when burned in a strongly reducing fire can it attain a black colour.

Testing Terra-cottas.

Causes of Disaggregation and the Remedies.—All terra-cottas when well manufactured should be able to resist indefinitely the action of the weather, and the mechanical effects to which they are subjected in building.

If disaggregation of a terra-cotta is noticed, the probable causes are:—

(1) External physical causes: damp, vegetation, ice, saline atmosphere.

(2) Mechanical causes, inducing it to crack, breaking it by burning or by external pressure or blows.

(3) Internal chemical causes: the presence in the terra-cotta of lime, magnesia or soluble salts.

When terra-cottas are too friable, a prolonged damp or frequent rains are sufficient to crumble them away. If porous, they may also be covered with vegetation, the roots of which will help to destroy them. This defect arises from the use of bodies which are too sandy or insufficiently burned.

Frost has a more powerful and more dangerous action. In consequence of a lowering of the temperature, any water absorbed by the terra-cotta solidifies in the interior of the pores. The increase in volume of ice at the moment of freezing creates internal tension, which may make the surface crack, then gradually crumble away. The saline atmosphere of the seaside exerts a similar action; this must be attributed to the formation of salt crystals inside the pores, which act in the same way as ice does. [But other crystals often act more powerfully than ice.—A. B. S.]

It is not the intensity of the cold that is to be feared, but a cold of only 2° or 3° C. below zero, following quickly on a rainy season, because then the water contained in the pores of the terra-cotta has not had time to evaporate. Nothing need be feared from cold, however intense, following a dry season. On the other hand, snow may very effectually protect the covering. This explains why some terra-cottas, which perfectly resist severe climates, can be crumbled away in temperate but damp countries.

In order that a terra-cotta should resist the action of frost it is necessary:—

(1) That the walls of the pores should have a sufficient tenacity to bear the pressure of ice; this can be obtained by using sufficiently plastic bodies and especially by burning them at a high temperature.

(2) That the pores should be uniformly spread over the whole mass, that is to say that the latter could be homogeneous without planes of cleavage, or of thin layers. This condition is naturally fulfilled when a very homogeneous body is shaped by hand either in a mould or on a wheel. Expression and pressing on the contrary

always tend to give a lamellar structure to the body. In that case, the water instead of being enclosed in a number of small cells, the tensions in which balance each other, forms a sheet between the different leaves, and on being changed into ice exerts a pressure which, being unbalanced, may cause these layers to crack. This lamellar structure is more noticeable when the moulding is done with a stiff body, as, the plasticity being less, the layers cannot join together. In pressing a dry body, this primal cause of thin layers [lamination] is decidedly aggravated by the air enclosed in the mass at the time of pressure, layers being formed which destroy all cohesion between the different leaves.

The best methods for obtaining terra-cotta absolutely impervious to frost are:—

(1) A thorough mixing of the raw materials in such a way that lean and rich parts cannot be found in the body. In a badly mixed body these would slide on one another when being moulded, without mixing together, and would cause a lamellar structure.

(2) Moulding with a body the consistency of which is as nearly as possible like that used for moulding by hand.

(3) The employment for moulding of processes and machines which reduce to a minimum the lamellar structure of the body.

(4) When the last two conditions cannot be fulfilled, it is necessary to raise the temperature in the burning sufficiently to cause the fluxes in the mass to begin to vitrify. If this raising of the temperature cannot be done without causing the ware to lose its shape, the only alternative is to modify the composition of the body.

In a general way, moulding by expression, or by presses with stiff or dry bodies, can only produce ware impervious to frost on condition that it is burned at a temperature causing incipient vitrification.

The chief mechanical causes which may account for the breaking of terra-cottas are the following:—

The weight the *bricks* have to bear may crush them. Except under certain exceptional circumstances, the resistance of brickwork is limited by that of the mortar used in joints. Only bricks made of very sandy bodies and under-fired can be crushed under ordinary circumstances. If very resisting bricks are wanted, plastic bodies must be employed, moulded at a comparatively stiff consistency without re-pressing, and burned at as high a temperature as possible. The resistance to crushing per square inch of bricks is, in fact, as much greater as they are denser, though except in special cases it is unnecessary to obtain great resistance at the expense of other qualities.

The greatest strain *tiles* have to bear is the weight of a man moving about on a roof. This resembles a weight of 2 cwt. placed in the middle of them, or needed to break them by bending them when they are overlapping. As their thickness can be modified, it is always possible to make tiles sufficiently resistant.

It is advisable to test *paving tiles* for wear, and *pipes* for their resistance to an internal hydraulic pressure. In these two cases the greatest resistance is obtained with close and well-burned plastic bodies.

It is also interesting to take into account the shocks they may receive during transport, or while they are being placed. From this point of view, the bodies which work best are those which are most plastic, but it is advisable not to carry the burning to the point of vitrification, because when they have attained the highest point of resistance by a suitable amount of heat a further increase in temperature makes terra-cottas become more brittle. Terra-cottas may crumble when they contain lime or caustic magnesia, which, when soaked, increases in volume and acts like frost. This may be avoided by a better preparation of the body; but if the expenses caused by a more careful working of the body are too great, relatively to the small value of the ware produced, the harmful action of the lime may be lessened by dipping the goods in water as they come out of the kiln. For this purpose the apparatus shown in Fig. 256 may be used; it consists of an underground tank full of water, into which are lowered barrows loaded with goods.

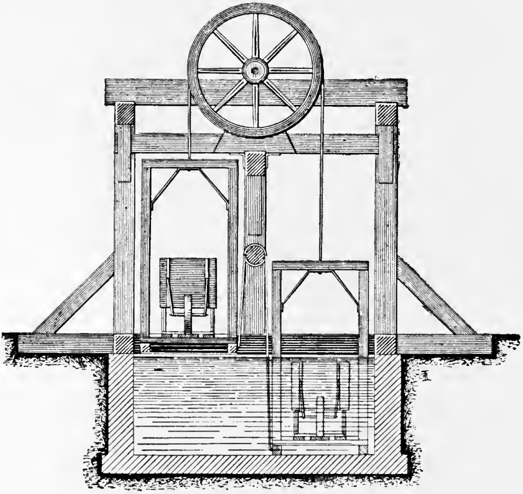

FIG. 256.—Arrangement for dipping bricks.

When a body contains a large proportion of soluble salts these may be dissolved by rain or damp and become crystallized in the pores on the surface, acting in the same way as the saline atmosphere of the seaside. This action is, however, rare, and usually the efflorescence of the soluble salts only discolours the surface and makes the parts above them scale off. This defect may be avoided by washing the bodies, or by burning them at a temperature sufficiently high to cause the conversion of these salts into insoluble compounds. The processes for chemically destroying these bodies which can sometimes be employed have been already stated on page 81.

The methods of testing terra-cottas were the subjects of resolutions discussed at the Conferences of Munich (1884), Dresden (1886), Berlin (1890), and the Commission on Methods of Testing Building Materials appointed by the French Government (1895). The conclusions arrived at by this commission, according to a report presented by M. Debray, General Secretary to the Commission, and by E. Bourry were:—

Samples.—The tests for terra-cottas should always be made on marketable goods.

If it is desirable to know exactly the value of a certain make, it is desirable to work with samples burned at various temperatures. Often it is sufficient to examine the samples which are least burned, which will be easily recognized by their appearance and more especially by their softness, and by their dimensions being slightly greater than the average.

General Directions.—The commercial mark on the samples should be indicated, together with their form, the state of their edges and surfaces, and their colour.

For bricks and paving tiles the dimensions should be measured as to length, breadth and thickness. In tiles the length and breadth should be measured, and sketches or sections should be made, in order to show in a clear way the hollows and projections as well as the methods of fitting the samples together. For pipes, the interior diameter should be measured; the usual length of the pipe, exclusive of the fitting part, the thickness of the walls, as well as the shape and arrangements for fitting them together, if there are any, should be noted.

For bricks and tiles, the dimensions should be checked on the samples, as in the same piece these ought to be identical; the difference should be noted if it is more than 1 per cent.

When the test laboratory has at its disposal a sufficient number of samples of the same product it will be useful to measure the most burned or the smallest ones, and the least burned or the largest ones. The differences observed, when there are any, should be noted.

Physical Tests.—(1) *Observation of the Structure or Homogeneity,* should consist of the examination of a fracture, either by naked eye or by a magnifying glass.

It will be advisable to note:—

(*a*) The appearance of the fracture, whether granulated, rough or smooth, or with a conchoidal surface.

(*b*) The sizes of the grains, marking according to the classification adopted for natural stones[1] whether the grains are fine, medium or coarse, and uniform or of different sizes.

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[1] Very fine grains (0·2 to 0·4 millimetre), fine grains (0·3 to 0·8 millimetre), rather fine grains (0·5 to 1·2 millimetres), medium grains (1 to 2·5 millimetres), slightly coarse grains (2 to 4 millimetres), coarse grains (3 to 7 millimetres), very coarse grains (5 millimetres and over).

(*c*) The homogeneity, by observing whether the mass is entirely, moderately, or slightly homogeneous, whether there are any planes of cleavage or scaling, and whether these are numerous and pronounced.

(2) *The specific gravity* [1] of a material may be determined on the powder produced from pieces ground up until they will pass through a sieve of seventy-five meshes per running inch.

The powder should be dried at a temperature of about 110° C., the determination of the specific gravity should be by means of a "bottle," in such a way as to obtain the first decimal exactly, and the second approximately to two points.

The liquid used should be benzine or mineral spirit.

The temperature should remain constant during the whole time of the operation; and ought not to be above 15° C.

(3) *Apparent density* should be determined whenever possible with whole samples after being dried at a temperature of 30° to 40° C.

When the samples are of a regular geometrical form, allowing the volume to be determined by measurement, an ordinary rule is used with a scale reading to one-hundredth of an inch or one-tenth millimetre; the weight should be determined by means of a balance sensitive to half a centigramme.

When the samples are irregular in form, or have any receding angles, the volume should be determined by means of difference in weight of the sample in the air and immersed in water. Care must be taken to first cover the surface with a varnish to prevent the water getting into the pores. A thin layer of melted tallow put on with a brush and spread about with a finger answers this purpose well.

(4) *Absolute porosity* should be calculated from the difference between the specific gravity and the apparent density.

(5) *Relative porosity or the weight of water absorbed in a given time* should be determined on at least three samples, previously dried, either in the open air or in an oven, at a temperature of 30° to 40° C. It is advisable to work as much as possible with whole samples, and not with broken pieces.

After they have been dried, the samples are put into water up to half their height for twelve hours, and are then completely immersed for twelve hours, thirty-six hours, seven days or twenty-eight days.[2]

If the samples contain a decided proportion of lime, magnesia or soluble salts, it would be wise to repeat the experiment once or twice on the same samples.

The quantity of water absorbed, or the relative porosity, should always be calculated by volume, but the percentage of water by weight should always be also noted.

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[1] The determination of the specific gravity is of no interest from the point of view of the quality of terra-cottas; it is only used for calculating the absolute porosity.

[2] In the case when the time of immersion passes forty-eight hours if it is desired to shorten the length of experiment, a pneumatic bell [vacuum chamber] can be used, as described in the tests on the natural construction of stones (Note of the Commission).

Special Arrangements for Tiles.—The Committee expressed the view that for roofing tiles a study be made of the quantity of water absorbed per square yard of tiles when fixed, as they usually are in practice, on a frame with the least slope used for roofs, by submitting this frame to a regular rain of a definite intensity for a given time.

(6) *Permeability.*—The test should be made with at least three whole tiles previously immersed for forty-eight hours, as described in paragraph 5. There should be fixed with pure cement towards the middle of the upper face of each tile, placed horizontally, a glass tube, of about $1\frac{1}{4}$ inches interior diameter and about 4 inches high; the tube, closed at the upper part by an indiarubber stopper, is put in communication with a reservoir giving a pressure of 4 inches of water; the water which can pass through each tile is collected in a vessel placed under the lower face.

The permeability is determined by the volume of water which has run through in an hour, after the experiment has lasted twenty-four hours.

(7) *Tests for the Resistance to Frost*[1] ought as much as possible to be carried on with whole goods, though they could be made on broken pieces if the cut or broken parts of the tiles were protected by varnish or a thin layer of tallow to prevent the water from penetrating during the immersion, except through those faces of the samples which are usually visible.

The tests for a normal resistance to frost[2] comprise:—

(*a*) The examination of the samples with the aid of a magnifying glass to see whether cracks or splits are caused in those samples submitted to the action of successive freezings and thawings repeated up to twenty-five times.

(*b*) The determination of the loss of weight in the frozen samples.[3]

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[1] Great reservations must be made in this method, the only one at present in use, but so far removed from the actual conditions of practice that it does not seem possible to draw any conclusions from the results obtained.

[2] In carrying out these tests the following details must be observed:—

(*a*) Distilled water must be used for the immersion, taken at the temperature of + 15° to + 20° C., or if distilled water cannot be had, then drinking water, taken at the same temperature, which is equally satisfactory if the quantity of soluble salts need not be determined.

(*b*) The samples should be exposed to a temperature of − 15° to − 20° C.

(*c*) The length of exposure to the cold should be four hours.

(*d*) The thawing should be done by the complete immersion of each sample in distilled or drinking water at a temperature of + 15° to 20° C. (For natural stones a volume of 500 cc. of water is suggested for a cubic sample with sides of 7 cm.) For dried samples, after being immersed for twenty-four hours, the thawing is accomplished in damp air and not in water. In the interval which separates the successive thawings and freezings, the samples are kept in closed cases, to prevent too large a loss of the water absorbed. Care is to be taken before submitting them again to the action of the cold to plunge them for some moments into water so as to keep them during the whole period of the test at the same degree of saturation as they had at the commencement of the experiment.

[3] If the samples have borne without deterioration the test for resistance to frost, the resistance to compression and to bending of these samples may be compared when they are dried again with that of samples of the same production subjected to the same tests when dried but without having been subjected to the action of frost (Note of Commission).

For these tests at least three samples soaked with water by being immersed for twenty-four hours and three samples soaked with water until saturated must be used.

Mechanical Tests.—*Resistance to being broken by crushing* should be measured on pieces as nearly cubical in form as possible, obtained with ordinary bricks; for example, by putting two half-bricks on another and joining them together with a thin layer of pure Portland cement paste; the surfaces to be compressed should be exactly parallel by a covering of the same body.

The tests for resisting crushing may be made by means of lever apparatus or by hydraulic presses.

The test pieces should be placed between the pressing plates covered over with a sheet of thin cardboard.

The dimensions of the bearing surfaces must be shown in the official report of the test at the same time as the resistance per square inch of the carrying surface.

The test should be carried out on at least three test pieces of the same sample and the mean of the results calculated.

It is wise for the test to be made on two sets of test pieces, one in a dried state, the other in a soaked condition, the degree of saturation being noted.

Resistance to breaking by bending should be measured for ordinary bricks on whole bricks placed on two knife-edges 8 inches apart, and loaded in the middle continuously until they break; the total weight which causes the breaking of each test piece being noted. Goods longer than ordinary bricks (flooring bricks) may be tested with a support between the two edges on which they rest, equal to the support which they would have in use.

For tiles, the tests of resistance to bending should be made on whole tiles placed on two knife-edges and loaded in the middle continuously until they break. When the tiles have not a rectilineal profile, little transverse horizontal bars of pure Portland cement should be put half an inch wide at right angles to the supports and to the medial knife-edge for the purpose of levelling the undulations and of making the action uniform over the whole width.

One of these bars should be placed at the point where, in the roof, the tile ought to lean on the roof-ledge, and the other on the place where it rests on the lower tile.

The test should also be made on tiles soaked with water, the amount of saturation being noted.

Resistance to being worn by rubbing may be determined by measuring the extent to which the samples are worn when, under a given load, they are subject to the rubbing of a normal sand spread evenly about on a circular cast-iron plate, which is rotated at a given speed.

The dimensions of the samples should be 2½ by 1½ inches base, and a height varying from 4 to 4¾ inches; they should be put two and two on all sides of the axis and on the same diameter of the mill, in such a way that their centres will be on a circumference of 10 inches radius, the small dimension being placed perpendicularly to the radius.

The total load on the plane of rubbing should be from 250 grammes per square centimetre.

The sand used should be obtained by pounding and then sifting moderately hard, quartzose, Fontainebleau stoneware, passing through a No. 50 sieve, and kept entirely back on a No. 200 sieve.

The quantity of sand to be spread on the mill should be one litre (1¾ pints) per test piece and per 1000 turns of the mill. The apparatus should be turned at the rate of 1000 turns per half-hour, and the sample subjected to 4000 turns of the mill. The diminution in height of the sample should be measured and the loss in weight which it has sustained determined. The same particulars should be noted in the course of the test after 1000, 2000 and 3000 turns.

The sample may be turned over from end to end after 2000 turns of the mill, so as to compare the results obtained on the lower and upper faces. [In America the standard test for abrasion consists in placing the bricks in a kind of pebble mill called a "rattler" and noting the loss in weight.—A. B. S.]

Resistance to breaking by a blow.—No rules have been fixed for this test.

Resistance to breaking pipes by internal pressure should be tested either by the help of a force pump, or by means of a hydraulic accumulator.

The unit of pressure adopted is the kilogramme per square centimetre [or pounds per sq. in.], and the figures, when not otherwise mentioned, are in relation to the pressure used.

The pipes to be tested should be exactly filled with water, the pressure being gradually and not suddenly produced. The gauge should show, directly, the pressure exerted in the pipe itself. The test may be made either on a single pipe or on several pipes put together.

The joints closing the extremities of the pipes should be arranged in such a way that they will not leak, and be made in such a manner that the tightening of them will not lead to a premature bursting of the pieces subjected to the test.

Chemical Tests.—*Lime and Magnesia* may be tested by immersing five samples for three hours in boiling water, and noting whether any exfoliations are produced.

Determination of the soluble salts should be made on five samples, which are powdered so as to make them pass entirely through a sieve of 75 meshes per running inch. Twenty grammes of the powder thus obtained is boiled for an hour in ten times its volume of distilled water, replacing the water that has evaporated. After it has been filtered it must be evaporated to dryness, and the residue of soluble salts thus obtained must be weighed.

CHAPTER XI.

FIRECLAY GOODS.

Fireclay goods are distinguished from others made of clay, by their resistance to heat. Even at the temperature used for burning hard porcelain they do not become vitrified. They are of a dull yellowish-white or slightly greyish colour, except one variety which is black. Chemically they may be divided as follows:—

Acid products, formed of pure silicate of alumina, of a mixture of alumina and silica, or of nearly pure silica; their acid properties being in proportion to the silica.

Basic products containing a large proportion of lime or magnesia, or a mixture of these bases.

Neutral products, formed of silicates of alumina which are more aluminous than pure clay, the alumina acting as a base to acids, or as an acid to certain bases such as lime.

Reducing or carburetting products containing carbon.

Oxidizing or decarburetting products formed of iron ores and at present only used for the fittings of some kilns, and not as fireclay products.

Pure clay makes slightly acid goods, because when sufficiently strong bases are present, it, being a bi-silicate, may be changed into a mono-silicate, thus giving up one equivalent of silica, at high temperatures. By adding more silica to the clay the acid properties are increased, as by adding alumina they are diminished when they are completely neutralized; the composition of the ware corresponds to that of a mono-silicate of alumina. On the other hand, by adding a sufficiently large proportion of lime or magnesia, ware of a basic reaction is obtained, and by adding carbon to clay reducing or carburetting ware can be produced.

Silica, lime, or magnesia may be taken as a starting-point, and goods made containing as high a proportion as possible of these substances, only the quantity of agglomerant strictly necessary to allow of their manufacture being used. In this case, the agglomerant may be clay or any other material answering the same purpose. Fireclay goods thus obtained are not "pottery". The following classification is convenient:—

(1) *Argillaceous fireclay goods,* more or less acid, having fireclay as the chief constituent.

(2) *Aluminous fireclay goods,* slightly acid or neutral, made of a

mixture of clay and alumina, or of compounds relatively rich in alumina.

(3) *Carboniferous fireclay goods*, reducing and carburetting, in which there is a large proportion of free carbon.

(4) *Silicious fireclay goods*, strongly acid, composed almost exclusively of silica.

(5) *Basic fireclay goods*, containing a preponderating proportion of lime or magnesia, or a mixture of these two bases.

Chromate of iron is sometimes employed as a refractory material which resists acids as well as bases, and bears a very high temperature; but bricks of this kind do not belong to pottery.

1. *Argillaceous Fireclay Goods.*

Shapes, Dimensions, and Properties.—The manufacturer of argillaceous fireclay goods in special factories only dates from the beginning of the nineteenth century. By accurate chemical analysis it is often possible to distinguish the fireclays scientifically from other clays, and to decide the composition they must have to be able to resist high temperatures and the attacks of the materials with which they come in contact in the kilns. A great advance was also made in heat resistance when the clays were "opened" by means of a grog of fireclay (p. 36) instead of sand, as in ordinary bricks. The use of grog was known in the Middle Ages, but it is only since the beginning of the nineteenth century that it has been used methodically.

Fig. 257 shows some common applications of argillaceous fireclay goods, but the shapes may be infinitely varied. Plain bricks are usually of the shape and dimensions of building bricks: (I.) in France, $8\frac{2}{3} \times 4\frac{1}{3} \times 2\frac{1}{3}$ inches; in England, $9\frac{1}{2} \times 4\frac{3}{4} \times 3$ inches, and in Germany, $9\frac{3}{4} \times 5 \times 2\frac{1}{2}$ inches. In the usual way, knife-edge bricks (II.) and wedged-shaped bricks (III.) are made for building domes and arches. Other special and complicated patterns (IV. and V.) can be easily made when required. When the pieces are much larger than ordinary bricks they are called blocks. These latter are better for building kilns, as they lessen the number of joints, which are always a weak place in masonry. A length and width of 24 inches by a thickness of $15\frac{3}{4}$ inches should not be exceeded, as above that the blocks are unwieldy, and there is a risk of their not being burned enough in the middle.

Slabs (VI.) [or quarries] are made $1\frac{1}{2}$ to 4 inches thick with a length of 39 inches and a width of 20 to 24 inches.

In some cases hollow bricks are made, as tubular bricks for receivers (Fig. 180), gas burners (VII.), channels (VIII.), etc.

Muffle kilns, ordinary crucibles (IX.), the height of which varies from 2 to 24 inches; glass pots, ordinary retorts (X.), measuring up to 28 inches wide by 20 inches high and more than 40 inches long; gas retorts (XI.) being similar in width and height, but 6 feet long; laboratory furnaces, etc.

All refractory goods ought, as far as possible, to fulfil the following conditions:—

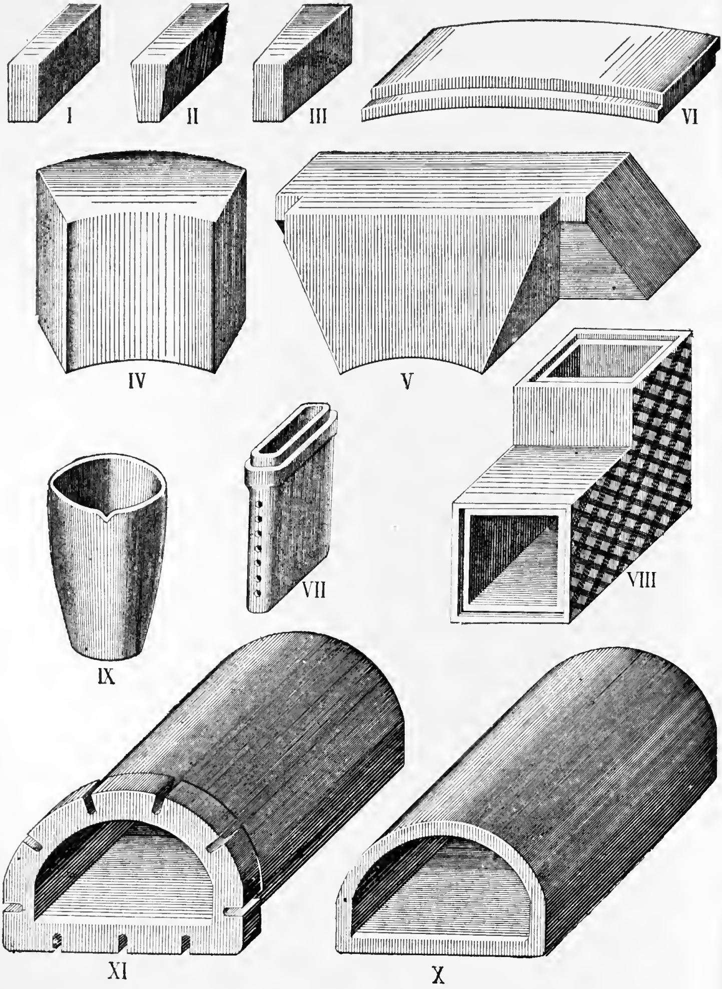

Fig. 257.—Fireclay goods.

(1) They must resist, without warping, the highest temperature to which they can be subjected. This resistance to heat depends mainly on their chemical composition and partly on their physical texture.

(2) They should bear variations of temperature without cracking or breaking, though it is not the variations themselves which are to be feared, but the differences of temperature between the parts of the same article, and these are the more difficult to prevent in proportion as the heating or cooling is more rapid. Thus, a thick crucible might break under some conditions of heating which a thinner crucible would have resisted. The more open the texture of the ware and the less it is burned, the more quickly is the temperature of the mass equalized, and the less liable will it be to crack or break. In dense pastes which are partially vitrified the conductibility is less, it is more difficult to keep the temperature equal, and the result is that the goods expand irregularly and this causes unequal tensions which the mass cannot resist and so breaks or cracks.

(3) Fireclay goods ought also to resist the action of different materials with which they come in contact in the kiln. Those which principally exert a harmful influence are the ash of the fuel, the materials themselves or the gases which escape from them. Argillaceous fireclay goods are easily attacked by all substances which unite with silica to form silicates, viz., alkaline bases, alkaline earths, and certain metallic oxides. At low temperatures an opposite reaction may be produced; the acid displacing the silica from its combination with the alumina and other bases in the body. The fireclay goods are attacked more vigorously the more porous the wares, the less so the denser the ware, or the higher the firing temperature.

As the two preceding conditions are contradictory, it is impossible to make ware that can, at the same time, bear a rapid heating and resist the action of alkaline ashes, or the corrosive action of melted glass. It is necessary to compromise in each case.

If fireclay goods are heated to a higher temperature than that to which they were heated during the burning they will usually shrink, and this may cause cracks or dislocation of the masonry. If the bodies contain a considerable proportion of quartz, the opposite may occur, as quartz expands; under great and prolonged heat, its density changes from 2·7 to 2·3.

Resistance of Fireclays to High Temperatures.—In the chapter on burning, the effect of the different materials of the body on the fusibility as well as the modifications caused by burning on the different properties of the body were explained.

The chemical composition of fireclays plays a more important part than in any other kind of ware, whatever their resistance to high temperatures.

Natural fireclays are composed of pure clay, of silica and fluxes, the latter being always in small proportion, but the amount of silica may be as high as 50 per cent. This term "natural fireclays" includes not only clays properly so called, but also the primary clays, providing they are sufficiently free from alkalies and iron to be used in the manufacture of fireclay goods.

Bi-silicate of alumina ("pure clay") melts at the temperature corresponding to Seger's cone, No. 36, which is about that for fusing platinum (1775° C.). The "fusion point" is lower when an increasing proportion of silica is added to the pure clay until the mixture contains one equivalent of alumina to 17 of silica (90·84 per cent of silica; 9·17 per cent of alumina). From that point, if the amount of silica is further increased, the body becomes more refractory again, until when it contains only pure silica (rock crystal) it can resist a temperature corresponding to cone 35, and equivalent to the "fusing point" of pure clay containing a trace of alkalies. If, however, alumina is added to pure clay, the mixture becomes more and more refractory, until pure alumina is reached, which resists a temperature above any of the preceding ones, and does not show any trace of vitrification at the temperature of fusing platinum.

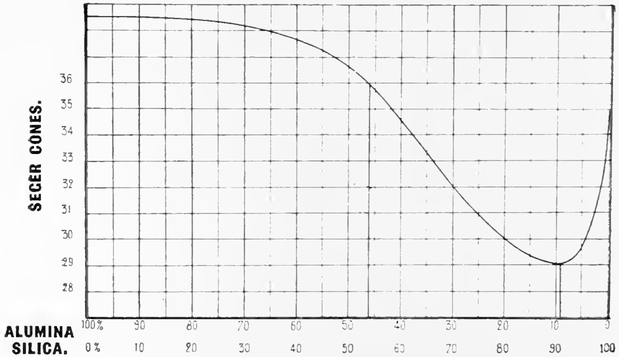

Fig. 258.

Fig. 258 represents the foregoing statements in a graphic form. The temperatures are expressed in Seger's cones, the curve and the horizontal base showing the centesimal proportion of silica and alumina in the mixture.

According to Richter, the action of fluxes as regards fusibility is apparently, but not decisively, in proportion to their equivalence; that is to say, that 20 parts of magnesia act the same as 28 of lime, 31 of soda, 36 of ferrous oxide and 47 of potash. This rule seems also to apply to the peroxide of iron (ferric oxide), which appears to be as infusible as alumina, and the equivalent of which is 80. Other reactions may also occur; thus at high temperatures the peroxide of iron is always partially changed into the protoxide.

It is well known that these relative fusibilities of the different fluxes can only be accurate at high temperatures, at the moment when, the whole mass of the body being softened, a definite compound is formed. It is not so noticeable at a lower temperature, because then the fluxes may be mixed up with other compounds which are still unfused at that temperature. This frequently happens with alkaline fluxes, which often occur in the bodies in the form of feldspar, and can only act when that rock begins to be vitrified. Lime occurring as calcium sulphate behaves similarly.

Bischof tried to define the fusibility of fireproof clays numerically, taking as a basis the proportion of fluxes present, expressed according to their equivalents, and comparing it with the proportion of silica and alumina. In this way he represented the composition of the clays by a formula in the form—

$$a\ Al^2O^3 + b\ SiO^2 + RO.$$

RO is taken as the unit representing the fluxes, a and b indicating the amount of alumina and silica in proportion to those fluxes. He suggested that the coefficient of fusibility is equal to $\frac{a^2}{b}$, the highest number being supposed to indicate the most refractory clay.

M. Bischof's theory seems to correspond fairly well with direct pyrometric results for certain clays, but as it rests on a chemical analysis, it is far less reliable then a direct fusing test, in which the clay is compared with Seger's cones. This theory is only mentioned because it has numerous partisans in Germany. [But it is doubtful whether any method of calculation can show reliably the fusing point of a clay from its analysis, though Ludwig's work, like Bischof's, is of great interest.]

Composition and Preparation of the Body.—Fireproof bodies are composed solely of fireclays or china clays (kaolins) with the addition, when necessary, of some opening material such as grog or free silica. For very plastic clays the proportion of opening material may be as high as two parts by weight to one part of clay, while it may not be possible to open very silicious clays at all.

The use of silica as an opening agent modifies the chemical composition and reduces the temperature which the material can resist; it does not allow the grains to be as coarse as is desirable, and makes the body liable to swell, and even crumble, in consequence of the expansion of the silica. Hence for all best fireclay goods only grog should be used as a non-plastic material. Fireclays which are decidedly silicious are only pure clays thinned with sand, and naturally present all the disadvantages just pointed out, and they can never be used to make fireclay goods of the highest quality.

The largest part of the grog used in the manufacture of fireproof goods is furnished by the rubbish of fireclay works, viz., bricks, crucibles, retorts, saggers, etc. This rubbish is bought for grinding up, and then sifted to obtain grains of various sizes. If sufficient of this grog cannot be obtained, it may be made by forming natural clay into balls and burning these in the same kilns as are used for ware. It is very seldom that special kilns are used for this purpose.

Fireclay is usually dug out a long time before it is needed. It is dried in the open air or in special kilns, and finally ground to powder.

This clay and the grog is mixed in bulk by putting the two materials into a pug-mill and adding the desired proportion of water to them. In well-arranged factories the clay powder and the grogs of different coarseness are stored in hoppers placed in the upper part of the buildings, from which they naturally run down into the pug-mill, which may be either vertical or horizontal. The latter is usually preferred because it makes the body closer with fewer air-bubbles in it. A good method consists in first using an open pug-mill or mixer, as shown in Fig. 32, and then passing the body through a second pug-mill which makes the body into large blocks. These are kept for some time in a damp place before being used for moulding.

In a general way it is best to use as infusible a clay as possible; but in some cases it is advisable to use clays which, at the temperature at which they are burned, show signs of beginning to soften, as they then make the body closer and better able to resist the action of the materials with which it comes in contact in the kilns.

To manufacture terra-cottas that will resist rapid changes of temperature, as much grog as possible must be incorporated with the clay, the former being of a fairly coarse grain. The dimensions of these grains depend largely on those of the object to be made. For thick blocks they may be as much as ¼ inch diameter, but can be reduced to ⅛ inch for thin ware. By employing coarse and fine grains at the same time, the smaller grains enter between the larger ones and allow a larger proportion of water to be mixed with the clay.

Moulding.—Fireclay goods are made by moulding by hand or by "drawing".

If the former, the body employed must be of a decidedly stiffer consistency than that used for moulding ordinary bricks, because it is essential to obtain more compact goods. This consistency necessitates the body being pushed or beaten inside the mould, instead of being made in the manner described in the preceding chapter. The moulds must be more solidly made. They are of wood, the joining being done with wooden corsers or bolts. For large pieces it is sometimes necessary to strengthen them with iron bands.

This hand moulding, to be successful, needs great technical skill, care and regular work.

Fire-bricks are made in moulds similar to those used for building bricks, but the output is much less, because of the stiffness of the paste. For larger pieces and blocks the moulds are filled by throwing the pieces in to form horizontal layers. When the shapes are complicated, or when there are empty parts, a rough model is moulded, and afterwards easily carved. Some round pieces may be "thrown," but this operation is not usually very easy, because of the granulated texture of the body.

For hollow pieces of a large size, such as pots for glass making or gas retorts, the bottom is first made on a plank of wood, either by putting lumps of clay paste side by side, or by sticking together slabs cut off from the blocks of body which issue from the pug-mill. The bottom is roughed out first with a thickness decidedly greater than is needed, then it is reduced by pressing it in such a way as to make the body spread towards the edges. Round this bottom is then placed the mould to be used for the walls, and on this is put more body, beaten out and suitably joined together. Fig. 259 shows the moulding by this method of a pot for making glass, the mould being in two pieces, joined together by bolts or hooks, so that it may be removed without disturbing the contents. In Fig. 260 is shown the making of a gas retort; the mould being in several pieces, joined by pins, which are put on one another as the moulding advances. The inside shape is obtained by smoothing the surface with the hand, and passing a template over it, or by measuring the thickness of the body by means of a pair of compasses.

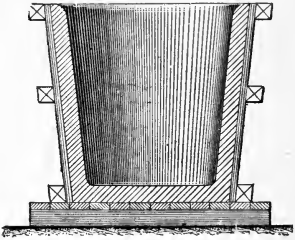

Fig. 259.—Moulding a glass pot.

Plain, ordinary bricks can also be made in the pipe machines already described. By inclining the wires of the cutting board, bricks with sloping sides or wedge-shaped ones can be made.

For hollow goods of a rectangular section, when made in moderate quantities, piston propellers worked by hand are generally used. But crucibles or retorts, with a cylindrical or a prismatic section, and stoneware pipes of large diameter are expressed from machines with vertical piston propellers (Fig. 295). The bottoms or ends are always added and joined by hand.

Some goods, e.g. saggers, are made by first moulding slabs of the body by hand, on a table dusted over with grog, on which are fixed four rules, the thickness of which is equal to that of the slab. The body should be firm enough to be roughly shaped by striking it with a wooden bat. It is then smoothed and rolled round a wooden mould, the inside of which is the shape of the sagger. To add the bottom, the mould is placed on another slab of body, and the whole is joined together by hand. To take the mould from the article it is sufficient to strike the body, which

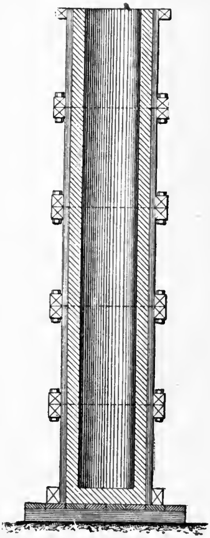

Fig. 260.—Moulding a gas retort.

lengthens slightly and becomes detached from the mould, which is then drawn off vertically.

When a machine replaces handwork, the slabs of body are placed in the interior of the mould, which corresponds to the outside of the product; then a piston is pushed in, and presses the body together and makes it join. Fig. 261 shows a machine of this kind, made by Boulton.

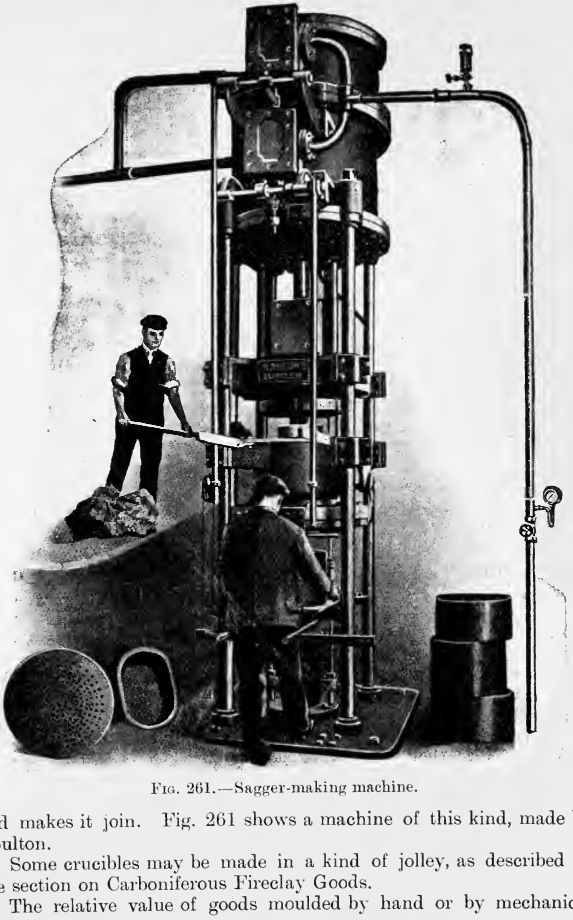

Fig. 261.—Sagger-making machine.

Some crucibles may be made in a kind of jolley, as described in the section on Carboniferous Fireclay Goods.

The relative value of goods moulded by hand or by mechanical pressure is often disputed; the former are more porous, and their value depends on the care taken by the workmen, but the latter have the defects previously mentioned as belonging to all pressed goods. In most cases, both processes are equally good, but the cost of installing moulding machines limits their use to large quantities of similar pieces.

The drying of fireclay goods, when thin or of a small size, does not present any special difficulty; it is done by the same methods as those employed for plain building bricks. Thick and heavy goods which are difficult to handle, and which, unless made in a warm dry climate, can only be completely dried in artificially heated dryers, often cause much trouble.

When moulded by hand, the goods are usually left in the mould for about twenty-four hours, and are then taken out and carried to the drying-shed. This is a room heated either by (1) pipes running under the floor, or (2) by means of a hot-air stove. In the former case the waste heat from the kilns or from the steam-boiler can be used. The drying must be done very slowly when the pieces are thicker; sometimes several weeks are needed. In theory, it is better to have several drying-sheds, so as to graduate the temperature according as the drying advances. From time to time, if the shape will permit, the pieces are turned over so as to render the drying uniform.

In some potteries the drying is done in the moulding shop, which should be heated, unless favoured with a special climate.

The burning of argillaceous fireproof goods is usually done in round down-draught kilns, like those described on page 213 (Fig. 151). The capacity of these kilns varies from 1400 to 5000 cubic feet, the diameter being equal to or slightly greater than the height.

According to the amount of moisture in the ware, and to its size, the slow firing (smoking) may vary from twelve hours to two days. The full firing needs two to three days. The consumption of fuel is extremely variable, owing to the nature of the body, the temperature at which it is burned and the skill or otherwise of the firemen. In some works 209 lb. of coal of a good quality to a ton of ware is sufficient; in others it is necessary to use 550 lb. and even 670 lb. In kilns of the same type, equally well managed, the higher the temperature of burning, and consequently the greater consumption of fuel, the better is the quality of the goods.

For burning bricks and blocks, continuous kilns may also be used. In these, the consumption of fuel is reduced by 176 to 264 lb. per ton of ware, so that it is more economical to use this class of kiln, though with those in which the fuel is burned in contact with the goods some of them will be spoiled. The use of coal or gas in continuous chamber kilns needs slightly more fuel, but the goods are kept free from ash and are generally well burned, so that this type of kiln is certainly the best for burning fireclay bricks and blocks.

For burning retorts, crucibles, etc., in large quantities, continuous chamber kilns may also be used, but as in this kind of kiln the accumulation of heat is less than in kilns with one chamber and the heat lost by heating the walls is much greater, there is no reason for prefer-ring them when, as for retorts, the flames ought to be descending, or when the production of crucibles, for example, requires a very regular rise in the temperature.

Whilst, in a general way, continuous kilns are more economical for burning fireclay goods, it is necessary to state that they are only of commercial value where the output is large. In the fireclay industry, orders are somewhat irregular; it is difficult to manufacture for stock, because of the various shapes and qualities of the goods, so that, commercially speaking, it is sometimes better to choose intermittent kilns, as these adapt themselves better to the needs of a variable business.

General Arrangements of the Manufactories for Fireclay Goods.—The manufacture of fireclay goods is sometimes carried on in brickfields or in tile works. Usually the fireclays found in the neighbourhood are used, and the implements employed in making ordinary bricks are employed for the manufacture of the firebricks. The goods thus obtained are generally of a medium or inferior quality, and, on account of their relatively low price, are used for many purposes which do not need a better quality.

The larger works for making metal, glass, gas, faience, porcelain and some chemical works manufacture all the fireclay goods they need. They prepare the grog from their waste and buy the fireclay. In such works, therefore, there is no need to economize in the price of the clay, as they must have fireclay goods of the right quality, and those which experience has shown to be the best for their own special purpose. These firms usually have bad implements and poor facilities.

There is a certain number of special factories for fireclay goods, usually placed near the clay-beds. The cost of the fuel, which is an important factor, also exerts a certain influence on the placing of these factories. In some cases it is best to place the works near a centre of consumption and transport the raw materials.

The general arrangement of a factory for fireclay goods is very simple. The factory is composed of sheds, in which are arranged the shops for preparing the body and for moulding, the drying sheds and the kilns. It is necessary to keep the goods, when made, sheltered from the rain, in order to prevent the formation of a very disagreeable green colour, due to vegetation.

2. *Aluminous Fireclay Goods.*

Aluminous fireclay goods are used when it is necessary to have neutral goods, only slightly attackable by alkalies, and resistant to high temperatures. The silicious fireclays, which contain at most 30 per cent of alumina in a natural state, or about 33 per cent when burned, cannot be used for the manufacture of truly aluminous goods. The plastic fireclays, with a proportion of 30 per cent to 35 per cent of alumina, produce goods having from 34 to 40 per cent of alumina, and some very pure clays contain when burned as much as 43 per cent of alumina.

Under the term "aluminous fireclay goods" are included all those which contain more than 33 per cent of alumina. This amount is insufficient to combine with all the silicate to form a bisilicate, and theoretically only those goods can be properly called aluminous which have an amount of alumina greater than that of pure clay. It is therefore necessary to introduce even into the most plastic bodies a supplementary quantity of alumina.

Unfortunately highly aluminous minerals are rare and often costly, and only halloysite or lenzenite and the bauxites, can be profitably used.

Among the last, the varieties containing the least iron oxide (under 5 per cent) must be chosen. Although these bauxites are hydrated silicates of alumina,[1] they are destitute of all plasticity, and cannot be used except as non-plastic materials, that is to say, their proportion must not be more than 66 per cent. If a fairly pure plastic clay, containing when burned 33 per cent of alumina, 60 per cent of silica, and 4 per cent of fluxes, is mixed with a bauxite containing 76 per cent of alumina, 18 per cent of silica, and 6 per cent of fluxes, a ware could be made having a maximum of 61 or 62 per cent of alumina with 33 per cent of silica, that is to say, which corresponds to a monosilicate of alumina. This monosilicate is needed to obtain really neutral goods.

Bauxite is found as rather hard rock, or as an earth, and must be well calcined and reduced to powder before being mixed with the clay. It must not be mistaken for fireclay grog, for the latter, having the same composition as the clay, does not alter the composition of the body. The bauxite, on the contrary, must be very intimately mixed with the clay, so that the mass may be homogeneous. The result is that the goods, thus obtained, are dense, and resist the action of ashes or kiln gases well, but bear rapid changes of temperature badly.

The manufacture of aluminous goods is the same as that of argillaceous goods and is carried on in the same factories.

Attempts to bind bauxite powder with different agglutinants, as tar and silicate of soda, have been made. This manufacture then becomes similar to that of silicious fireproof ware (see later).

3. *Carboniferous Fireclay Goods.*

The carboniferous fireproof goods fulfil all the conditions required in fireproof materials: resistance to the highest temperatures, to rapid variations in temperature, and to ashes and other materials with which they may come in contact, but they have the disadvantage of being burned up rather rapidly and of being costly. They are seldom made into bricks or blocks, but are much used for the manufacture of plumbago crucibles, which are employed in several metallurgical operations on account of their reducing qualities.

[[1] They are more usually regarded as impure alumina, the proportion of silica in the best bauxite being small.—A. B. S.]

The carbon used is natural graphite or blacklead, or even the deposit of carbon which is found in gas retorts.

Graphite or plumbago is a mineral of a metallic, grey colour, crystalline, greasy to the touch and leaving marks on the fingers. Its density is 2·1. It is found in France; in Germany; in England at Borrowdale and Keswick (Cumberland); in Austria and in several parts of Moravia and Styria; in the United States at Sturbridge (Massachusetts), at Ficouderora (New Jersey), at Fishkill (New York), and in some localities in California; important beds are found in the Island of Ceylon, but the most important mines are those in the Batougal and Ural Mountains, and on the banks of the river Anotte in Siberia. It only occurs in the primitive strata along with gneiss, granite, and mica-schists. The proportion of carbon varies from 75 to 97 per cent, the remainder being a silicious or silicious-aluminous gangue.

The carbon from gas retorts is generally purer, but the price has risen considerably since its use in large quantities in the electrical industry.

Carbon, in whatever form it may be employed, is first powdered, and then mixed with the powdered clay. The quantity of carbon used varies from 25 per cent to 50 per cent, according to the purpose for which the crucible is to be used. A part of the clay may be in the form of fine grog. Sometimes magnesia is also added.

The measuring and mixing is first done in a dry state, and the mass is then put into a pug-mill, the proportion of water necessary for moulding being added; the pugged body is left for several days without being used.

The moulding is done mechanically, as it is necessary to compress the material. For this purpose a jolley (Fig. 262) is generally used. The exterior mould, either of plaster or cast-iron with a movable bottom, is placed on the table of a turning lathe, set in motion by means of pulleys or a hand fly-wheel; the required quantity of the body having been put in the bottom of this mould a plunger is lowered and makes a rough form. Then, by working a lantern wheel, this plunger, which is in two pieces, is forced open, and compresses the body sideways against the outer mould. This compression is made stronger by the upper rim which carries the plunger, and prevents the body from going out at the top. When the plunger is fully open, a final pressure is given by working the hand fly-wheel; after which the plunger is closed and raised and the mould emptied.

The crucibles thus made are dried for some time in the moulding shop, and are placed in hot-air stoves.

The drying being finished, the crucibles are heated in muffle kilns to a temperature of about 700° C. Round down-draught kilns are sometimes used, the goods being then placed in saggers.

4. *Silicious Fireproof Goods.*

Silica is less refractory than alumina, but, as the ores of alumina are nearly always impure, while numerous beds of silica can be found which only contain traces of fluxes, fireproof ware which resists high temperatures can be made more cheaply with silica than with fireclay. These silicious wares are decidedly acid, a property which is desirable in some metallurgical operations, and, as they tend to increase in volume in the kilns, by making due allowances, very close and non-shifting masonry can be built.

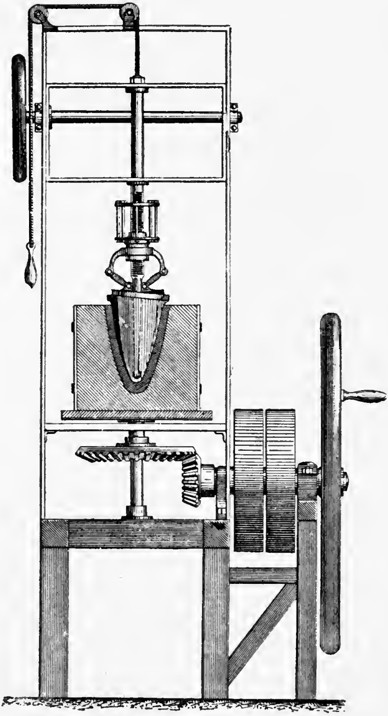

Fig. 262.—Machine for moulding crucibles.

Silicious fireproof goods are scarcely used except for the manufacture of bricks and blocks; the best known are those from Dinas, which have been made since 1822, of a sand found in the South of Wales, which contains 97 to 98 per cent of silica. It is mixed with 1 to 2 per cent of lime, made into a paste with water, and the mass is moulded in a press similar to those used for making ordinary bricks of dry body.

In some factories a hand press only is used. The moulded bricks should be carefully and well dried artificially, and burned in round down-draught kilns. The "smoking" must be carried out very slowly; then the temperature is raised until it reaches 1300° to 1600° C. The cooling should also be very slow; it is usually done without admitting any air, the heat disappearing simply by radiation from the kiln.

On the Continent an imitation of Dinas bricks is much used, but as there is no natural sand of the quality of that used at Dinas, it is necessary to crush pure silicious rocks to a fine impalpable powder, and to grains of ·04 to ·26 inches which are sieved and afterwards mixed with a powder in suitable proportions. The best proportions for the mixture seem to be $\frac{1}{3}$ of powder, $\frac{1}{3}$ of grains from ·03 to ·12 inches, and $\frac{1}{3}$ grains ·12 to ·26 inches. The processes used for grinding the rocks have already been described; it is wise to calcine them first, so as to make them more easy to grind. Afterwards $1\frac{1}{2}$ per cent of lime is added to the silica, and the making is continued as was described for Dinas bricks.

The lime not only supplies some of the plasticity necessary for moulding, though the very fine silica has a plasticity sufficient for moulding bricks, but it is chiefly used for giving a greater resistance to the burned ware, as it forms a silicate of lime which binds the silicious grains together. A larger proportion of lime would make the ware more fusible. Lime has recently been replaced advantageously by calcium chloride dissolved in water, which decomposes with the heat; the chlorine is given off, and the lime alone remains, but more finely divided in the mass than when added direct.

Attempts to replace the impalpable powdered part of the silica, which is necessary to obtain a certain plasticity, by adding clay instead, ought to be condemned, as the refractory properties of the ware would thus be materially diminished (Fig. 258).

Other binding materials such as silicate of soda, tar, treacle, etc., do not give results to be compared with true Dinas bricks.

When very light bricks are wanted, which have not to resist very high temperatures (as those employed in locomotives, or marine boilers), infusorial earths, mixed with a little fireclay (p. 39), may be used with advantage, the manufacture being the same as that of argillaceous firebricks.

Some silicious bricks are made with the sand which has been used for polishing glass. This sand is moulded in presses, and the ware, when made, is dried and burned at a moderate temperature. The sand particles are cemented together with the rather large proportion of glass which this sand contains. White ware is thus obtained of a beautiful decorative appearance, imitating stone, but containing too much flux to be considered as a fireproof material.

5. *Basic Fireproof Goods.*

Basic fireproof goods owe their properties to the proportion of magnesia or lime which they contain. *Magnesia* seems slightly more fusible than alumina, but it can more easily be obtained nearly pure, containing only about 2 per cent of lime and 1 to 1½ per cent of silica, oxide of iron and clay. When calcined above 400° C. it loses its water of combination. Heated to a lower temperature, it may afterwards absorb moisture from the air, and by changing back into the hydrate be used again. It is less fusible than silica.

Calcined magnesia is usually mixed with some magnesia that has simply been dried, and a body is obtained which is sufficiently plastic to be moulded into bricks, and which has even been used for making crucibles or retorts, especially if a little plastic clay is added to it. Very refractory bricks should be made with a press, dried first in the open air, then in a heated drying-shed; the burning is the same as for ordinary fireproof goods [but at a higher temperature].

This method for making magnesia bricks is relatively recent; most magnesia bricks are obtained from carbonate of magnesia or giobertite (sometimes improperly called magnesite) from Frankenstein (Silesia) and the Isle of Eubœa.

The giobertite is calcined at a high temperature to decarbonate it; then a certain quantity of water and raw material is added to it, and the resultant paste is moulded in hydraulic presses. The plasticity, which is very slight, may be increased by moistening the mass with a solution of magnesium chloride. After being dried in the air, it is burned at a high temperature, but this is often difficult on account of the great shrinkage of the goods.

For goods made of magnesium limestones or dolomite, a mixture of lime and magnesia seems to possess the same fireproof qualities that each of these bases has by itself, but any silica and alumina present rapidly increases the fusibility. It is, however, difficult to work these limestones or dolomites without the mass containing some percentage of these materials, either naturally, or as clay added purposely. These bricks, which are fairly cheap as compared with the preceding ones, are only suitable where it is necessary to use basic materials, but not for very high temperatures. They are manufactured by grinding the raw materials to a paste which is afterwards moulded in a press. The drying is very slow. The burning is difficult, because the shrinkage of the bricks is considerable, and is not lessened, as in bricks made of giobertite, by previously calcining a part of the material. According to Walrand, a body containing silica 5, alumina and oxide of iron 5, lime 28, magnesia 18, water and carbonic acid 44, makes bricks of a good quality.

Lime is one of the most refractory materials known. Even when well burned, lime retains the property of being hydrated in air, so that it is not possible to preserve goods made of lime in an atmosphere that is not absolutely dry. Except for a very limited use in electrical kilns it is not possible to make bricks with lime except by combining it with alumina and iron oxide. Lime cannot be added to silica, as that forms silicates of lime, which are much more fusible than the silicates of magnesia. The manufacture of bricks of lime is similar to that of dolomite, and has the same difficulties to contend with when they are being burned.

6. *Fireclay Mortar (Pug).*

The material used as mortar in fireproof masonry is usually furnished by the makers of fireproof goods. Theoretically, this material has the same composition as the goods. The mixture, instead of being made into a paste, is dried and put in sacks. Water is only added to it immediately before use.

As the material ought not to contain any opening material in coarse grains, only fine sand or powdered grog can be employed. This mortar shrinks in the kiln, so that it is best to open it more than the body and only to give it as much plasticity as is absolutely necessary for it to be used with a trowel.

For silicious or basic goods, a little clay may be added to the body to give it a certain amount of plasticity.

The mortar is also used for stopping cracks in masonry or in crucibles and retorts. Ordinary mortar may be used in the first case, but in the second it is usually insufficient. All kinds of mortar containing clay shrinks thus causing them to break off the parts repaired and making this repairing often only imaginary. By taking advantage of the property of silica of swelling when submitted to a high temperature, as by using gannister (p. 40), this difficulty may be overcome.

A similar material to gannister may be made artificially by using crushed quartzose rocks, to which is added about 10 per cent of clay. This mixture is suitable for high temperatures; or some flux may be added to it, so that the mortar may commence to vitrify to make it adhere to the goods.

7. *Tests for Refractory Goods.*

Refractory goods, up to the present time, have not been the object of any general method of testing. Having regard to the very different conditions under which fireproof goods are used, it may well be argued that actual use is the only means of obtaining absolutely conclusive results. This is not satisfactory to the manufacturers of fireproof goods, who would like to give their patrons numerical results to prove the quality of their wares. Also, from the point of view of general scientific interest, it is desirable for standard methods of testing to be adopted in order that wares of different kinds may be compared.

Exact chemical analysis of the wares seems to be the first and most important basis of comparison. It is so complicated and the quantities to be tested are often so small, that it can only be done in properly arranged laboratories and by competent chemists. The measurement of the temperature which causes the goods to begin to vitrify or lose their shape, or that at which they fuse, can be made in test kilns such as those described on page 191. The most practicable standard at the present time seems to be Seger's cones [or electrical pyrometers for direct temperature measurement]. The material to be tested ought, preferably, to be in the form of small triangular pyramids of $\frac{1}{3}$ inch sides and 1 inch high.

To measure ability to resist rapid changes in the temperature, nothing has been discovered better than heating a test-piece to redness and then plunging it into water.

The measurement of the coarseness of the grains, expansion under the influence of a certain definite temperature, and porosity, would frequently give interesting comparative results.

CHAPTER XII.

FAIENCES.

Classification.—Faiences (from Faenza, a town in Italy) are pottery of a porous body, either white or coloured, but always covered with a glaze. It is the existence of this glaze which distinguishes them from ordinary terra-cottas and the fireproof terra-cottas.

Some potters do not admit of this definition, but the author agrees with Deck: "I call faience all ware of an earthy fracture (consequently porous) covered over with an enamel".

It may appear strange to term an enamelled brick or tile "faience," but there are stoneware and porcelain bricks and tiles; so it is difficult to see why there should not be faience ones. The meaning of the word "faience" has been considerably widened since the time when it was only used to denote Italian wares of the fifteenth and sixteenth centuries, and it is a singular anachronism to apply it to the ware of the Persians. But it is better, by accepting the clear and precise definition of the celebrated faience manufacturer Deck, to get away from the confusion that has arisen from Brongniart's classification. The advantage of having a single word to denote all porous wares covered with a glaze is especially felt if the French terminology is compared with that used in England and Germany. There is no common English term to denote all classes of faience: *majolica, delft ware, earthenware, flint ware, ironstone, queen's ware,* etc.

In Germany, *Steingut* denotes the fine faience of Brongniart, but the other faiences all have a series of names: Terra-cotta, Majolika, Irden-geschirr, etc., without any general designation being universally adopted.

The term faience having been adopted to designate all porous wares covered with a glaze, it is not necessary to call table-ware, as Brongniart does, "fine faience," and "common faience" the wares from Urbino, from Rouen, and consequently all the silicious faiences, the most beautiful productions of ceramic decoration. It was certainly not the intention of Brongniart to cast a slur on these latter wares, the adjectives "fine" and "common" being applied by him to the bodies, which are entirely hidden by the glaze.

By being satisfied by defining precisely the principal kinds of ware, and with grouping together those which, by the similarity of their properties, were the most like one another, it is possible to distinguish six kinds of faience, forming sufficiently well-defined groups, in which may be classed nearly all wares of this order. The distinctions are based upon the composition of the body, which includes, to a certain extent, that of the glaze. The classification adopted in this chapter is the following:—

(1) *Common faiences, with a fusible argillaceous body*, in which the fluxes are in a sufficiently large proportion to make the body fusible, without any of them being in an overwhelming proportion. This body is the same as that used for many terra-cottas. It is formed of one or more clays, natural or washed, with the sole addition of sand, or grog, if necessary.

The glaze is plumbiferous, or alkaline boracic. The principal varieties of this kind of faience are the following:—

Common pottery, architectural faiences, encaustic tiles, stoves; vases, dishes and decorative objects.

(2) "*Enamelled" faiences, with a fusible argillaceous calcareous body*, which is formed of a natural marl or of a mixture of clay with marl or with calcium carbonate; the glaze is stanniferous, or plumbiferous. The term "enamelled" is improper here. Sometimes the word stanniferous is used; this is still worse, as the tin is only to make it opaque, and its presence in a glaze gives no indication of the composition of the latter. The word has only been used in default of another, and not to break a terminology which has become customary.

(3) *Silicious faiences, with a fusible silicious body*, containing a little clay, much silica, and a good proportion of alkaline fluxes or limestone. This very slightly plastic body is, at the present time, composed of silica, with the addition of non-ferruginous plastic clay and lime, or alkalies of different kinds. The glaze is alkaline plumbiferous.

(4) *Pipeclay faiences, with a slightly fusible argillaceous calcareous body*, formed of a mixture of white fireclay and a small proportion of calcium carbonate or marl. The body is decidedly plastic and needs a higher temperature for burning it than the preceding ones. The glaze was formerly alkaline plumbiferous, but now alkaline earthy bases and boracic acid are often added to it.

(5) *Flint faiences, with a fireproof argillaceous silicious body*, formed of a mixture of white fireclay and a large proportion of silica. The body is somewhat plastic and must be burned at a high temperature. The glaze is plumbiferous, alkaline, alkaline earthy, or boracic.

(6) *Feldspathic faiences, with a slightly fusible argillaceous alkaline body*, are usually formed of white refractory earth (kaolin), silica and an alkaline flux in the form of feldspar or pegmatite. The glaze is plumbiferous, alkaline, alkaline earthy, or boracic.

1. *Common Faiences, with a Fusible Argillaceous Body.*

Common plumbiferous ware has been in general use for all domestic purposes since the twelfth century. The body is that of ordinary ware, or is made of a fusible clay, generally a ferruginous calcareous one, with the addition of grains of sand or grog to make it less sensitive to variations in temperature. The resistance to irregular heating is greater the larger the proportion of non-plastic materials. In this direction, the only limit is the necessity for keeping the body sufficiently plastic for it to be shaped.

This shaping is almost exclusively done by throwing, the handles, spouts or feet being fastened on afterwards. The goods are easily dried in the moulding shops. When the drying is finished, the glaze can be put on the unburned ware, or the body may be burned first and the glaze melted on a second burning. The glaze, which is thin and transparent, is only used to make the body impermeable.

The glaze is a silicate of lead whose fusibility is in proportion to the amount of lead present. The composition of it usually varies between silica 28·8, oxide of lead 71·2, and silica 44·7, oxide of lead 55·3; the first composition having the formula $\text{PbO}, 1\tfrac{1}{2}\text{SiO}^2$ and the second the formula $\text{PbO}, 3\text{SiO}^2$.

There is usually added to the glaze a certain quantity (from 5 per cent to 20 per cent) of clay, that employed for the body being used for this purpose, in order to give the glaze a certain amount of plasticity. The use of clay makes a glaze less fusible, so that it may be necessary to modify the relative amount of silica and lead oxide. In any case there should be at least one and a half equivalents of silica to one equivalent of base, to ensure all the lead oxide being combined. If the proportion of silica is above three equivalents of the base the glaze usually becomes too infusible for this kind of ware.

The inside of vases is sometimes covered with a white opaque glaze, usually obtained by adding 10 per cent to 15 per cent of tin oxide to the preceding glaze, and at the same time reducing the proportion of silica so as not to alter the fusibility. Any clay present ought, in this case, to be a white burning one.

The glaze is generally applied by pouring, sometimes by dipping, and seldom by dusting: the lead compound employed is either red lead or galena for the commonest wares. The glaze is often colourless or slightly coloured by the oxide of iron contained in the clay. In that case, the ware is a brighter colour than the body. Sometimes 5 to 12 per cent of manganese oxide is added to produce a brown colour, or 2 to 3 per cent of copper oxide (scales of red copper) to give it a green colour, the shade of which is modified by the colour of the body beneath.

This ware is often burned in horizontal kilns with one fireplace, but it would be more advantageous to use round down-draught kilns. For large quantities, which are rare, it would be better to use continuous chamber kilns.

Common ware is manufactured in small local potteries near the clay pits. The quality of the ware depends almost entirely on that of the clay that is used. The ware is cheap and however rough it may be it is useless to improve it, because then only more expensive goods would be obtained, without their quality being comparable to that of other wares.

Among the common plumbiferous wares may also be classed some pipes used for conveying liquids, the inside of the permeable body of which is covered over with a thin and transparent plumbiferous glaze. These pipes, made by throwing or expression, were formerly very much used but are now almost entirely replaced by stoneware pipes.

The employment of a plumbiferous glaze presents certain dangers in pots intended for cooking food. When the firing temperature is not high enough to combine all the lead oxide, or when the glaze does not contain enough silica (many compositions given in works on pottery are of this kind), this uncombined lead oxide may be dissolved by the acids in the food and cause blood poisoning.

The following method of testing will show whether these wares are harmless. Boil some vinegar gently for about half an hour in the pots to be tested, filling up the liquid with water as it evaporates and making the volume in proportion to the capacity of the pot (50 grammes of vinegar being sufficient for a half litre pot). When the liquid has been sufficiently heated it is allowed to cool, filtered and some sulphuretted hydrogen dissolved in water added to one part of the colourless solution, or a current of this gas is passed through it. The presence of lead will be detected by a black precipitate or else by a brown colour. In another part of the solution some potassium iodide solution would produce a yellow precipitate of lead iodide if sufficient lead were dissolved out.

Common Non-Plumbiferous Ware.—Cases of lead poisoning have been serious enough to have caused numerous researches for the purpose of replacing plumbiferous glazes by other compounds that do not contain lead. The problem is very difficult as the glaze must not be made too fusible and the price must not be increased out of proportion to the low value of the ware.

The lead may be partly replaced by alkali, usually introduced in the form of silicate of soda or soluble glass, but soda or potash can be used direct so as to obtain a double silicate of lead and alkali. The chemical composition of these glazes may be represented by the formula

$$1 \left\{ \begin{matrix} PbO \\ K^2O \text{ or } Na^2O \end{matrix} \right\} 1 \text{ to } 1\tfrac{1}{2} SiO^2.$$

If it is advisable to leave the lead out entirely, lime must be introduced into the glaze, so as to obtain a non-soluble mass, and a part of the silica must be replaced by boracic acid, to increase the fusibility.

According to Seger, it would also be necessary for the glaze to contain a certain proportion of alumina (clay) to make it sufficiently transparent, the composition of the glaze being between the limits of the two following formulæ:—

$$\left\{ \begin{matrix} 0{\cdot}6K^2O \text{ or } Na^2O \\ 0{\cdot}4CaO \end{matrix} \right\} 0{\cdot}5Al^2O^3,\ 4SiO^2,\ 0{\cdot}5B^2O^3$$

and

$$\left\{ \begin{matrix} 0{\cdot}2K^2O \text{ or } Na^2O \\ 0{\cdot}8CaO \end{matrix} \right\} 0{\cdot}6Al^2O^3,\ 5SiO^2,\ 1B^2O^3$$

which correspond approximately to the following proportions:—

Silica	60·5	58·6
Boracic Acid	11·5	18·0
Alumina	13·0	12·0
Lime	5·6	9·0
Alkalies	9·4	2·4

The relative amount of lime and alkalies depends on the composition of the body; alkaline glazes having to be applied to silicious bodies and the calcareous glazes to aluminous bodies.

A white glaze may be obtained by adding 10 to 12 per cent of tin oxide to the glaze if the body is slightly coloured, or 12 to 15 per cent for ferruginous bodies. If this addition reduces the fusibility the proportion of boracic acid may be slightly increased.

Some glaze merchants sell leadless glazes, the composition of which they keep more or less secret, but these compounds, which contain the substances already mentioned, cannot be adapted indiscriminately to any body, as can the plumbiferous glazes by the simple addition of silica or clay.

The addition of the salts of baryta—heavy spar or witherite—to these glazes has also been suggested, but these substances present difficulties which are not easy to overcome in works making common ware.

Architectural faiences as bricks, tiles, paving tiles, and architectural terra-cottas, mentioned in Chapter X., may be covered with glazes, this use of glaze dating back to the remotest antiquity.

At the present time, the body of architectural faiences is usually formed of a fusible clay. All terra-cotta bodies cannot receive glazes, as, independently of the agreement necessary between the glaze and the body, it is essential that the latter should have a fairly smooth surface and not be too porous. These defects may be partially corrected by smoothing the body after it has been moulded or by covering it over with thin slip.

The composition of the glazes and their application depends on the composition of the body, on its colour and on that of the glaze. If the body is inclined to orange or red, a transparent plumbiferous glaze gives it an intense red colour. By adding to this glaze 5 per cent to 8 per cent of manganese oxide, darker or lighter brown colours are obtained. A mixture of iron and manganese oxides with a touch of cobalt makes black. All other colours can only be obtained on this body by means of intermediate slips or opaque glazes.

With yellowish bodies, the series of transparent colours is much richer. Lead silicate alone gives yellow. Lead silicate and iron oxide or manganese produces the preceding various red and brown colours. Green can easily be obtained by means of copper oxide and blue with cobalt oxide. Only light colours and white need to be opaque or applied on an intermediate body or engobe.

It is only exceptionally that an article made of white body has to be slipped, as on it, with a colourless glaze, white ware can be produced. A light yellowish tint, however, may be hidden by a glaze containing a little cobalt.

The coloration of architectural faience resolves itself into the employment of:—

(1) A transparent glaze on a body covered by coloured slip.

(2) Transparent coloured glazes.

(3) An opaque white glaze, which may be slightly coloured for light tones.

There are special conditions of manufacture, colour and shape of the wares, which limit the use of slips or coloured glazes; it is impossible to give any general rule for them.

Colourless, transparent glazes are always plumbiferous; their composition is usually one equivalent of lead oxide to 2, 2·5 or 3 of silica, that is to say it usually varies from 60 to 55 per cent of lead oxide for 40 or 45 per cent of silica. The most silicious bodies are used with the most plumbiferous glazes.

Coloured glazes are generally formed from the preceding plumbiferous glaze, with the addition of colouring oxides in the proportion of ½ to 5 per cent, according to the shade required, the amount of silica being slightly varied, so as to obtain glazes which are equally fusible.

To obtain certain colours it is necessary to introduce alkalies into the glaze, part of the lead oxide being replaced by alkali. The proportion must, in no case, be above one equivalent of lead for one of alkali: the chemical composition in that extreme case being

$$\left\{\begin{matrix} 0{\cdot}5Pb^2O \\ 0{\cdot}5K^2O \text{ or } Na^2O \end{matrix}\right\} 3SiO^2.$$

The amount of silica should not fall below 2½ equivalents. The introduction of the colouring oxides modifies the fusibility, but this may be corrected by varying the proportion of silica within the preceding limits. If, in spite of this correction, the glaze is still too fusible, the proportion of alkali may be lowered, or a little lime or oxide of zinc added in place of the lead, as these are more refractory.

Boracic glazes are seldom employed for architectural faience, because the degree of fusibility required can always be more economically obtained with lead oxide.

Opaque white glazes are more difficult to produce, as the opacifying material lessens the fusibility of the glaze. If the body contains a large proportion of lime, the white enamel for enamelled faience, mentioned later, may be used. If such is not the case and the body is slightly coloured, an enamel composed of 60 per cent of lead oxide and 40 per cent of silica, with 10 to 12 per cent of tin oxide, may be used, though for highly coloured bodies this enamel is not opaque enough, and it is often too refractory. Boracic acid must then be employed as a flux, replacing some of the silica. Such enamels may be roughly represented by the formula—

$$\left\{\begin{matrix} 0{\cdot}7PbO \\ 0{\cdot}3CaO \end{matrix}\right\} 1{\cdot}5SiO^2,\ 0{\cdot}5B^2O^3 + 10 \text{ to } 12 \text{ per cent } SnO^2,$$

though all the proportions may vary, according to the nature of the body and the degree of fusibility to be obtained.

Further, the whole or part of the lead oxide may be replaced by alkali, but the amount of silica must be increased, and the product then resembles the glazes used for the common non-plumbiferous wares just mentioned.

The glazing is done by different methods: (*a*) by dipping, for bricks, which are always glazed on one or two faces only; (*b*) by spraying, for the upper face of tiles or paving tiles. Other kinds of architectural faience are glazed by one of these methods, unless the glaze must be put on with a brush, which is naturally compulsory when the pieces are many-coloured. When the goods are round, this application with a brush may be more easily made by turning them on a wheel, the brush being moved in height only when a whole turn has been accomplished.

The glaze is generally applied to the unburned dry body; for some more delicate objects it is preferable, however, to apply the glaze to the burned body.

The burning may be in the continuous kilns used in tile works or brickfields, especially if they are heated by gas and if the glazed or enamel goods are carefully protected. But it is generally preferable to burn architectural faience in a muffle or in saggers in round intermittent kilns. The atmosphere of the kilns must always be oxidizing, and the length of the full firing should be short enough to prevent too great a volatilization of the lead oxide or of the boracic acid.

All the methods mentioned in Chapter IX., and especially gilding, may be used for decorating architectural faience. Successful attempts have been made to lessen the gloss of the glaze by diminishing its fusibility, especially by adding to it a larger proportion of silica. Vitrification is then not complete, and the surface remains dull or *matt*, without having the completely dull look of the ware slipped with body.

The resistance of architectural faience to the weather, and especially to frost, is important, and it is evident that the body itself must fulfil the conditions of resistance mentioned in connexion with terracottas, and that under-burned bodies must not be covered with a glaze, as has sometimes been done.

If a perfectly resisting body is used, it is easy to see that the glaze diminishes rather than increases the resistance. If the body when saturated with water is subjected to frost, the ice formed in the pores exercises, on the whole interior surface of the glaze, a pressure which tends to detach it, or at least to make it crack off in scales. To remedy this defect it is necessary to obtain a close union between the body and the glaze, the latter penetrating sufficiently deeply into the pores of the body, and not simply forming a layer on the surface. This object is attained by giving the glaze a composition which allows it to harmonize with the body, and even to act upon it chemically. Thus, a strongly alkaline glaze would adhere better to a silicious body than to an aluminous body, in consequence of the combination of the alkalies of the glaze with the silica of the body. The opposite effect is more difficult because the excess of silica in the glaze, which would be sufficient to act upon a basic body, would make this glaze difficult to vitrify. It is also necessary that the vitrification should be complete and sufficiently prolonged to allow the glaze to penetrate well into the body, and to give time for the chemical actions to take place.

Faience manufactured under these conditions would resist all weathers, as has been proved by numerous examples of faience in the Middle Ages, employed outside buildings, which have remained intact up to the present day. Nevertheless, it is prudent to place the faience in such a way that the surfaces which are not enamelled should not be too much exposed. This condition is nearly always easy in walls; roofs should have an ample slope.

Encaustic tiles deserve a special place among architectural faiences, because of the great development which took place in their manufacture in the Middle Ages.

These tiles are usually square, of small size and from ¾ to 1¼ in. thick.

The manufacture of encaustic paving tiles includes the following different operations:—

(1) Moulding the tiles by hand from a clayey body.

(2) Stamping a design on them in hollows by means of a block, when slightly dried.

(3) Filling the hollows thus obtained with a liquid body of a different colour to that of the tile, and scraping off the surface by means of a metallic straight edge.

(4) Beating the stiffened tiles to harden their surface.

(5) Glazing the upper surface of the dry tile by spraying it with a plumbic glaze.

(6) Burning them in muffles or saggers.

This method of making them may be simplified by moulding them in a press, using a metallic mould in the bottom of which is placed a little piece of plaster with a projection equal to that of the hollow required. A rough cake of fine body is put into the mould, then a thicker slab of coarser body is put over it, after which a stroke is given with the press to mould and weld the whole together. The employment of two different bodies is to economize the more costly fine body. The rest of the manufacture takes place as described.

The tiles are generally yellow, orange, red, brown, or black. The slips may be coloured green or blue by copper, chrome and cobalt. As they are put on with a more liquid body than that of the tile, they would shrink more and become detached if the precaution were not taken of putting more non-plastic material into them. The glaze is a lead silicate and does not differ from those already described for the preceding ware.

Vases, dishes, and decorative objects were decorated with plumbiferous glazes by the Egyptians, as is proved by the pottery found in the hypogea, but it was not until the twelfth century that glazed pottery was regularly manufactured in Italy, whence it spread in the thirteenth century to France and Germany.

The body was always coloured, consequently the colours introduced into the transparent glaze could only give yellow (this only on light bodies), red, brown, and green.

Slips were known to the Greeks and Romans, but they appear to have fallen into oblivion, to be used afresh in Italy in the fifteenth century, whence they spread over the whole of Europe. Since the sixteenth century this process has only been used for common ware.

Some potters have classed the ware made by Bernard Palissy among enamelled faience, but the following composition given by Brongniart puts it among the argillaceous non-calcareous bodies:—

Silica . . .	67·50	per cent.
Alumina . .	28·51	„ „
Iron oxide . .	2·05	„ „
Lime . . .	1·52	„ „

The glaze is distinctly plumbiferous; any tin present being, according to Deck, accidental, and not to make the glaze opaque; and whenever Palissy's faiences have been imitated, argillaceous calcareous bodies have been used in preference to stanniferous glazes.

The moulding of ornaments, leaves, feathers, various animals, etc., must be done separately, the pieces being afterwards stuck on to the vases or dishes.

The colours of the glaze are yellow and yellow-brown—doubtless obtained with ochres—an indigo blue from cobalt, a greyish blue, an emerald green from copper, a yellow-green from copper and ochre, a violet from manganese, and a violet-brown from manganese and ochre.

The artistic decoration of glazed faiences has been much developed in recent years, and several important potteries have made them a speciality.

2. *Enamelled Faiences, with a Fusible Argillaceous Calcareous Body.*

Enamelled faiences were used for table-ware and for decorative pieces from the sixteenth to the eighteenth century, but are now only used for imitation Moorish, Italian or French faiences, and for stove tiles.

Brongniart gives as the body-composition of some of these faiences:—

	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Undetermined.
Persian faience (fourteenth to sixteenth century)	48·54	12·05	3·14	19·25	0·30	16·72
Hispano moresque faience . .	46·04	18·45	3·64	17·64	0·87	13·96
Hispano moresque faience from Manises	54·71	18·80	2·20	19·69	tr.	4·60
Luca della Robia faience . .	49·65	15·50	3·70	22·40	0·17	8·58
Nevers faience	56·49	19·22	2·12	14·96	0·71	6·50
Rouen faience	47·96	15·02	4·07	20·24	0·44	12·27
Delft faience	49·07	16·19	2·82	18·01	0·82	13·09

The last column includes the alkalies and the carbonate of lime which is not decomposed on account of the temperature for burning the ware being insufficient.

In these bodies the proportion of lime varies from 15 to 22 per cent. With the high temperatures now used for burning the bodies it is best to reduce the proportion of lime to about 16 per cent. Below this, the stanniferous enamel tends to shell, and above it, the body behaves badly when burned, and absorbs the plumbiferous glazes used to decorate it.

Deck recommends for the imitation of Palissy ware, when burned, a composition as shown below, but Bourry thinks it better to lessen the proportion of lime and to keep to the bodies of which the composition would vary between the limits shown :—

	Deck.	Bourry.
Silica	65 to 66	60 to 65
Alumina	14 to 15	13 to 20
Iron oxide	—	2 to 4
Lime	19 to 20	13 to 16
Alkalies	—	2 to 4

All the ancient bodies for enamelled faience and most of the new ones are entirely covered with opaque white glaze, which forms the background, and has the following composition :—

Sand or Flint		45
Calcine	Oxide of Lead	36
	Oxide of Tin	10
Sea Salt		9

It is wise to frit the sea salt and the sand first, then to add the calcine and to remelt them. If, as is often done, the whole is fritted together, the salt may not be completely decomposed.

Decoration.—The white enamel, just given, may be coloured by the addition of 3 to 10 per cent of metallic oxides. Thus, yellow is obtained by 9 per cent of lead antimoniate, blue with 5 per cent of cobalt oxide, green with 5 per cent of copper oxide, violet with 4 per cent of manganese oxide, etc.

The body having been burned at a temperature sufficiently high to decompose the carbonates (1000° to 1200° C.), the enamel is applied either by dipping or pouring; it is then left to dry. The decoration can be done either by putting the colours on the unburned enamel and following this by a second burning, or the enamel is first burned and then decorated, the colours being afterwards fixed by a third firing.

The first method, called *painting for hard firing on raw enamel*, was the only one used for the Italian, French and Dutch faiences from the fifteenth to the eighteenth century. As pointed out on page 262, this method presents great difficulties, on account of the friability of the raw enamel, but for painted decorations it gives deeper tones which become partly embodied in the glaze. The vitrifiable colours used are generally plumbiferous, sometimes alkaline plumbiferous. In Italy and Holland the raw enamel was sprinkled with a second alkaline plumbiferous glaze, which allowed the employment of alkaline vitrifiable colours and gave a greater gloss to the ware.

Painting on burned enamel has been employed since the beginning of the eighteenth century by Hannong and the potters of the Strassburg school, the decoration being easily done with vitrifiable colours. Transparent coloured glazes may also be used by surrounding the different enamels with a black outline as in Cloissonné enamels (p. 262).

The object of the preceding methods of decoration is to use a white stanniferous enamel to hide the colour and defects of the body, hence the name "stanniferous faience" for this class of ware. But now, as it is easy to obtain almost white argillaceous calcareous bodies, these can be covered with transparent glazes of varied colours as noted in Palissy's faience. The calcareous composition of the body allows the use of transparent and opaque enamels for light tones, and especially for white, which is so difficult to obtain with argillaceous bodies.

Stove tiles, panels, etc., and, in a general way, the faiences which have to bear irregular heating, must be made of a body similar to fireproof terra-cottas, and formed by the mixture of a clay quartzose sand or grog. Unfortunately, the porous mass thus obtained cannot be covered with glaze until its surface has been covered with a slip. This may then be covered with a plumbiferous glaze, but not with an opaque enamel as this latter can only be fixed to a calcareous body.

Thus, on the one hand, in order to resist heating, an argillaceous, porous, coarse body is needed; and on the other hand, a compact calcareous fine body is required for the glaze. It is difficult to exactly balance these contradictory conditions. If the tiles are made of a coarse fireproof body, covered with a slip of fine calcareous body, the difficulty is simply shifted; there being no agreement between the two bodies, the slip would shell off.

It is now usual to open a moderately calcareous body by means of sand and grog, and cover it with a slip made of the same body, only finer, or to use a body of medium composition and texture.

As physical texture plays as important a part in the composition, it is impossible to give a definite type of body, but the following general rules are useful. The amount of carbonate of lime may vary from 10 to 14 per cent; below this limit the enamel shells off, above it, the body splits. The higher proportion corresponds to a body containing but little iron oxide (say 1 to 2 per cent), while the lower proportion is applicable to bodies containing from 5 to 6 per cent of iron oxide. The proportion of alumina should be reduced as much as possible, so as to leave only enough plasticity for moulding, usually about 12 to 14 per cent.

According to Barral's analysis, the ancient body used by Pichenot was composed of—

Silica . . .	56·3 to 55·4	per cent.
Alumina . .	29·2 „ 26·6	„ „
Oxide of Iron .	0·9 „ 1·3	„ „
Lime . . .	14·7 „ 13·2	„ „

and was formed by mixing plastic clay twenty-three parts, marl twenty-five parts, sand twelve parts, and fireclay grog thirty-seven parts.

The grog should contain about half the alumina present.

In Germany at the present time, Velten clay is much used for the manufacture of stove-tiles which, according to Seger, contain 45 per cent silica, 11 per cent alumina, 5 per cent iron oxide, 15 per cent lime, and 4 per cent alkalies.

This clay, washed in a Schoene's apparatus (p. 46), gives 73 per cent grains of less than ·0004 inches, 12 per cent grains between ·0004 and ·0015 inches, 14 per cent grains between ·0015 and ·0078 inches.

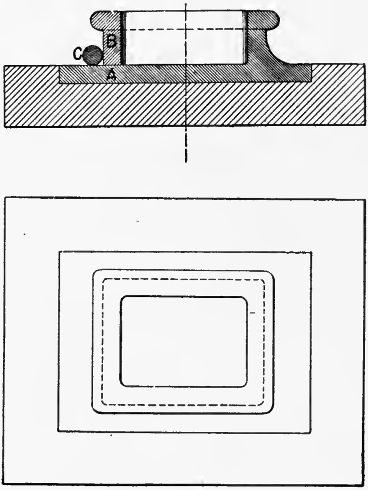

Fig. 263.—Stove-tile mould.

The clay is first sorted, and prepared as described for argillaceous fireproof bodies. The moulding is always by hand, generally in plaster moulds.

In a plaster mould (Fig. 263) a slab (A) is made as just described; then a column of body (B) obtained by expression is put on it, and given a rectangular form with rounded corners by joining it to the slab. A round roll (C) is next added to the outside, and flattened in the hand so as to make a *curve* which strengthens the previous weld.

The angle tiles, or corners, are made in the same manner, but the plaster mould must be in two pieces (Fig. 264).

These operations may be simplified by using the machine made by

Schlickeysen (Fig. 265) in which a flat cake of body is put in the mould,

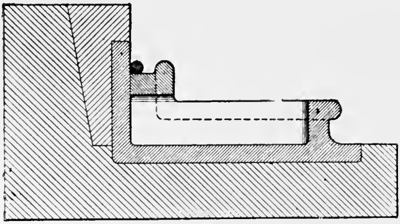

Fig. 264.—Stove-tile mould.

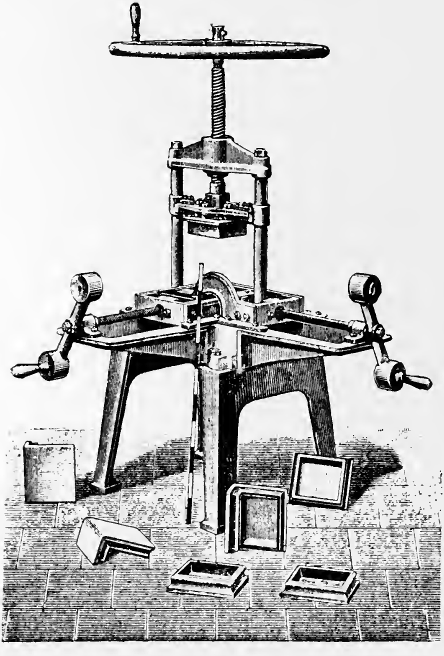

Fig. 265.—Tile-press.

as just described, and the shaped plunger, with the shape of the interior hollow of the tile, is lowered, then, by means of two lateral screws, a pressure is exerted so as to weld the whole. Attempts to mould the tiles in a press without first making a rough form will be abortive.

The drying must be done very slowly, as the unsymmetrical shape of the tile always creates a tendency to bulge, and when the body is dry it must be straightened by striking it on a marble slab or levelling it on a flat stone.

The tiles are placed open in the kiln, two being set against each other, the "faces" being in contact. The burning does not present any special difficulties, but it is necessary to straighten the burned pieces a second time by rubbing them on a large horizontal table, usually of cast-iron, covered with polishing sand and water.

The glaze is applied by pouring and is burned in muffle kilns, or, better still, in saggers. Its composition has been already mentioned, though in Germany enamels having a larger amount of alkali are now used. They are composed of limestone [? marble], sea salt and a felspathic sand, or pure sand and felspar, and correspond to

$$\left.\begin{array}{l}0{\cdot}53PbO\\ 0{\cdot}06CaO\\ 0{\cdot}10K_2O\\ 0{\cdot}31Na_2O\end{array}\right\} 0{\cdot}21Al_2O_3,\ 3{\cdot}43SiO_2 + 0{\cdot}79SnO_2$$

or

$$\left.\begin{array}{l}0{\cdot}56PbO\\ 0{\cdot}10CaO\\ 0{\cdot}03K_2O\\ 0{\cdot}31Na_2O\end{array}\right\} 0{\cdot}16Al_2O_3,\ 3{\cdot}00SiO_2 + 0{\cdot}46SnO_2$$

When the surface of the tiles is ornamented in relief, this relief is simply made by forming hollows in the plaster mould.

These tiles are usually decorated with transparent glazes; the different colours being separated either by a black outline (close on the enamels) or by engraving deep lines in the mould, which reproduce the design and prevent the enamels from mixing together.

3. *Silicious Faiences, with a Fusible Silicious Body.*

The first kinds of faience manufactured by the Egyptians, and later by the Persians, were pottery with an extremely silicious body formed of sand, alumina and fluxes (alkalies and lime). The glazes were alkaline-plumbiferous silicates, with brilliant colours. Two frescoes which adorned the palace of the kings of Persia at Susa, but now in the Louvre, are the most beautiful examples of ancient Persian art.

The raw materials used are still unknown. The slight plasticity of this body must have made the moulding very difficult, unless organic materials were added to the body to give it a certain softness, and then disappeared when they were burnt. In any case, the body was covered in an unburned state with a first glaze or rather a lustre, composed of a sodium silicate and doubtless intended to fill up the pores of the body. Then the whole must have been burned at a rather high temperature, probably 1200° C., at which, by the action of the fluxes, the body would attain a certain hardness. The second glaze, according to Lindhorst, corresponds to the formula—

$$\left.\begin{matrix}0{\cdot}32\mathrm{PbO}\\0{\cdot}68\mathrm{Na_2O}\end{matrix}\right\}2{\cdot}82 \text{ or } 3{\cdot}48\mathrm{SiO_2}.$$

In 1861 Deck attempted to reproduce these Persian faiences, in a decidedly different body, but one equally silicious and relatively fusible. He used a frit formed of—

Fontainebleau sand	85 per cent.
Potash	7 ,,
Soda	3 ,,
Chalk	5 ,,

The body consisted of—

White earth	24 per cent.
Meudon white	24 ,,
Flint	48 ,,
Frit	4 ,,

Twelve per cent of flint may be substituted for the Meudon white and an additional 10 per cent of frit may be added in making stove tiles.

The biscuit body is covered with a slip composed of—

Frit	63 per cent.
White stanniferous enamel	32 ,,
White earth	5 ,,

The exact chemical composition of these mixtures is not known. Deck adds that "it is not absolutely necessary to add frit to the earth to prevent it cracking, as the silica and lime may be sufficient to hinder it, but the frit adds to the intensity of the colours, and the whole article has a more powerful character".

The glaze is an alkaline-plumbous silicate composed of—

Sand	48 to 50 per cent.
Red lead	30 ,,
Potash	12 ,,
Soda	8 to 10 ,,

The mixture is melted, then powdered dry; the powder does not need to be impalpable; the temperature for burning it is 1000° to 1200° C.

Lastly, these are the compositions of some of the colours set down by Deck:—

Flux.

Silica	70
Red lead	5
Potash	15
Soda	10

Dark Blue.

Flux	50
Red lead	20
Cobalt oxide	30

Light Yellow.

Calcine	62
Red lead	21
Antimony	14
Ammonia	3

Rose.

Silica	14
Chalk	24
Stannic acid	55
Borax	3
Potash bichromate	3
Alumina	1

Red Brown.

Red lead	20
Calcined Armenian bole	80

Black.

Silica	14
Alumina	3
Red lead	20
Antimony oxide	10
Iron oxide	16
Iron chromate	9
Manganese oxide	18
Cobalt oxide	3
Copper oxide	7

Turquoise Blue.

Flux	47
Red lead	6
Copper oxide	47

Green.

Silica	30
Alumina	5
Flux	5
Red lead	40
Antimony oxide	20
Copper oxide	50
Iron oxide	10
Iron chromate	30

Dark Yellow.

Silica	5
Alumina	2
Calcine	18
Red lead	17
Litharge	15
Antimony oxide	24
Iron oxide	14
Zinc oxide	5

Red.

Red lead	20
Thivier's stoneware	80

Dark Brown.

Zinc oxide	25
Iron sulphate	20
Iron chromate	40
Magnesia oxide	15

White.

Flux	34
Stanniferous white enamel	66

White.

Nevers sand	34
Chalk	16
Powdered porcelain body	50

These mixtures are diluted with a silicate of potash at 33° Baumé. The colours, having been mixed on the slab or with a palette knife with a little gum arabic, are put on with a brush.

The decoration with coloured glazes is done by making cells with a black outline, $\frac{1}{16}$ or $\frac{1}{32}$ inch thick, of a mixture of a body, flux and black colour. The transparent enamels are these:—

Flux.	
Silica	50
Red lead	36
Potash or soda	14

Blue.	
Flux	83
Silica	14
Cobalt oxide	3

Yellow Brown.	
Flux	44
Silica	20
Red lead	25
Iron oxide	8
Magnesia	3

Deep Violet.	
Flux	92·4
Magnesia	7·0
Cobalt oxide	0·6

Turquoise blue.	
Flux	80
Copper oxide	20

Green.	
Silica	31
Borax	5
Red lead	55
Potash	5
Copper oxide	4

Grenat.	
Flux	82
Soda	5
Nitrate of soda	5
Antimony oxide	2
Magnesia	6

Ivory Black.	
Flux	52
Silica	20
Red lead	25
Iron oxide	3

All these enamels are melted, poured into water and then powdered.

The relatively tender body of the silicious faiences is not resistant enough to be used for domestic purposes, but is admirably suitable for artistic wares, the moulding of which does not need a plastic body, and the decoration of which consists chiefly in the incomparable brightness of the colours.

4. *Pipeclay Faiences, with a Slightly Fusible Argillaceous Calcareous Body.*

The pipeclay faiences have an almost white and hard body formed of fireclay, flint, and chalk; a part of the calcareous flux is sometimes replaced by an alkaline flux.

This body, when slightly burned, resembles that used for making tobacco pipes, hence its name, but has a larger amount of silica, and is burned at a higher temperature (1200° C.).

The fireclay serves as a base for the composition of the body. Silica (sand or flint) is added to it, according to the degree of plasticity of the body, this silica being in the form of sand for ordinary products. Sometimes, also, a grog made of the burned body is used, but only in small proportion. If the lime is added in the form of marl, the relative plasticity of which is added to that of the clay, and more "opening" material is required, either in the form of chalk, flint or grog, the first of these reduces the plasticity, although in a less degree than does silica. The alkaline flux is introduced as felspar; it is usually as "opening" a material as flint. The following are typical bodies of this class:—

Fireclay	40	40	40	25	60
Flint	40	35	35	42	20
Grog	—	5	5	5	—
Chalk	20	20	16	—	16
Felspar	—	—	4	—	4
Plastic Marl	—	—	—	28	—

Sometimes china clay is added to the body to whiten the mass.

The glazes formerly used were very tender alkaline plumbiferous silicates of the following composition (Bastenaire):—

Sand	36
Red Lead	45
Carbonate of Soda in solution at 80° Bé.	17
Nitre	2

Corresponding to the formula—

$$\left.\begin{array}{l} 0{\cdot}57\mathrm{PbO} \\ 0{\cdot}03\mathrm{K_2O} \\ 0{\cdot}40\mathrm{Na_2O} \end{array}\right\} 1{\cdot}75\mathrm{SiO_2}$$

Since then, the alkaline plumbiferous boracic glazes have been preferred.

The following examples are five compositions for glazes by Prossel.

Frit.					
Feldspar	41	35	16	30	24
Sand	13	18	39	22	30
Red Lead	18	16	—	—	—
Borax	16	22	29	30	35
Kaolin	3	3	10	3	6
Potash	1	—	—	4	3
Chalk	6	6	15	11	12

Glaze.					
Frit	90	82	58	65	65
White Lead	9	8	26	24	13
Sand	—	—	—	—	11
Feldspar	—	10	16	11	11

To hide the slightly yellowish tinge of the body, a half to one-thousandth part of cobalt oxide is added to the glaze.

Pipeclay faience is made chiefly in the North-east of France and the West of Germany. Its composition and glaze have gradually become similar to the felspathic faiences, which are now more generally used, though, for cheap ware, pipeclay is still of service. The methods of manufacture are the same as those employed for felspathic faiences (see Section 6, later).

5. *Flint Faiences, with a Fireproof Argillaceous Silicious Body.*

The body for this kind of faience is almost white, hard and fireproof. It is formed by the addition of flint to a white fireclay. The flint is burned and ground before use, the proportion added depending on the plasticity of the clay and varying from 10 to 30 per cent.

In order to give added whiteness to the body, part of the clay and flint may be replaced by a silicious china clay (kaolin).

The glaze is plumbiferous, alkaline, or alkaline-earthy and boracic, of a composition similar to that for pipeclay faience (4). Harder faiences, like those employed for feldspathic faiences, may also be used.

Flint ware was very much in fashion in the end of the eighteenth century, but is very little used at the present time. The body should be burned at a very high temperature, because of the absence of flux, but it never acquires the hardness and gloss of the feldspathic faiences, nor even of the pipeclay ones.

6. *Feldspathic Faiences, with a Slightly Fusible Argillaceous Alkaline Body.*

The feldspathic faiences have a white, slightly yellowish, hard body, which in some varieties becomes very slightly translucent, thus approaching porcelain. They are formed of the mixture of plastic fireclay, china clay, flint and feldspar, or pegmatite. The plastic fireclay naturally serves as a basis. To it is added the china clay to whiten the body, as even the purest fireclays always have a yellowish tinge when fired. The flint helps to open the body and to give it whiteness and hardness. Lastly, the feldspar or pegmatite serves as a non-plastic material and as a flux.

The proportions in which these four substances are mixed are variable; they depend not only on the variable composition of the raw materials, but on the quality of the body desired, and on economical considerations.

The English method of manufacturing feldspathic faience may serve as a type of all the others. The raw materials are: blue clay from Wareham and Corfe Castle, Dorsetshire; china clay from Cornwall; flint from the pebbles of the Thames and the Somme, and pegmatite (Cornish stone) from Cornwall. The following are some of the best-known examples of the composition of bodies obtained with these materials:—

Blue Clay . . .	47	43	31	24	21	18
China Clay . . .	24	24	36	27	28	43
Flint	22	23	21	36	38	24
Pegmatite . . .	7	10	12	13	13	15

The quality of the body may be varied by varying the proportion of the four constituents or by altering the temperature at which it is burned. A more intense heat allows of less flux being used.

The glazes are of a similar composition to those for pipeclay faience (4), but they are usually rather harder and contain more silica and alumina. This hardness is, however, compensated for by a larger proportion of boracic acid. The following, according to Prossel, are the compositions of several of these glazes:—

	Frit.						
Cornish Stone	—	—	31	25	—	41	—
Sand . .	35	28	17	10	26	24	32
Borax . .	35	—	30	—	—	32	—
Boracic Acid	—	17	—	18½	15	—	18
Red Lead .	—	—	—	—	19	—	—
Soda Crystals	—	22	—	23½	16	—	20
China Clay .	12	15	11	8	11	3	13
Chalk . .	18	17	11	15	13	—	16

	Glaze.						
Frit . .	52	47	74	60	70	59	60
White Lead	18	21	12	18	6	18½	22
Cornish Stone	30	31	8	22	—	11	18
Feldspar .	—	—	—	—	23	—	—
Flint . .	—	—	6	—	—	—	—
Chalk . .	—	—	—	—	—	11½	—

Preparation of the Bodies.—The raw materials which enter into the preparation of the bodies ought first to be purified and ground.

The *clays* employed in faience work are either in a natural state or have been washed; this washing can be done at the pits or in the factory. It is necessary, as a general rule, to wash them, employing the methods described on page 74.[1]

The *china clay* is always washed.

The *flint* should be heated and ground before use, this being done either in the faience works or in special works (p. 61).

The *feldspar* and Cornish stone are broken up and ground chiefly in the faience works, but sometimes near the quarries. The methods of grinding them have been described in Chapter IV.

In the preparation of the body, which is always done in a liquid state, it is necessary:—

(1) To break up the clay in water when the washing of it is not done in the faience works, so that the liquid body can be used directly.

(2) To break up the china clay.

(3) To reduce the flint to an impalpable powder and mix it with water.

(4) To do the same with the feldspar.

The methods used for this purpose have been described in Chapter IV. It is sufficient to add here that these four operations are usually done in blungers, mills with blocks or separate Alsing cylinders. When there is any limestone in the body it is generally ground and made into slip at the same time as the flint. The usual method is to put into each machine a definite proportion by volume of the solid material and water, then, when the substance is entirely pulverized and completely mixed with the water, to run it out into four reservoirs. It is then tested to see whether the consistency of the different liquids is correct. For this purpose, the weight of a certain specified volume (a pint or half-pint of the liquid for example) is found. It is nearly always necessary to add a little more water to obtain the proper consistency; it is seldom that a thicker body contained in a special reservoir must be used to correct it.

In order for the mixing to be well done, it is necessary that the four liquids should be of about the same consistency, though they are not of the same density. The usual weights in England are:—

[[1] British ball clays are seldom, if ever, washed.—A. B. S.]

	Ounces per pint.	Grammes per litre.
Plastic Clay (blue-ball clay)	24	1200
Kaolin (china clay)	26	1300
Silica (flint)	32	1600
Pegmatite (Cornish stone)	32	1600

The four liquids, being of the required consistency, are run into a single tank, in succession, the quantities added being measured by the level reached by the liquid on a vertical scale.

[The depth of the slip is measured in inches, and as the area of the tank is constant the volume of the slip is expressed by the depth in terms of "wet inches". Thus, if slips with the weight per pint just mentioned were to be used to make a body containing—

(Dry) ball clay	2 parts
(Dry) china clay	1 „
(Dry) flint	1 „
(Dry) Cornish stone	1 „

the proportion of each slip in "wet inches" may be found as follows:—

Divide the number of parts of each material required by its pint-weight less twenty, and multiply each by a number to clear the fractions. Thus:—

Ball clay	2 parts $\div (24 - 20) = 2 \div 4 = \frac{1}{2}$ wet inches
China clay	1 part $\div (26 - 20) = 1 \div 6 = \frac{1}{6}$ „ „
Flint	1 part $\div (32 - 20) = 1 \div 12 = \frac{1}{12}$ „ „
Stone	1 part $\div (32 - 20) = 1 \div 12 = \frac{1}{12}$ „ „

To clear the fractions in this case multiply each number by twelve, which gives:—

Ball clay	6 wet inches
China clay	2 „ „
Flint	1 „ „
Stone	1 „ „

Conversely, to convert "wet inches" into dry "parts by weight," subtract twenty from each of the pint-weights and multiply the number of wet inches by the result. Thus, in the example just given:—

Ball clay	6 wet inches $\times (24 - 20) = 6 \times 4 = 24$ parts
China clay	2 „ „ $\times (26 - 20) = 2 \times 6 = 12$ „
Flint	1 „ „ $\times (32 - 20) = 1 \times 12 = 12$ „
Stone	1 „ „ $\times (32 - 20) = 1 \times 12 = 12$ „

W. J. Furnival, of Stone, Staffs, has published a set of tables which give, without calculation, the quantities in "wet inches" of slips of different weights containing the same dry contents.—A. B. S.]

The body is then mixed up, sifted once, twice or even three times, through finer and finer sieves, run off and made firm by filter presses. The cakes thus obtained are put in cellars and then kneaded and wedged before being used for moulding.

Moulding.—The body, which is fairly plastic for feldspathic faience, is usually suitable for all the methods of moulding described in Chapter V. Special moulding by hand in plaster moulds is used for all pieces which cannot be thrown; throwing on the wheel is generally used for making all round objects for domestic purposes, and pressing is employed for paving tiles. These two methods are both of special importance in faience potteries.

In moulding flat or shaped pieces, dishes, plates, saucers, bowls, etc., or *flat ware*, are distinguished from taller goods or those contracted at the upper part, or *hollow ware*. Flat ware is made by two operations: (*a*) throwing a bat, and (*b*) moulding it on the jigger.

For large objects the throwing is done on the head of a wheel working on the principle shown in Fig. 86. The templet may be worked by hand or automatically, as shown in Fig. 266. The machine having been stopped, a ball of clay is placed on a slab on the wheel-head and the machine started. The templet descends, makes the "bat," then rises again and the machine unloads itself automatically.

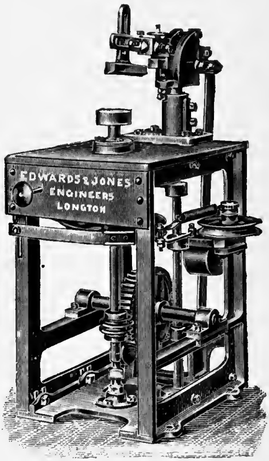

Fig. 266.—Bat-making machine.

The "bat" is then placed on a plaster mould having a profile similar to that of the interior of the ware (Fig. 87), and a templet is lowered by hand, which shapes the body and gives it the outside form. Fig. 267 shows a machine of this kind. In some cases, the two preceding machines are placed side by side in such a way that one moulder can work both. An arrangement of this description shown in Fig. 268 (Boulton) allows of 500 pieces an hour being made.

The slabs can also be made on leather discs, stretched over a ring placed on the bed-plate or head of the machine. These discs are afterwards carried away with the shape and turned over on to the mould. In this case, the machine shown in Fig. 269 is used, four moulds being placed on a carriage. Two of these moulds are centred on the bed-plates of two twin wheels, the templets for which are moved automatically, while a workman takes away the manufactured objects from the other two and replaces them by "bats". When the moulding is finished, the workman pushes the carriage towards the left to allow of the finished pieces being taken away and new "bats" being placed, while the fashioning of the two new "bats" goes on. A machine of this kind will make 500 to 600 pieces an hour.

For making hollow goods when the objects are not too large, the arrangement described on page 126 (Fig. 87) is used. Fig. 270

(Boulton) represents an automatic machine of this kind in which 500 articles an hour can be made. As soon as one cup is made and the templet raised, the mould is replaced by another containing a fresh "bat". For wares of large size it is necessary to throw it first or to give the body a rough shape, as the see-saw motion of the templets is, in large ware, replaced by an up-and-down motion, the templet—then termed a "plunger"—being fixed to a transverse beam, as shown in Fig. 84 (p. 124). Fig. 271 shows a machine of the same kind for very large objects. If the latter have a narrow neck, the arrangement described on page 127 (Fig. 88) is used.

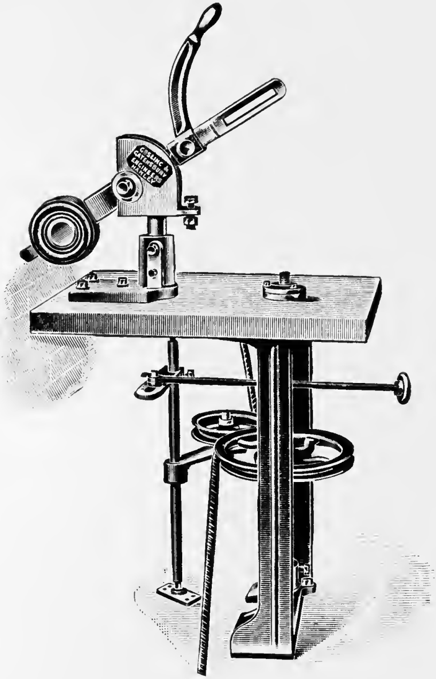

Fig. 267.—Jigger for flat ware.

Paving tiles are often manufactured of firm or even dry body in a press, the cake of body from the filter press being dried either in the open air, on heated surfaces, or else in hot drying-rooms.

The dry body is then broken up coarsely by hand, and put into a

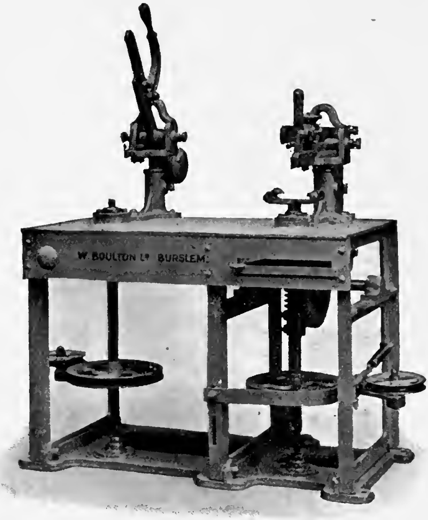

Fig. 268.—Combined jigger and bat machine.

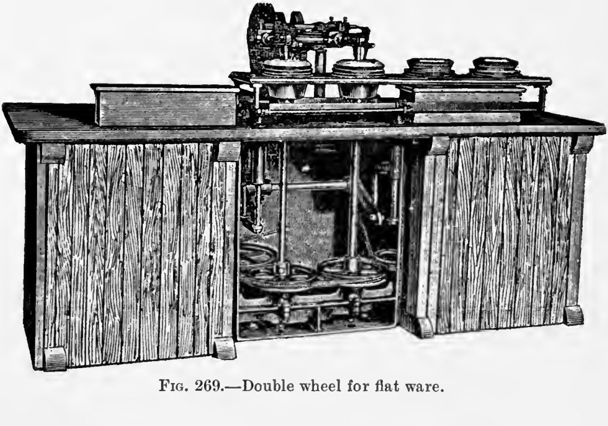

Fig. 269.—Double wheel for flat ware.

pug-mill; when necessary, the quantity of water needed to make it suitably moist is added. The material passing out of the pug-mill falls into a centrifugal pulverizer which reduces it to a powder. These two operations may be done simultaneously in the machine shown in Fig. 272, which can produce 6 cwt. to 2 tons an hour, at an expenditure of 4 to 5 horse-power.

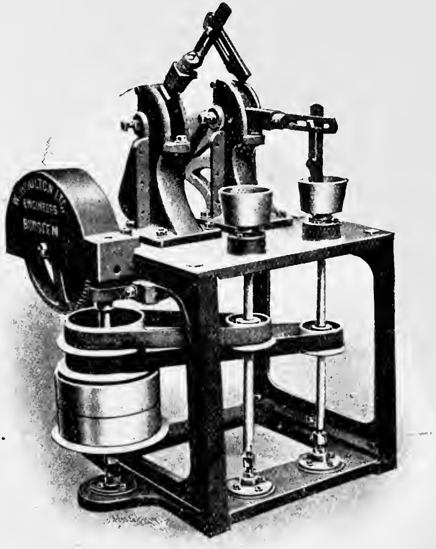

Fig. 270.—Twin-jolley for cups, etc.

The powder is afterwards pressed in a metal mould by means of a machine with a fly-wheel. Figs. 93 and 273 show a press of this description in which the emptying of the mould is done by raising the lower part of it by a lever or a pedal. These presses are made in several patterns, according to the dimensions of the paving tiles. The following are some of their outputs :—

		Production per hour.
To press one paving tile	2 inches diameter	250 to 320
,, ,, two paving tiles	2 ,, ,,	300 ,, 400
,, ,, one paving tile	4 ,, ,,	150 ,, 200
,, ,, two paving tiles	4 ,, ,,	250 ,, 300
,, ,, one paving tile	6 ,, ,,	120 ,, 140
,, ,, ,,	8 ,, ,,	100 ,, 120
,, ,, ,,	12 ,, ,,	40 ,, 60

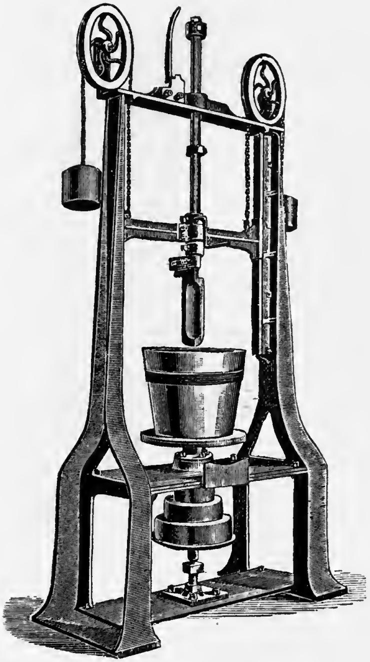

Fig. 271.—Jolley for large ware.

For large quantities, friction presses worked by an engine must be used (Fig. 94).

The manufacture on a lathe (turning) and also "casting," which are sometimes employed in faience potteries, are mentioned in Chapter XIV., as they are much used in the manufacture of porcelain.

Drying.—When the goods have been made in plaster moulds, they are left to dry in them until they can be piled up and put to dry. The moulds containing the body are placed on stages arranged in the moulding shops. In some cases, drying-sheds heated by hot air, or by steam pipes, are used. In Chapter VI., pages 154 and 155 (Figs. 111 and 112), the revolving dryers which were generally used are described.

Artificial drying is indispensable in the moulding shops where power-driven wheels are employed, as their large output would involve a vast increase of drying space which would be incompatible with the economical use of the motive power and of hand work. As during bad weather the drying can only be done by means of a fairly intense heat, and as a sufficiently active ventilation cannot be obtained in places where people are at work, as the atmosphere of the workrooms would be charged with steam which would act in an injurious manner on the health of the workpeople, it is necessary to have special dryers.

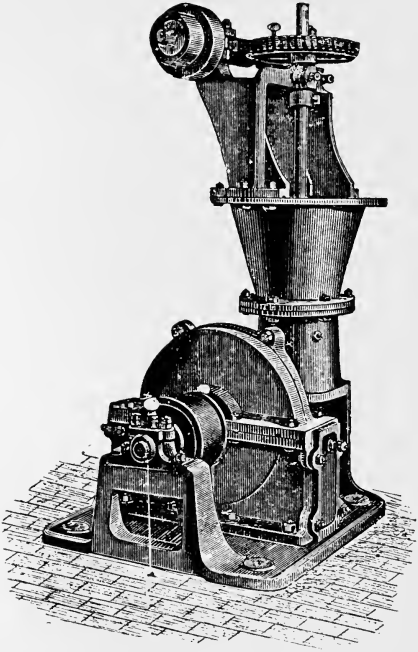

Fig. 272.—Centrifugal pulverizer.

Burning.—For burning earthenware, round up-draught kilns surrounded by a cupola (hovel) ending in a chimney (Fig. 274) are used. The cupola is for the double purpose of ensuring a draught and of isolating the kiln from the workrooms, or when placed outside the buildings to protect it from the weather.

Potters on the Continent prefer round down-draught kilns, the draught being caused by means of a separate chimney which may serve for several kilns. Fig. 275 represents a kiln of this kind. The furnaces, six to ten in number, communicate with a central opening for the fire. The gases are carried off by a series of concentric openings in the lower hearth, which communicate with a circular receiver, connected by several flues to a central passage for the smoke, into which opens the chimney-flue. The diameter of these kilns varies from 11½ to 20 feet, and the height from 13 to 23 feet. The medium-sized ones give the best results. The slow firing usually lasts from six to eight hours, and the hard firing from sixteen to twenty-four hours. The consumption of fuel, which varies greatly in the different potteries, may be reckoned at 6 lb. per cubic foot of the capacity of the kiln. It is advisable to lose as little space as possible in placing, as the quantity of fuel consumed remains the same, whatever may be the weight of the goods put into the kiln.

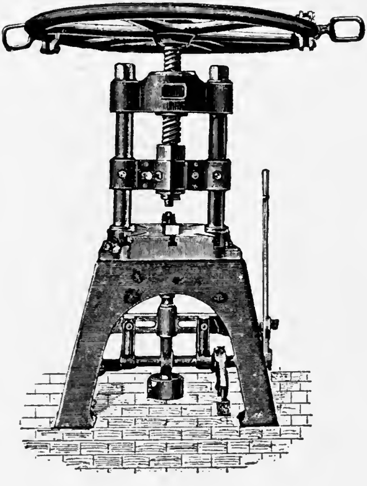

Fig. 273.—Screw press.

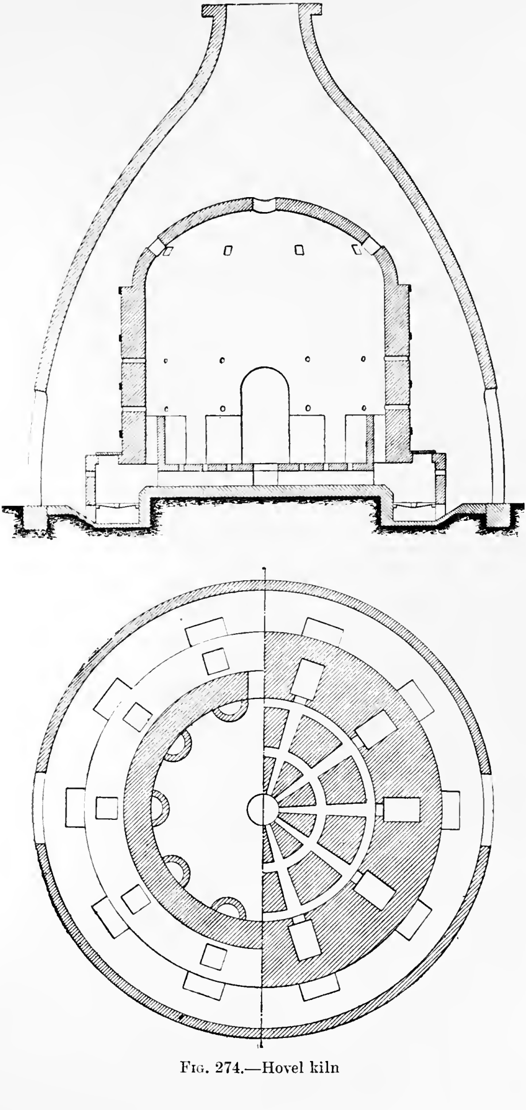

Fig. 274.—Hovel kiln

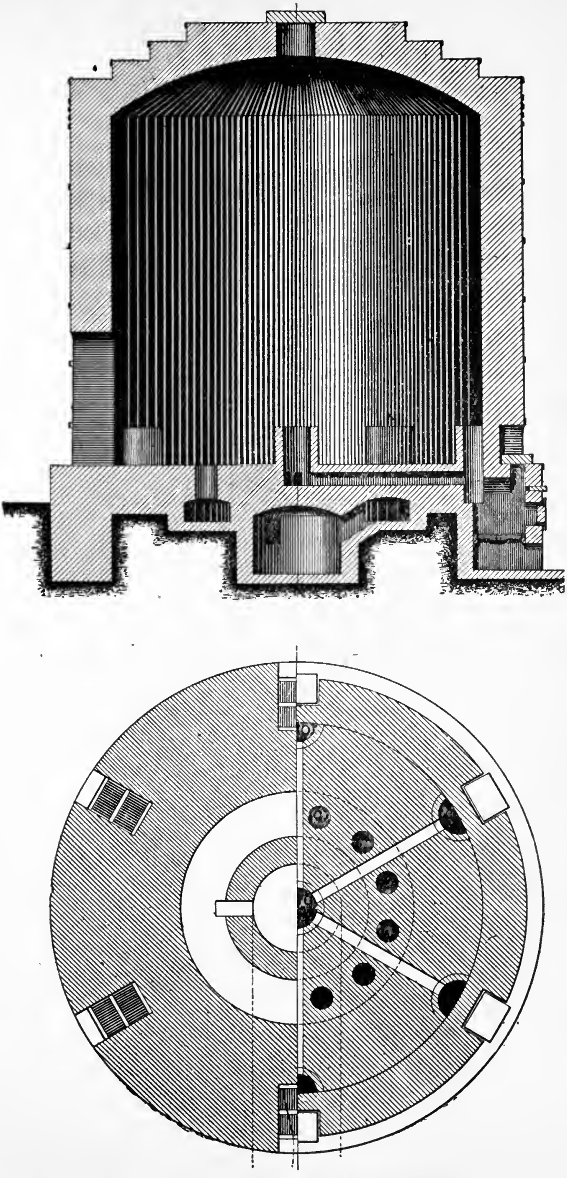

FIG. 275.—Earthenware kiln.

The thermic balance sheet of a kiln of this description is, roughly :—

Heat produced by fuel	100	Heat theoretically necessary	17
		Heat lost in placing	34
		Heat lost by heating the walls	10
		Heat lost through the chimney	25
		Heat lost by incomplete combustion	4
	100		100

For burning faience continuous kilns (p. 223) heated by either coal or gas have also been employed. The results obtained are not very satisfactory, though this problem will be solved in the near future About 30 per cent of the heat produced by combustion could be regained and the loss through the chimney could be reduced to 5 per cent or 10 per cent; but the losses due to heating the walls and by radiation would be increased, and it would be necessary to add to them the loss due to generating the gas if this is used. Thus a saving in fuel of 20 per cent or of most 30 per cent would be all that could be attained. It is probable that the workman's labour in "placing" would also be noticeably reduced.

Faience needs two heatings, the first at a temperature of about 1200° C. for burning the body, and the second between 1000° and 1100° C. for vitrifying the glaze. These two heatings are usually done in succession in the same kilns, the latter using only 5 lb. to 6 lb. of coal per cubic foot of ware set in the kiln; but the quantity of ware it is possible to place at one time being smaller, the expenditure of fuel is really the same or even rather greater for burning the glaze than for heating the body.

Setting or Placing in Saggers.—The setting is always done in saggers, these being piled on one another, leaving a certain space between the top sagger and the dome. These piles of saggers are arranged concentrically, the outer row being placed at a short distance from the wall (3 to 6 inches). The piles which compose it are put against one another in such a manner as to guide the flames towards the dome. The inside piles are also close together, but to allow of the circulation of the gases on the hearth the first sagger at the bottom is placed on a pedestal formed of firebricks.

As saggers of different sizes have to be used, the workmen try to fill the kiln as full as possible by arranging the smaller ones in the spaces left between the larger ones. This method of setting is the one suitable for down-draught kilns; for up-draught kilns it is necessary to separate the piles, supporting them against each other by means of little pieces of fireclay put against the saggers.

The filling of the saggers with unglazed bodies does not, as a general rule, offer any difficulty, because they can be piled up in a heap. The art consists in placing the largest possible number of objects in a sagger. For pieces like plates, which have a diameter equal to that of the sagger, which prevents their being put into the sagger by hand, the method shown in Fig. 276 is employed. On a round block of wood, placed on a table in the middle of a sagger, is arranged a piece of fireclay, on which are piled up ten to twelve plates, then by raising the sagger, the operation of filling the sagger is completed. It is necessary not to overload the lower pieces or they may break.

The filling of the saggers for burning the glaze is much more difficult, because in that case the glaze prevents the piling up of the ware. The usual method consists in placing the ware on small fireclay supports, leaving only a point or a small part in contact with the piece.

The following are some examples of the most usual arrangements:—

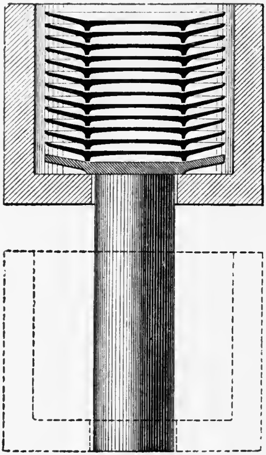

Fig. 276.—Filling a sagger with plates.

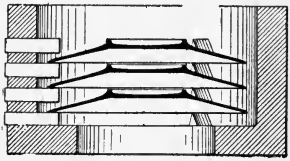

Fig. 277.—Use of head-pins.

Fig. 277 shows a section of a sagger, into the walls of which are embedded small triangular pieces called *head pins* which serve to support the pieces. For this purpose, the saggers are pierced with triangular holes, which, when the head pins are put in, are filled up by means of a little fireclay. Contrary to what is shown in the drawing, these head pins are not placed along a vertical line, but follow the line of a helix, so as not to weaken the sagger too much.

Instead of piercing holes in the saggers, *bowl pins* which are approximately of the shape of truncated or triangular pyramids, and which are piled up on one another, may be placed along the walls as shown in Fig. 278.

Thimbles or small hollow truncated cone-shaped pieces, fitting into one another and having a small triangular projection, on which are placed the plates or tiles, as shown in Fig. 279, may be used. In order to keep this scaffolding up, a ring with three thimbles fastened to it is put at the lower part and at the upper part a similar ring with three projections, fitting into the upper thimbles and keeping the whole together.

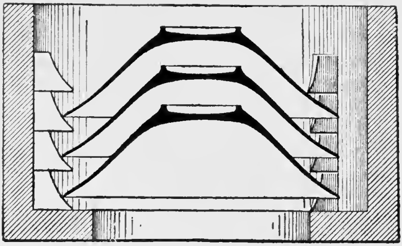
Fig. 278.—Use of bowl-pins.


Fig. 279.—Use of thimbles.

Instead of the pieces leaning on the saggers or on the supports, they may rest on one another by separating them by little triangular pieces having three lower points and one upper one, called *cock-spurs* (Fig. 280), or the pieces, especially plates, may be placed upright in

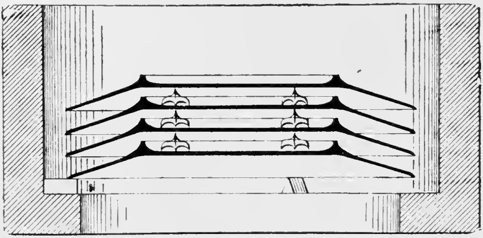
Fig. 280.—Use of cock-spurs.

rectangular saggers, kept up at the bottom by rectangular saddles and at the top by a series of thimbles as shown in Fig. 281.

The methods used depend entirely on the shape of the ware, and can be infinitely varied in details. All these "supports for burning" or *stilts* have separate names due to the shape: simple *pins*, cut-off pins, or pins with a top, simple or double *spurs*, stilts with three or six points, thimbles, *butterflies*, *easels*, etc., etc.

These sundries, made of fireclay, are stamped out of firm body by means of small lever presses worked by hand. A machine of this kind is shown in Fig. 95. It is usually best to buy them from special makers.

Decoration.—All the methods of decoration which were described in Chapter IX. can be used for faience.

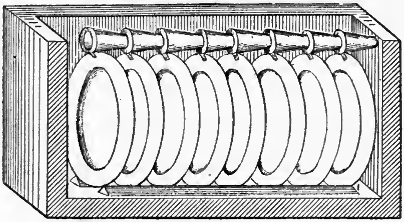

Fig. 281.—Use of saddles and thimbles.

Coloured slips are sometimes used for making backgrounds, and are then generally put on to the unburned body with a brush. The bands or borders on plates are easily done by turning the ware on a wheel in front of a brush kept in one position. The slips are manufactured by adding colouring matter to the body. As the proportions of the colouring materials which must be added are usually somewhat large, the composition of the body must be modified, so that the shrinkage may be the same, by adding plastic clay or flint and correcting the diminution of the fusibility by a little feldspar. The composition of these slips thus varies with that of the bodies, and it is impossible to give more exact details on this subject.

Under-glaze colouring is the method of decoration chiefly used, especially for table-ware. At the present time decoration by printing is almost exclusively employed (p. 259), painting with a brush being only used for making bands or backgrounds or to lighten the designs obtained by monochrome printing.

The following are the most usual colours:—

Black.

Iron oxide	44
Lime	44
Manganese oxide	10
Cobalt oxide	2

(This mixture is burned, then washed.)

Iron sulphate	65
Bichromate of potash	28
Manganese oxide	10
Cobalt oxide	6

(The first two substances are heated together, the others are added to them, then heated afresh and washed.)

Blue. I.

(Oxide of cobalt, in proportion varying with the depth of the colour, mixed with a little flint and carbonate of lime.)

Precipitated alumina	70
Nitre	10
Cobalt oxide	20

(Well wash the alumina, mix together and heat.)

Blue. II.

Ammoniacal alum	80
Zinc oxide	12
Cobalt oxide	8

(Heat and wash.)

Bluish-Green.

Flint	22
Borax	22
Zinc oxide	20
Chrome oxide	16
Cobalt oxide	8

(Frit together.)

Green. I.

Flint	66
Borax	13
Chalk	1
Chrome oxide	20

(Melt a part of the flint with the borax, complete the mixture and heat it again.)

Green. II.

Flint	32
Borax	42
Zinc oxide	11
Chrome oxide	11
Cobalt oxide	4

(The same as above.)

Brown. I.

Iron sulphate	38
Zinc oxide	38
Bichromate of potash	24

(Heat and wash.)

Brown. II.

Iron chromate	50
Manganese oxide	50

Red.

Zinc oxide	50
Chalk	25
Flint	18
Bichromate of potash	3
Borax	4

[*Continued on next page.*

Red (*cont.*).

(The following fluxes are added when heated.)

Red	70
Feldspar	10
Borax	16
White lead	4

(Then it is heated at a low temperature.)

Yellow. I.

Lead oxide	17
Tin oxide	66
Antimony oxide	17

(First calcine and then mix the oxide of antimony. For the deepest ground and orange, oxide of iron is added.)

Yellow. II.

Lead oxide	41
Tin oxide	21
Antimony oxide	28
Iron oxide	10

Violet (*unique*).

Tin oxide	100
Boracic acid	10
Cobalt oxide	
Lead bichromate	1½

(Heat and add 20 per cent of white lead. For the dark tones add cobalt oxide.)

For decorating by printing, these powder colours are added to the printing ink; when put on with a brush, gum tragacanth or glycerine is added to them.

The colourless glazes, the composition of which has already been given, are usually applied by dipping. They are sometimes tinted with a little cobalt oxide to neutralize the yellowish colour of the body.

Coloured glazes are often used also for decorating. They are composed of a colourless glaze, with the addition of colouring oxides, and sometimes with a little extra red lead, which increases the brilliancy of the colours, but makes them run easily. The colouring oxides are mixed in the proportion of 3 to 12 per cent according to the shade desired. Colourless glaze may also have the preceding under-glaze colours mixed with it.

Faiences with under-glaze decoration or with coloured glazes are burned in saggers in ordinary kilns.

Over-glaze colouring may be used in the form of vitrifiable colours, which are burned in muffles. This method, less employed for faiences than for porcelain, is mentioned in Chapter XIV.

General Arrangements of Faience Works.—Faience is now made in a small number of large works. In England, nearly all the faience works are situated in the north of Staffordshire, round the towns of Hanley and Stoke-on-Trent.

France, Germany, Belgium, and Austria also possess important faience works. These faience works were originally placed near the beds of plastic clay, and as near as possible to the coal-fields, or in localities particularly favourable for cheap transport, but with improved facilities for the transport of raw materials they are now often put near the large centres of consumption.

Faience works are composed of storied buildings, on the ground floor of which are the workshops for the preparation of the bodies, the manufacture of the saggers and the muffles. The moulding and decorating shops are generally on the first and second floors; the kilns are either outside, or, what is more convenient, placed under a large closed shed which communicates with the other buildings; other smaller sheds contain the supplies of raw materials and manufactured wares. A forge, workshop for repairing, pattern shop, warehouse, etc., are also necessary.

CHAPTER XIII.

STONEWARE.

STONEWARE (Fr. *Grès*) is an opaque impermeable ware, with a coloured body, although it is often only slightly yellowish, greyish or bluish. Its surface may be either dull or covered with glaze. The impermeability of the body distinguishes it from terra-cotta and faience; its opacity makes it differ from porcelain.

The distinctive characteristics of stoneware are impermeability and opacity, but this distinction is not as simple as it looks, as absolute properties are not present, but only relative ones. The opacity will be discussed in the chapter on porcelain, so that it is now only necessary to define "impermeability".[1] Complete impermeability exists in bodies in which the material exactly fills the volume occupied, as good specimens of metals and glasses. This complete impermeability does not exist in pottery; as in all ceramic productions, even when completely vitrified, the density of the finely ground material is higher than that observed in broken pieces. The difference shows the proportion of the pores or voids. The weight of liquid which can be absorbed by a body depends entirely on the condition of the experiment. Pieces of porcelain and stoneware, when perfect, can often be soaked indefinitely in water without increasing in weight; but by submitting them several times alternately to the vacuum produced by an air pump and to a considerable pressure of water, the pores can be filled with water. Even when simply immersed in water, wares which do not show any noticeable increase in weight at the end of some hours do show it after several months, and even porous wares increase indefinitely in weight on prolonged soaking, though the increase becomes increasingly slow after the first hour. Thus, the weight of water absorbed tends to correspond to the total volume of the pores, but never equals it.

A continuous series of wares can be arranged, passing insensibly from terra-cottas and faiences to stoneware and porcelain, without it being possible at any point to trace the limit between permeable and impermeable ware. Arbitrary limits—fixed for the application of Custom House duties, for example, and based on a maximum amount of water absorbed by a ware under definite circumstances—can have only a relative value from a ceramic point of view. From that point it is convenient to reckon as stoneware all pottery which is opaque, has a vitrified body, and thus almost impermeable. It frequently happens

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[1] [Potters usually employ the term "non-porosity" (see footnote, p. 416).—A. B. S.]

that wares made with bodies suitable for stoneware are too porous to be reckoned commercially as stoneware, because the burning has not been carried to a high enough temperature, but, ceramically, they are none the less stoneware bodies. Frequently, this name (stoneware) is given to wares that are not strictly impermeable, but which are sufficiently so for some purposes, as certain pipes with a fireproof body which is relatively porous but has been made impermeable by a coating of salt glaze, and certain paving tiles, which are only slightly permeable and very hard. As these wares are manufactured by the same method as true stoneware they are treated in this chapter, though this classification is theoretically incorrect. Brongniart and, after him, most other writers have divided stoneware into (1) common stoneware, the basis of the body being a vitrifiable clay and the glaze saline; and (2) fine stoneware, having a body and glaze similar to those for feldspathic faiences. Fine stoneware, the manufacture of which has not been noticeably modified since Brongniart's time, has a composition which distinguishes it from the other kinds; but common stoneware has been considerably developed, and certainly will become increasingly important in the future. It is no longer used for making jugs and pipes; it will take other glazes than salt glaze, and may be decorated so effectively as to be classed amongst the most beautiful wares the ceramic art can produce. Under these conditions, the epithet of "common" has lost its meaning, and gives rise to the same errors and objections as the terms applied to faiences. If, in the absence of any other term and on account of its being the one generally used, fine stoneware must still be designated by this name, it is desirable to suppress the adjective "common" for the others and to consider them simply as "stoneware".

(1) *Stoneware Proper*: (*a*) *Paving Tiles*.

Stoneware tiles and those which are sold as such are of varied shapes, according to their different uses and to the variable quality of the body.

For lining walls and for in-door pavements, square or hexagonal tiles are generally used (type I., Fig. 282), with sides 4 to 9 inches. The thickness, which is the thinner the better the body, varies from ¼ to ½ inch. They are of one colour: white, red, brown, black, or sometimes yellow.

For paving footpaths, porches, stables, etc., square tiles are used (type II.), plain or grooved, about 6 to 7 inches side and 1 to 1½ inches thick. They are of one colour: yellow, brown, red or black.

For pavements subject to heavy wear they should be thicker; shapes similar to those shown in type III. being generally adopted.

These tiles may be decorated with coloured slips applied by in-laying, as shown in type IV. They are then generally square, of 4 or 6 inches side, though they may be of other shapes. The thickness varies from ½ to ¾ inches.

The composition of the body varies: sometimes a vitrifiable clay is used; sometimes a fusible clay is made more refractory or a fireproof clay is made vitrifiable.

Vitrifiable clays vitrify in a porcelain kiln, but they remain dull in faience kilns. They contain a certain proportion of fluxes—alkalies, lime, and iron oxide. This last, however, is nearly always in the form of peroxide (Fe_2O_3) and, consequently, can only act as a flux if the burning is done in a reducing atmosphere, which turns it into the form of protoxide (FeO). All vitrifiable clays containing iron are more fusible when the burning is done with a reducing atmosphere than when it is oxidizing. In the latter case, the alkalies, lime, and magnesia can be relied on to cause vitrification. The proportion of lime and magnesia is not usually high, being seldom above 2 per cent.

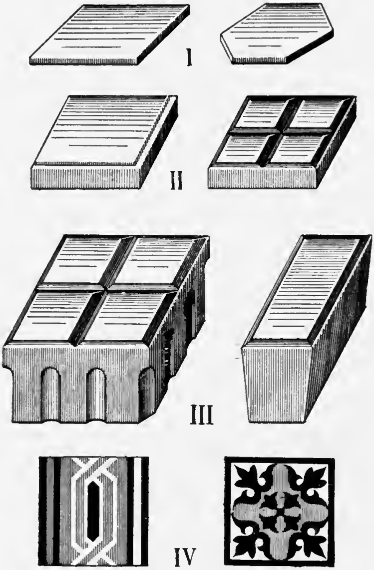

Fig. 282.—Paving tiles.

The amount of alkali, on the contrary, is seldom below 3 per cent, and may be as high as 6 per cent. According to Vogt, these alkalies are in the form of extremely fine particles of mica.

Vitrifiable clays are usually plastic; the proportion of alumina varying between 25 and 30 per cent. The lime, magnesia, and alkalies being in an impalpable state in the whole mass, may cause it to soften and warp as soon as it vitrifies, so that it is generally necessary to add a certain proportion of silica to the body to serve as a stiffener and to allow it to vitrify without the goods losing their shape. The coarseness of the grains of silica is of very great importance: if too fine, they melt too rapidly when the body fuses; if too large, they prevent it from becoming impermeable. Hence the composition of stoneware bodies made of vitrifiable clays can only vary between narrow limits.

The following are average quantities:—

Silica	68 to 75 per cent.
Alumina	20 „ 25 „
Lime and Magnesia . .	2 „ 12 „
Alkalies	3 „ 5 „

In some cases there must be added to the foregoing a notable proportion of iron oxide, which may reach as high as 15 per cent.

A mixture of fusible clays and refractory materials may be used to form a vitrifiable body similar to the preceding ones, though as fusible clays usually contain much more lime than alkali the vitrification occurs at a distinctly lower temperature. There is a wide difference between the behaviour of lime and alkalies, for the lime, at the moment the temperature for decomposing the carbonates is reached, tends to form quickly through the whole mass a double silicate of alumina and lime, perhaps also some lime aluminates, so that, in spite of the silicious strengthening, the mass softens shortly after it begins to vitrify, and the ware may quickly get out of shape. With alkalies in the form of mica or felspar, on the contrary, the action commences with the fusion of these rocks, and the little grains of flux enter very slowly into combination with the silica and alumina surrounding them, so that there is a fairly long interval between the commencement of the vitrification and the moment at which the article loses its shape. For bodies of this description, the proportion of alkalies seldom exceeds 2 per cent, while that of the lime is 6 to 10 per cent, the amount of silica being 68 to 75 per cent and the alumina 20 to 25 per cent, although the relative plasticity of the carbonate of lime would allow of less aluminous bodies being used.

A Mixture of Fireclay and Fluxes.—The forms in which the fluxes are added to a fireclay are as various as the proportion of them, because the latter depends upon the coarseness of their grains.

The mixture which gives the best results is made by the addition of felspar or finely powdered Cornish stone. By giving the body the composition indicated for bodies of vitrifiable clays with 5 to 6 per cent of alkalies, stoneware of a very good quality that will resist high temperatures for a very long time without losing shape can be obtained, because the fluxes are in a coarser form, whatever the fineness to which they are powdered, than those in the natural clays.

Unfortunately, this method is rather costly for goods which are not of a high commercial value. Alkalies may also be employed in the form of salts, but the vitrification then takes place at a low temperature, and has almost the same disadvantages as lime. For economical reasons, calcareous fluxes are very much used, calcareous clay, marl, and limestone being used, but the substance which has given the best results is blast-furnace slag, which is a somewhat impure lime silicate.

The bodies thus obtained have somewhat the following composition:—

Silica . . .	51 to 55 per cent.
Alumina . . .	19 „ 22 „
Lime . . .	22 „ 25 „

plus a small quantity of iron oxide, manganese oxide, magnesia and alkalies. Tiles made with bodies of this class are always slightly porous, as they can only be heated to the commencement of vitrification without risking a sudden loss of shape. Even when melted, the body does not become impermeable, so that, ceramically speaking, these wares are terra-cottas rather than stoneware.

Sometimes open fireclays have been mixed with coarsely broken glass. The body when burned is not then homogeneous, but is composed of refractory parts united to other (vitrified) parts. If the heating were carried to a fusing point, the material would remain heterogeneous, and pieces of clay and silica would be found incorporated in the vitreous flux. Glass cannot be used in a fine powder, because the softening would then take place at the same time as vitrification.

The tiles called pyrogranites, manufactured in Russia, are composed of a fireclay mixed with a fusible clay, the burning of which is carried on to the fusing point in fireclay moulds. These wares have a wonderful polish, imitating that of hard stones, which is produced by passing them through a mill. The introduction of grains of terra-cotta of different colours produces on the surface an imitation of granite.

Colouring.—In the chapter relating to burning (p. 184) the part played by iron oxide in the colouring of bodies was described, but it is necessary to complete what was said by some observations peculiar to stoneware.

The colouring of these wares is very variable. Sometimes only slightly yellowish or bluish, they are frequently of a bluish-grey (pearl grey), darker or lighter yellow, red, brown or black. Except in the very rare cases in which the body contains manganese oxide, these colours are due to iron oxide and to the way in which they are fired.

White can only be produced by using vitrifiable clays containing very little iron. These clays are extremely rare, for, as already observed, the lowest proportion of iron at the moment of vitrification is sufficient to colour it. Generally, white stonewares are obtained by a mixture of white fireclay, china clay and alkaline fluxes.

As in terra-cotta, the grey or bluish-grey colours are formed in a body containing a little iron and burned in a reducing atmosphere. In order to be sure of obtaining these colours, it is necessary to burn with a reducing atmosphere at a temperature above 800 C°.

Yellow colours are produced by the body containing very little iron, or by calcareous ferruginous bodies heated in an oxidizing fire during the whole of the burning process. Under similar circumstances bodies which are simply ferruginous become brown or even black when the proportion of iron is high. A decidedly red colour is much more difficult to get in stoneware than in terra-cotta; for the body must contain much iron peroxide, a little alkali and no lime, and the burning—which must naturally be in an oxidizing atmosphere—must be stopped when vitrification begins.

A uniform black can, in the absence of manganese oxide, only be produced by a reducing atmosphere, and the formation of a deposit of carbon in the pores of the ware before it vitrifies. In this case, the method used for the manufacture of black tiles can scarcely be used, because it would be difficult to keep a suitable atmosphere above 800° C. up to the time of vitrifying. The ware should be enclosed in saggers filled with powdered charcoal or coke (p. 329).

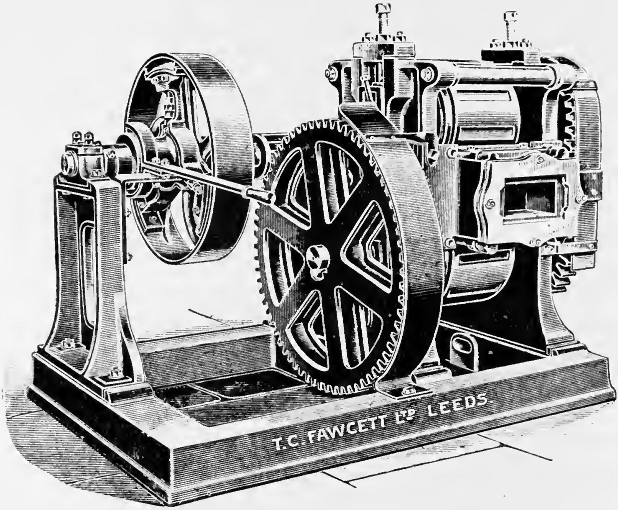

Fig. 283.—Expression rolls.

Methods of Manufacture.—Stoneware tiles may be manufactured by two processes: moulding the body (1) in a plastic state, or (2) as a moist or dry powder. In the first case the process previously described for terra-cotta paving tiles (p. 330) may be used, the tiles being repressed when they have been sufficiently dried, in order to reduce the spaces in the body as much as possible. This process, which need not be described at greater length, can only be used to make fairly thick tiles of a relatively low quality.

In order to get very thin and very hard tiles, moulding in plastic clay may be employed.

Thicker tiles, intended principally for paving, are pressed from a moist or dry powder. This process is described later.

All the tiles just mentioned are of one colour throughout. Tiles ornamented with polychrome designs (inlaid tiles) are also manufactured, and are one of the most beautiful forms of pottery. They are made almost exclusively from dry body reduced to powder and variously coloured (see p. 414).

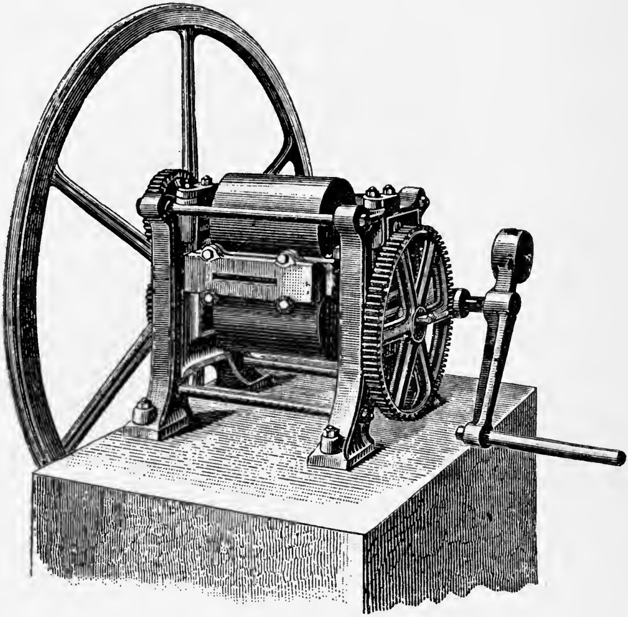

Fig. 284.—Expression rolls (hand-driven).

Manufacture in Plastic Body.—The bodies used for this manufacture are generally plastic and contain alkaline fluxes. White vitrifiable clays are used for white tiles, ferruginous tiles for red or brown ones. Black tiles are coloured either by manganese, or more often are burned in a sagger containing carbon.

The body is prepared as a soft paste or powder. The raw materials are often washed. The body is roughly shaped by forcing it through a die by means of expression rolls (Figs. 283 and 284). The paste coming out of the die is received on a fixed cutting table (Fig. 285) and passes first under a roller, on the two sides of which are stretched vertical wires, which cut it to the required width. The lengthway cut is made by a series of transverse wires, as in the similar apparatus already described. The tiles, thus cut, pass under a last roller, in order to smooth out the ridges caused by the cutting wires. Hexagonal tiles are cut on a special table with bands of the width desired, and a special cutting frame shown in Fig. 286 is used. The cut tiles are then piled up until they have acquired the consistency of a firm body.

When the body is not naturally of the required colour, or when it is not of the desired intensity, it is dipped in slip. This slip dries rapidly and the tile is then placed on a marble slab and struck on both faces with a wooden bat, after which the tile is put between two rolls (Fig. 287), the lower of which is grooved and the upper made of polished bronze. This machine indents the lower face of the tile so as to make it adhere more easily to the bed of mortar, and polishes the upper face. To give the tile a regular shape, templets or a special machine (Fig. 288) can be used. In the latter, a descending plunger cuts the edges obliquely and then opens out, so as not to carry up the tile as it ascends. The output of such a machine is 200 to 300 tiles per hour. The finished tiles are put in piles to finish drying. The method of moulding just described is that suitable for best tiles; it can sometimes be simplified, but at the expense of the quality of the goods.

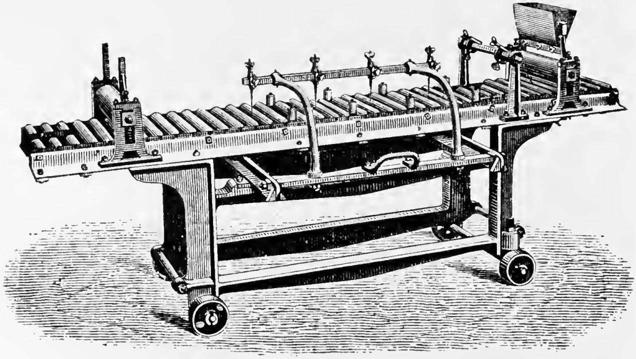

FIG. 285.—Cutting-table for floor-tiles.

For small quantities, the burning is done in intermittent muffle kilns on the type shown in Fig. 169. For large quantities it is better to use kilns heated by gas (Fig. 248). Whatever the type of kiln used, it is essential to have a very slow and careful smoking, by means of special fireplaces.

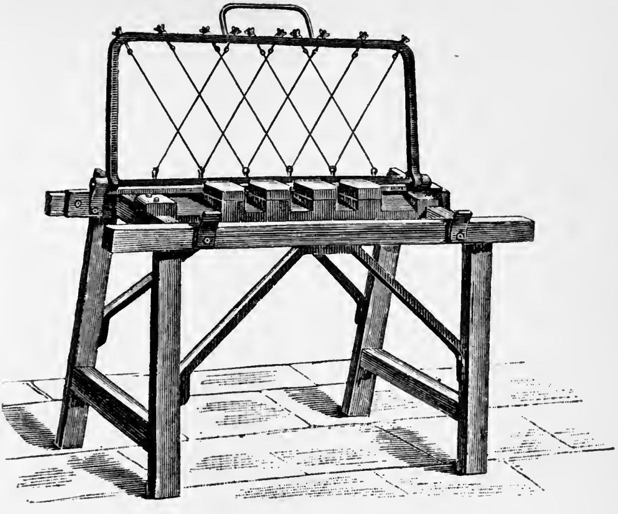

Fig. 286.—Cutting-table for tiles.

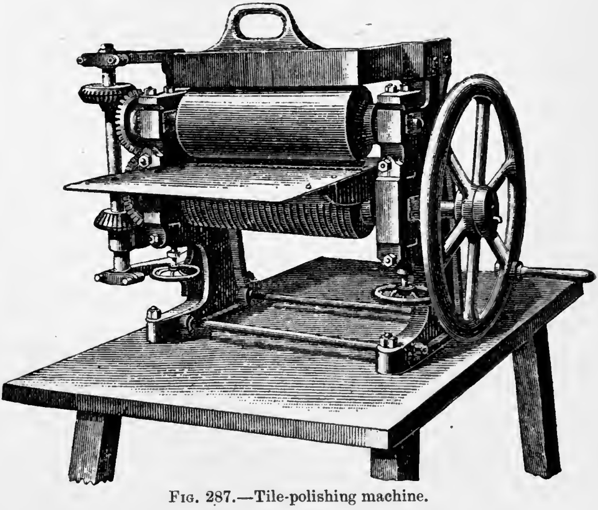

Fig. 287.—Tile-polishing machine.

A fresh difficulty is encountered during the burning, in consequence of the shrinkage, often considerable, which takes place in the body. The tiles are necessarily placed in the kilns in "bungs," which sometimes fall over if the heat is not uniform. This defect often necessitates the use of special devices.

This manufacture is one of the most difficult met with in pottery and one needing extreme care.

Manufacture in dry body is much simpler than the preceding one, but does not allow such thin goods to be made. It is, therefore, particularly suitable for paving tiles. All the bodies and methods for colouring previously described may be used.

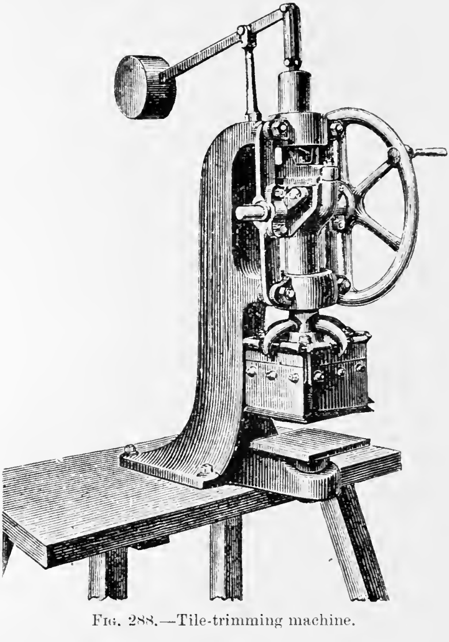

FIG. 288.—Tile-trimming machine.

The raw materials are prepared by the dry method, though certain substances, such as feldspar and Cornish stone, are ground in water (by preference in block machines, or in Alsing cylinders). The ground body is moulded by hydraulic presses driven by machine-power.

The moulding is generally done in the following manner. The body (in powder) is put into the mould, a little pressure is then given either by hand or by machine, after which the mould is placed under the hydraulic press.

It is compressed first at a low pressure, after which the compressed air in the body is allowed to escape, and this treatment is followed by a high pressure. The mould is then drawn away, and placed on an apparatus for emptying it, which generally consists of a second hydraulic press, in which the water which served for the high pressure is used.

For small quantities, two moulds on a slide, which are placed alternately under the press and emptied, can be used, but the ordinary arrangement consists in placing the mould on a slab revolving round one of the vertical pillars which hold the upper slab of the press (Fig. 289).

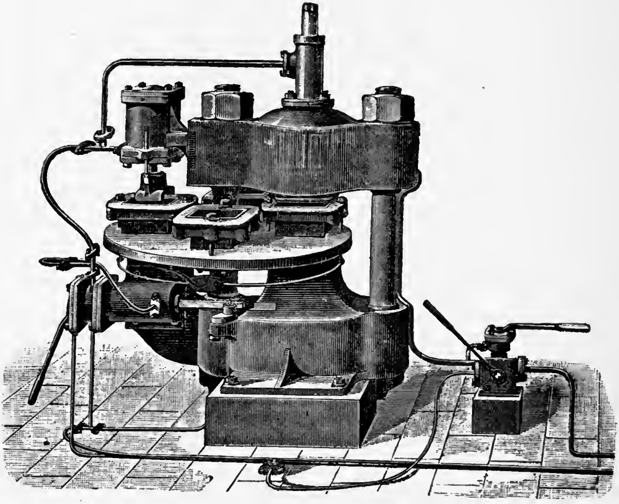

Fig. 289.—Hydraulic press for tiles.

These moulds are three or four in number, so that all the operations of the shaping may be carried on at the same time. The revolving plate is moved by means of a small pump.

The tiles when taken from the mould are hard enough to be handled. They are then placed in drying-sheds, usually heated by waste heat from the kilns.

The tiles are placed in the kilns in bulk, the goods being piled up to a height of 6 feet to 10 feet; if piled higher, the lower rows would be crushed, when they begin to vitrify, by the weight of the upper ones. Black tiles should be placed in saggers filled with carbon, as already stated, these saggers being placed in the middle of the other goods.

Small quantities are burned in round intermittent down-draught kilns, similar to those employed for burning fireclay goods, but less in height. The heat given off from the kilns when they are cooling is used in the drying-sheds.

Where the output is sufficiently large, it is more advantageous to use continuous kilns. For this purpose, kilns of the original Hoffman type have been used, but in spite of the expenditure of fuel being greater, it is better to use continuous kilns with chambers and fireboxes. A gas-fired kiln is much easier to regulate and ought, as a rule, to be preferred. Fig. 290 shows a kiln of this kind (Mendheim) made on the principle indicated by Fig. 165. Each chamber communicates with the following one by flues, starting at one corner, going underneath the floor and ending in the next chamber. In the floor are also found gas-flues placed parallel to the air-passages, so that the flames come up through a series of openings at the bottom. The gas is led into each chamber through an outside underground flue while the draught is caused by a central chimney.

Openings arranged in the walls separating the chambers, allow fireproof dampers to be used, and flues placed along the arches serve for smoking with warm air (p. 299) as for burning bricks.

When they come out of the kiln, the tiles must be sorted, as there are two or even three qualities produced, owing to irregularities in the burning.

The manufacture of these tiles needs large works to be remunerative; it is only exceptionally that they are made in other tile and faience potteries.

Inlaid tiles or encaustic dust tiles have been made since 1861. The body may be a vitrifiable clay or a fireclay with the addition of feldspar, and, when necessary, silica. It is decorated by means of slips, applied in the form of a powder. The tiles are generally square, with a side of 4 to 8 inches, the usual size being 6 inches; the thickness varies from $\frac{3}{4}$ to $\frac{13}{16}$ inches. Half- and quarter-tiles are made, the latter being divided either rectangularly or on the diagonal. Borders have a rectangular form.

The slips are made by mixing colouring oxide with the body; it is needless to repeat on this subject what was said on page 258. Naturally, the proportion of flux in the clay must be modified according to the fusibility of the colouring oxide. The slip is usually made a little more fusible than the body.

The application of the slip dust at the time of making the tile is the distinctive and original feature of this manufacture. A templet—a little piece from $\frac{1}{16}$ to $\frac{1}{25}$ inch thick, formed of bands of copper soldered together, which divide into cells having the shape of the outline of the design (Fig. 291)—is placed at the bottom of the mould after having been passed to a series of workpeople who each put a slip of a definite colour into the proper cells. When the templet has been filled a slight pressure is given to the slips and the mould is then filled with ordinary body, the whole being afterwards compressed in a hydraulic press.

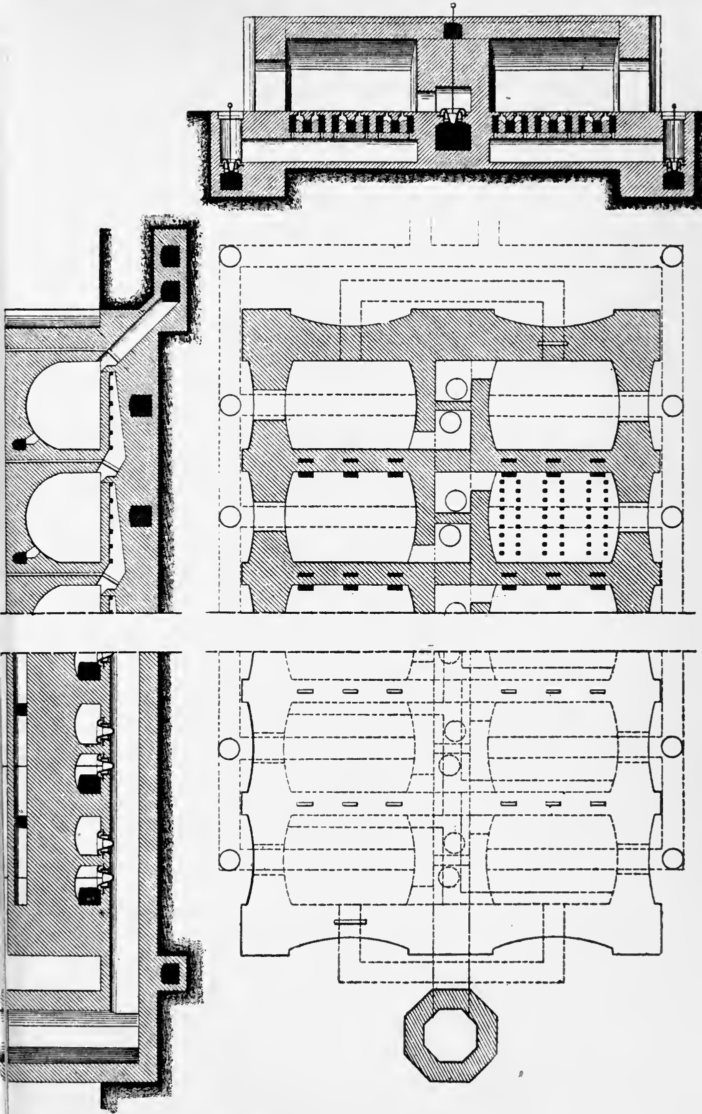

Fig. 290.—Mendheim's gas-fired continuous kiln.

Fig. 292 illustrates a hydraulic press used for this kind of manufacture. In the front is a table along which the moulds move. These moulds are formed of two pieces, one on the other, the lower being the thickness of the slip, and the upper that of the body. On the front of this table, the slips are put into the lower part of the mould, as just described, then the upper part of the mould is put on, and filled with the body by means of a funnel; it is slightly pressed, the mould is covered over with a piece of cast-iron or steel, and the whole is pushed under the hydraulic press.

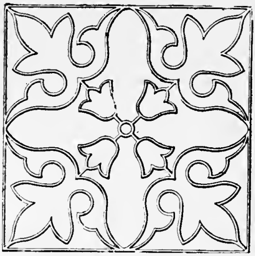

Fig. 291.

For larger quantities a circular table is preferred along which movable moulds run on rails (Fig. 293). The filling of the moulds is done by work-girls seated round the circular table; the whole working of the moulds and presses being attended to by a workman placed in the centre.

The drying of inlaid tiles is done in the same manner as smooth tiles, but the burning should be in saggers, the tiles being saggered in bulk. Round down-draught kilns are generally used, but for large quantities continuous kilns could also be employed.

Tests for paving tiles are of two kinds. Permeability[1] may be ascertained by first drying the tile at 110° C., plunging it into water, and measuring the increase of weight at the end of twenty-four hours. This increase is afterwards calculated as a percentage on the weight or volume of the dry tile.

The determination of the resistance to wear is the essential test. Various machines have been proposed for showing the diminution in weight or thickness which occurs in the tile when its surface is subjected to a lengthened period of use. See the conclusions of the Commission for the Methods of Testing Building Materials on page 343.

Tiles of true stoneware, when well made, offer a resistance to wear quite equal to that of the hardest natural stones.

(*b*) *Pipes.*

Fig. 294 represents the usual forms of stoneware pipes, elbows, junctions, syphons, etc., employed in forming drains. The inside diameter varies from 2 inches to 39 inches; those above 24 inches are seldom used. The length of the straight pipes varies from 24 inches to 39 inches.

The best composition for such pipes consists of a mixture of sand and

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[[1] Bourry uses the term "permeability" to include both permeability and porosity. In Great Britain the former is only used to indicate the extent to which a liquid can penetrate through the ware when applied to one face. Porosity is the amount of pore-space and is measured by the amount of water absorbed.—A. B. S.]

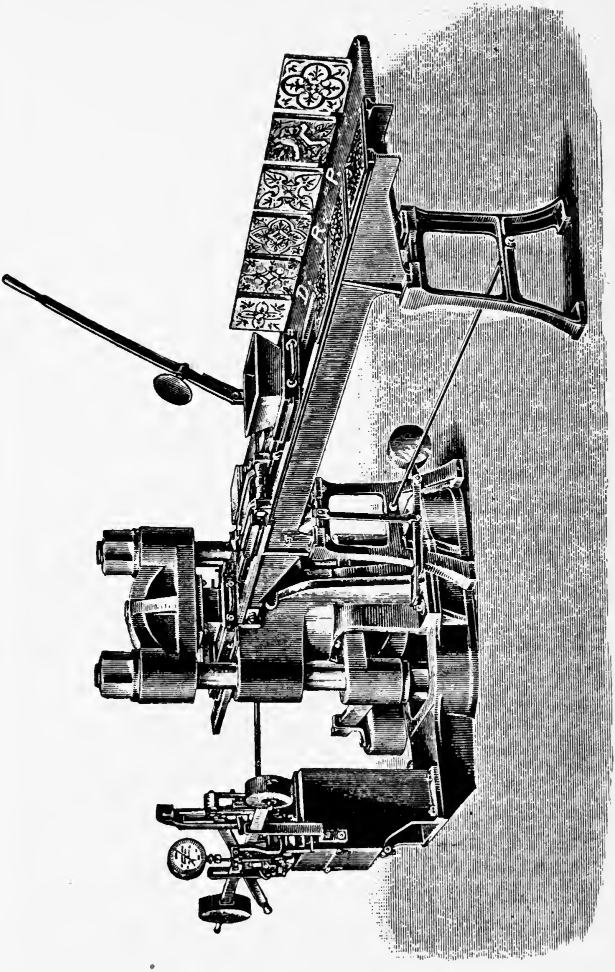

FIG. 292.—Hydraulic press for encaustic tiles.

vitrifiable clay, or of a fireclay with the addition of feldspar or Cornish stone. In this way perfect stoneware is obtained—very impermeable and resisting great pressure—the only defect in it being slight brittleness. For reasons of economy, the alkalies are sometimes replaced by a limestone flux, i.e., a certain proportion of a fusible calcareous clay is mixed with a slightly vitrifiable clay or with a fireclay.

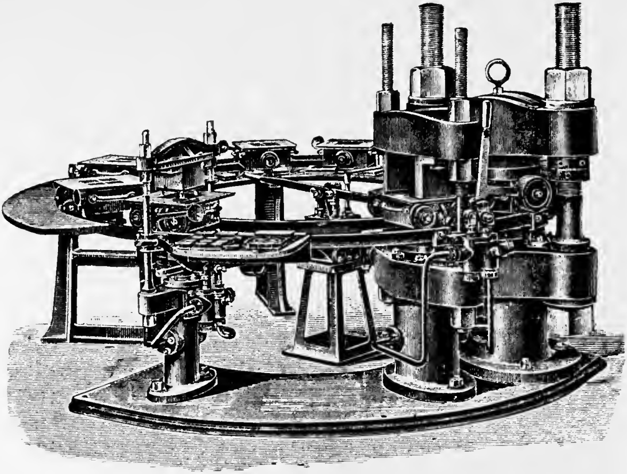

Fig. 293.—Hydraulic press for encaustic tiles.

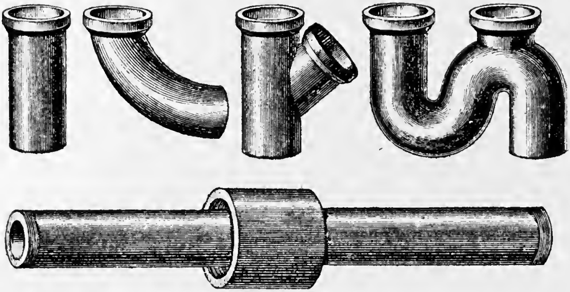

Fig. 294.—Stoneware pipes.

Fireclays may also be used if they do not show any trace of vitrification at the highest temperature at which they are burned. This is an excellent way of obtaining goods which do not lose their shape, but the ware obtained by this process is still porous, and should not be considered as stoneware from a ceramic point of view. English pipes, which are still largely exported, are all included under this head.[1]

The refractory body must naturally contain more flux than the body used for the manufacture of fireclay goods, and the grain should be finer, so as to be suitable for the glaze. In some factories, especially in Germany, the body is covered with a slip made of fine vitrifiable body.

Moulding is always done with a plastic body.

Straight pieces may be made in three ways:—

(1) On the potter's wheel. (2) By expressing the straight pipes and afterwards attaching the socket by hand, this socket also being made of a portion of a pipe similarly drawn, but of a larger diameter. (3) By expressing the pipes, the socket being made simultaneously.

The first method gives goods that do not look so well, in spite of the skill of the potter, and is more costly. The second is only suitable for making small quantities, the joints needing to be carefully made. The third is the method employed in all important factories. As it is essential that the goods should not get out of shape by their own weight, which might easily happen in the large sizes, the pressing must be done vertically. The body, on coming out of a circular die, strikes against a plunger, the shape of the socket; owing to its plasticity it bends round it, then, when it has become of the desired shape, the plunger is released and the pressing of the straight part is accomplished as in other machines. When the pipe has reached the desired length the machine is stopped, the pipe is cut with a wire, raised with the little board on which it rests, and turned over so as to enable the pipe to be taken away. Fig. 68 represents a machine of this kind in which the body is compressed in a cylinder by means of a belt-driven machine.

In England, the piston propeller is often set in motion by the direct action of a steam-engine. Fig. 295 represents a machine of this description, made by the Brightside Engineering Co. and others.

Sometimes the opposite arrangement is adopted, the expression being from bottom upwards, as shown in Fig. 296. In that case, the moulds are fixed on vertical rods, which are held immovable at their lower position while the fitting is made, and are afterwards raised by a counterpoise.

The working of the preceding apparatus is intermittent, because when the piston or propeller arrives at the end of its course it must be carried back and the box must be filled afresh with the body. This takes a long time, because the body has to be pressed by mechanical power in such a way as to prevent, as much as possible, any air remaining in it. This air, in spite of the valves with which the dies of

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[[1] This statement is no longer true, as a considerable number of English firms now make pipes with an impermeable (stoneware) body.—A. B. S.]

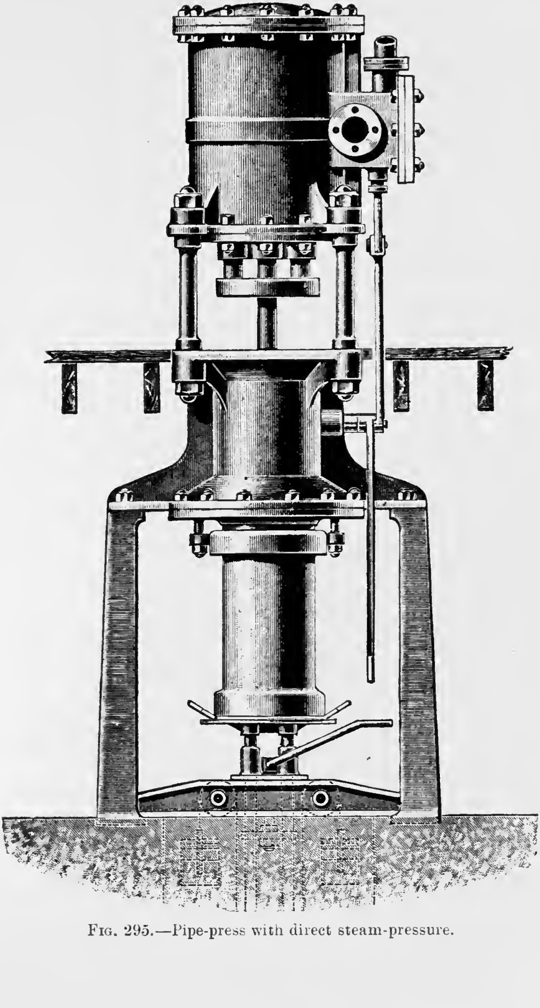

Fig. 295.—Pipe-press with direct steam-pressure.

these machines are provided, will sometimes form bubbles in the pipes and thus make them unusable.

In France, for pipes with a diameter below 28 inches, expression rolls are preferred for pipe-making (Fig. 297). The dies, as well as their core (bell) and the plunger, are covered with plaster. The presence of air-bubbles is less to be feared with this machine, if the men are careful never to let the pressing box become empty.

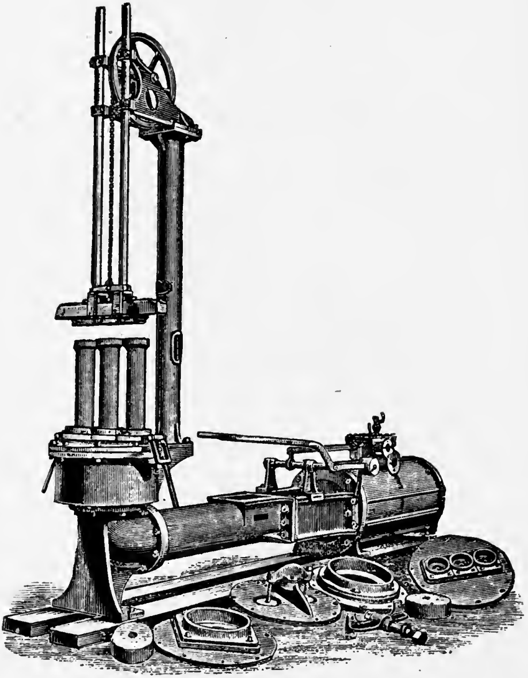

FIG. 296.—Pipe-press with upward pressure.

It is wise to use two of these presses, one for small-sized pipes, two or three of which can be made simultaneously, and the other for large sizes. The output is about fifty pipes of 8 inches diameter per hour.

When the pipes are sufficiently dried, they are placed on a horizontal cylinder or "fettler," sometimes covered with plaster, and are rotated rapidly to allow defective parts being touched up by hand, and of the pipes being indented so as to increase the adherence of the mortar. The finished pipes are placed in drying-sheds heated by waste heat from the kilns. In some works the tiles are rolled on plain sheets of iron before they are completely dry, so as to get rid of the elliptical form that may easily occur when they are unequally dried.

Elbows, junctions (Fig. 294), etc., are made from the ends of straight pipes which are cut off and joined together, or by direct moulding.

Burning and salting are done either in round kilns with down-draught, in semi-continuous kilns, or in continuous ones with several burning spaces, according to the output. The kilns are heated either by coal or gas. The pipes are placed in bulk, upright, fitting one into another to a height of 6 feet 6 inches to 8 feet. Care must be taken that the circulation of the gas reaches the inside of the pipes in order that the salting may be done regularly on all sides. Small pipes may be put inside the larger ones, but, in spite of this facility, the weight of the goods placed in a given volume is small, and considerably increases the cost of burning as compared with bricks.

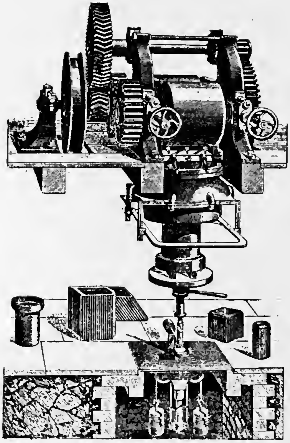

Fig. 297.—Expression rolls for pipes.

When heated by gas, the kiln already described (Fig. 290) for burning tiles may be employed. The arrangement shown in Fig. 166 may be used.

When heating by coal is preferred for small quantities, the kiln described later may be used (Fig. 301), and for a more important production the semi-continuous kiln shown in Fig. 298. It is composed of a series of chambers the perforated bottom of which communicates, by means of flues, with openings placed along the side of one of

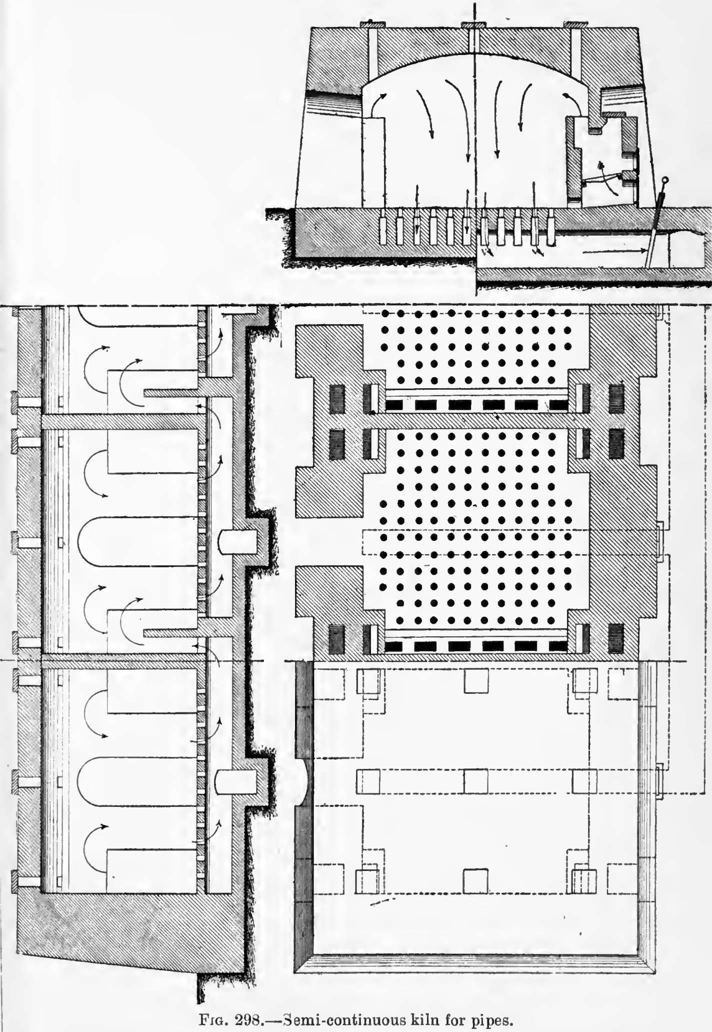

Fig. 298.—Semi-continuous kiln for pipes.

the following chambers. In the same way as in kilns with flues, the air strictly necessary for combustion is brought in under the fire grates; the recuperation is only applied to a small proportion of air in excess.

In theory, the heating by down-draught as in the types of kilns shown in Figs. 164, 166, 298 and 301, is preferable to heating in up-draught kilns as in Figs. 165 and 290; the maximum temperature is produced at the top of the goods instead of attacking the lower pieces which, being more loaded, sooner get out of shape.

The characteristic operation of burning stoneware pipes is salting, i.e. the throwing into the kiln, at the time when the highest temperature has been reached, of a certain quantity of salt. This volatilizes at a temperature slightly above 800° C., but only decomposes when towards 1200° C. it comes into contact with silica. The sodium set at liberty oxidizes, forms soda which combines with the silica of the body, and thus causes a superficial vitrification. The chlorine, on its part, decomposes the steam furnished by the combustion and escapes in the form of fumes of hydrochloric acid.

This decomposition is better, that is to say, the glaze is much thicker and more impermeable, the more the silica contained in the body. Aluminous or decidedly basic wares cannot be covered with a saline glaze applied in this way.

The salt is introduced into the kilns through openings arranged in the top of the kiln, care being taken that it does not fall directly on to the goods.[1] It produces a decided and rapid lowering of the temperature by 200° to 300° because of the considerable amount of heat absorbed by the salt, in order to heat, volatilize and decompose it. The salting ought, therefore, to be done in two or three operations from twenty to thirty minutes apart, and the heating increased between them. The proportion of salt put in varies from ½ lb. to 1½ lb. per cubic foot of capacity of the kiln.

While salting, the draught must be reduced to the minimum the intense heat will bear, so that the salt vapours may not be too quickly carried off into the chimney. The colour of the pipe naturally depends on the composition of the body and on the working of the fire during the time of burning which precedes the salting. It should not be reducing enough to cause a deposit of carbon on the goods, as this would afterwards prevent the contact of the silica and the salt vapour. If the proportion of salt is too great, the goods, after they have been some time in store, will show white deposits, which can be washed off.

The salt not only acts on the goods, but also on the walls of the kiln, and rapidly destroys them, if care has not been taken to employ sufficiently aluminous bricks, i.e. bricks in which little or no silica is found in a free state. Salting was practised for the first time in England about 1690 by the Brothers Flers.

Tests for Pipes.—The decisions of the Committee on the Methods of Testing Building Materials which were given on page 347 under the

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[[1] In Great Britain it is usually thrown through the fire-holes on to the glowing fuel.—A. B. S.]

heading *Resistance to Breakage by Internal Pressure*, apply especially to stoneware pipes. Real stoneware pipes resist considerable pressure, varying from 5 to 15 atmospheres, or even more, without breaking. When the experiment is well-conducted, that is to say, the joints are well made and do not cause a supplementary strain on the material, the final breakage is produced along one of the edges of the pipe. Pipes made of fireclay body are less resisting, and it is seldom that no leakage occurs before the end of the experiment.

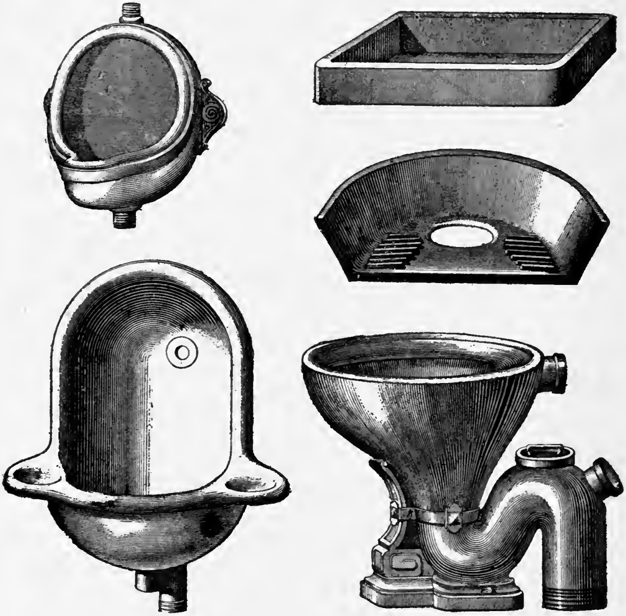

Fig. 299.—Sanitary ware.

The Tests are made either on a single pipe or on a series of two or three pipes connected together.

(c) *Sanitary Ware.*

For some years, pottery goods used for sanitary and various domestic purposes have been designated by this name. They are distinguished from the preceding ones by a finer body and a more careful preparation; sometimes they are covered with a salt glaze, but more usually with an opaque white glaze.

Fig. 299 shows some of the most usual types. The body is prepared in the same way as for pipes, but it is always vitrifiable[1] and with a somewhat fine grain so as to be glazed. Its plasticity makes it easier to mould the rather complicated shape of the objects that are often wanted, and can only be managed by moulding by hand. For some patterns the end of drawn pipes can also be used; these are afterwards cut and joined together.

As these wares are generally manufactured in pipe works, they are burnt in the kilns just described, but those which are to have an enamel are not salted.

The enamel used is of the same composition as for feldspathic faience, that is, an alkaline boracic plumbiferous one (p. 384), rendered opaque to hide the colour of the body by the addition of a little tin oxide. Coloured glazes may also be employed. The enamel may be applied to the "green" or to the fired goods, which, in either case, are fired in muffle kilns. In some cases, the glaze is gilded or covered with vitrifiable colours fixed by a third firing.

Sanitary wares are sometimes manufactured of faience or of fine stoneware body, the body being then white; transparent glazes are then used.

By manufacturing sanitary wares that are impermeable, with a glossy whiteness of irreproachable appearance, pottery has lent great aid to the science of hygiene. These wares, which were invented in England, were for a long time manufactured exclusively in this country, but now several works in France and Germany send out goods which will bear comparison with the best English ware.

(*d*) *Stoneware for Food and Chemical Products.*

The wares included under this heading are mostly "common" stoneware. The manufacture of pots intended to hold liquids was the first, and, for a long time, the only use for stoneware. Then, towards the end of the eighteenth century, they were used for making chemicals, and for this purpose have reached a high point of perfection. The principal merit belongs to Messrs. Doulton & Co., who thus rendered an inestimable service to this industry.

Fig. 300 represents some goods in common use.

The body employed for the manufacture of these wares is usually a fairly pure vitrifiable clay, which does not need to be washed. It is carefully prepared and made principally on the wheel. Some pieces, however, on account of their shape must be made in a mould.

For a long time these wares were burned in horizontal kilns with a single fireplace (Newcastle kilns), but it is better to replace them by round down-draught kilns. Fig. 301 shows a kiln of this description, which can also be used for burning pipes and other stoneware goods when the output is not sufficient to employ a continuous kiln. These

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[[1] The use of a non-vitrified fireclay for this work is most extensive. The employment of a vitrifiable body in this country is comparatively new, though increasing in popularity. In France and Germany this ware is exclusively vitrified.—A. B. S.]

kilns may be as much as 23 feet to 26 feet in diameter, the height not being more than 6½ feet to 10 feet, because, being filled in bulk, a greater height would cause the lower goods to be crushed when they soften. In the engraving, the gas is shown as passing away through a large number of small openings. This arrangement is specially used in burning salt-glazed goods; for other stoneware a smaller number of larger openings may be employed. The openings shown in the dome are used for salting, the salt being thus thrown on to the fireplaces, so as not to touch the ware.

This species of stoneware is generally rough or covered with a salt glaze when it is desirable to make them absolutely impermeable. This glaze may be given a deep brown colour by using the method indicated for making tiles black, immediately after the addition of the salt. There is then formed a deposit of carbon which becomes incorporated in the glaze whilst it is still pasty. This trick needs a certain amount of skill. The salt glaze is sometimes replaced by a cheap glaze, applied (1) by dipping, (2) with a brush, or (3) by dusting on the unburned body.

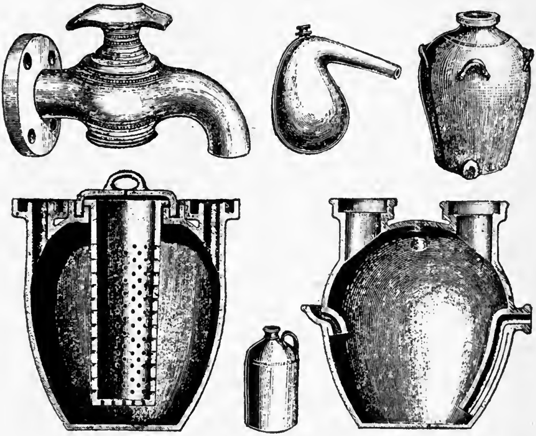

Fig. 300.—Chemical stoneware.

This glaze must melt at the temperature which suffices to burn the body and it cannot be plumbiferous. As the alkaline calcareous glazes are somewhat costly, they are sometimes replaced by blast furnace slag or by a mixture of cinders, lime and sand.

Stoneware for preparing food or for chemical purposes is manufactured in England in large factories, while in France and Germany it is the speciality of a number of small potteries, which are grouped together in the neighbourhood of the beds of vitrifiable clay; the quality of these goods depends upon that of the clay used.

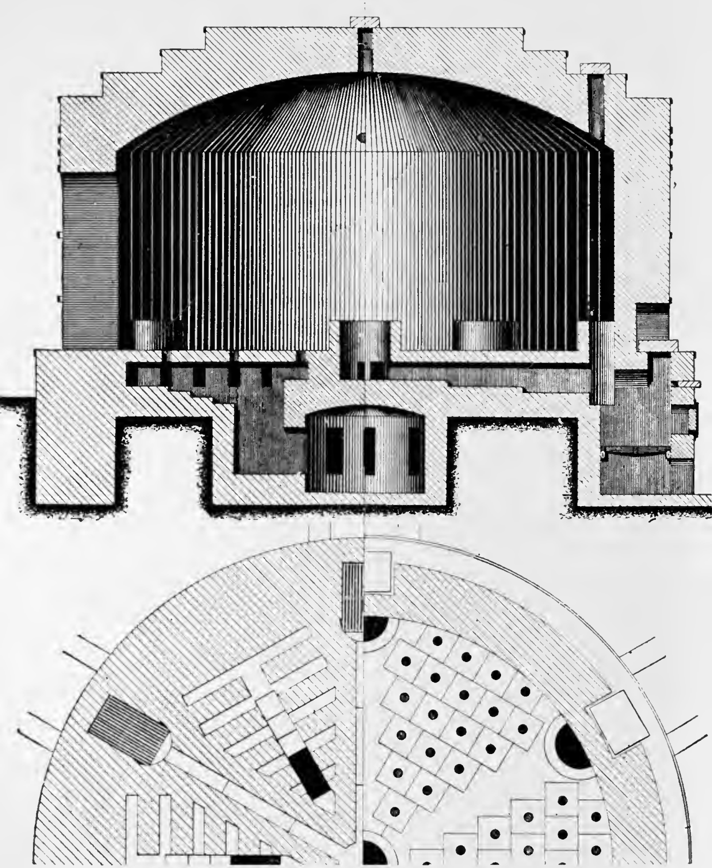

Fig. 301.—Kiln for stoneware.

(e) *Architectural Stoneware.*

This term includes those stonewares which are used in the construction and decoration of buildings.

The impermeability and hardness of stoneware give it a considerable advantage over terra-cotta. Unfortunately, this advantage is largely counterbalanced by the difficulties in manufacturing it, and especially of the tendency of stoneware to get out of shape when being burned.

Architectural stoneware may be dull, or covered with a salt or other glaze. Transparent or coloured glazes allow of very beautiful decorative effects being obtained, which harmonize better with the architectural decoration than the hard tones of the opaque enamels.

(*f*) *Vases, Statues and other Decorative Objects.*

The Chinese used stoneware from very ancient times for the manufacture of vases and other ornamental objects, and this manufacture began in Europe, in the fifteenth century, in the Duchy of Limburg. Since that time it has followed the fluctuations of fashion, disappearing completely, then reappearing again, without, however, at any time being of much importance. The first ware obtained by Böttger, which he called by the name of red porcelain, belongs to this class of goods. In the last few years, the favour enjoyed by stoneware has caused the development of this kind of ware.

For these articles, which are rather expensive, bodies of different colours can be employed, and they must be saggered with great care to allow the use of vitrifiable clays without bad effects.

The great advantage of this stoneware, as compared with porcelain or even calcareous or feldspathic faience, is the plasticity of the body, which allows it to be modelled by hand without employing moulds. As it lends itself to the same process as modelling clay, it makes possible the creation of original works of art that possess, when burned, the same qualities of resistance and indestructibility as stone or bronze, without requiring any retouching, or the troublesome working inevitably associated with sculpture.

The close grain of the body, as well as its colour, also gives a more agreeable appearance to the object when modelled in stoneware than to those made of terra-cotta.

Though decorative shaping should be the principal method of ornamenting stoneware, it does not follow that colour must not also be used; on the contrary, glazes blend very well with the more or less coloured background of the body, as they have not the hard appearance of other wares which are only partially glazed. All kinds of glazes and all methods of decoration can be employed; though gilding, which is so suitable for porcelain, does not generally yield satisfactory results with stoneware.

(2) *Fine Stoneware.*

In England, feldspathic faience, fine stoneware, and bone china are similar to one another, being manufactured by the same methods, and burned at about the same temperature, so that it is often difficult and sometimes impossible to distinguish them from each other.

The raw materials of fine stoneware are the same as those used for feldspathic faience, but the proportion of Cornish stone is increased and that of the flint diminished, thus :—

Blue Clay	10	25	29	45	28½
China Clay	15	12½	14	15	—
Flint	20	12½	—	—	—
Cornish Stone	55	50	57	40	71½

The greater the amount of china clay the whiter the body; with ball clay alone it is yellowish.

The chemical composition of white fine stoneware bodies is approximately :—

Silica	70 to 75 per cent.
Alumina	20 „ 25 „ „
Iron Oxide	traces
Lime	0·5 to 1 „ „
Alkalies	3 „ 5 „ „

Heavy spar [barium sulphate] is sometimes added in large proportion (as much as 50 per cent), the amount of Cornish stone being then reduced.

The body is coloured by means already indicated: ½ to 1 per cent of cobalt oxide gives blue, the same proportion of chromium oxide green, 7 to 8 per cent of a mixture of iron oxide and manganese oxide makes brown, etc. For basaltic black, the Cornish stone is replaced by a large proportion of red ochre and manganese oxide.

The body is prepared and moulded by the methods described for feldspathic faience. It is also burned in the same way, and at the same temperature.

Fine stoneware is frequently dull. Sometimes the surface is vitrified by covering the inside of the saggers with a coating composed of sea salt, saltpetre and white lead. The lead volatilizes, probably in the form of a chloride, and glazes the surface of the ware.

The glazes are usually alkaline, boracic or plumbiferous, like those for feldspathic faience; sometimes the lead oxide and a part of the Cornish stone are replaced by barium sulphate.

CHAPTER XIV.

PORCELAIN.

Before the sixteenth century, the word "porcelain" was used to denote objects manufactured of mother-of-pearl from the shell called porcelain. After that time it was used, from the similarity of appearance, to indicate Chinese ware.

Porcelains are impermeable, translucent ware with a white or coloured body, but the latter is only for a decorative purpose. Their impermeability distinguishes them from the terra-cottas and faiences, and their translucency makes them differ from stoneware.

In order to define translucency precisely, it is necessary to specify the thickness of the body and the intensity of the light. When only slightly thick, light coloured stoneware and some feldspathic faience are rich in flux and possess relative translucency. On the other hand, all kinds of porcelain become opaque when the thickness of the body is sufficiently increased.

At the present time, there is no precise rule for determining where opacity ceases and translucency begins; it is a question of appreciation.

"Hard" porcelain is distinguished from "soft" porcelain; these two adjectives should be taken first in the sense of resistance to heat, and afterwards of the mechanical hardness of the glaze.

Hard porcelain has a silicious body made of china clay and alkaline or partly calcareous fluxes. It is usually covered with a glaze, the vitrification of which takes place at the same time as the burning of the body, at a temperature of 1300° to 1400° C. The glaze cannot be scratched with steel.

Hard porcelains form a well-defined group, and are easily distinguished from other wares. From the point of view of use, the six following varieties may be distinguished. (*a*) *Porcelain for table-ware and for decoration.* (*b*) *Refractory porcelain* intended to be submitted to heat. (*c*) *Porcelain for electrical insulators.* (*d*) *Porcelain for mechanical purposes.* (*e*) *Architectural porcelain,* and (*f*) *Dull porcelain* (*biscuit porcelain*).

Tender porcelain, on the contrary, includes a number of wares which are very different from the hard porcelains, with which they have scarcely anything in common, being burned at a lower temperature, and having a softer glaze.

1. *Hard Porcelain.*

(*a*) *Porcelain for Table-ware and for Decoration.*

The manufacture of hard porcelain is concentrated in Haute-Vienne and Cher in France. In Germany, the principal centres are in Saxony, Bavaria, Thuringia, and Silesia. There are also factories in Bohemia, Belgium, Denmark, Russia (Finland and Poland), Italy (Tuscany), The United States (New Jersey and Ohio), China (Kiang-Si), and in Japan. Hard porcelain is not made in England.

It is generally agreed that 8 cwt. of various raw materials must be used for manufacturing 1 cwt. of porcelain. The chief of these are fuel, fireclay, china clay, feldspar or Cornish stone, quartz, plaster (for the moulds), etc. As all these products are not found in one single locality, it is necessary, in choosing the site for a new factory, to take into account the different expenses of transport, and especially that of the fuel. It is equally necessary to think about labour, because skill plays a large part in moulding, saggering and decoration.

The body for hard porcelain is a mixture of china clay, silica, and alkaline fluxes. Sometimes part of the alkalies is replaced by lime. In very rare cases magnesite or talc is partially substituted for the china clay.

Hard porcelain body should—

1. Have sufficient plasticity to be suitable for moulding.
2. Be burned at a sufficiently high temperature to allow the employment of a very hard glaze.
3. Have as great a translucency as possible.
4. Be of a slightly bluish-white colour.

Alumina hydrosilicate in the form of plastic clay, which serves as a basis for all the bodies previously described, cannot be used. It would produce bodies which are too fusible or opaque, and would not be of the required whiteness. On the other hand, in the form of china clay, alumina hydrosilicate is more refractory and makes the bodies more translucent and whiter.

The china clays, even if sufficiently pure to be used for the manufacture of porcelain, vary greatly in composition and properties. Their value must be decided on a "rational analysis" (treatment with sulphuric acid).[1] The alkalies dissolved by this treatment may be ascribed to mica, by regarding it as having the composition of muscovite, $6SiO^2$, $3Al^2O^3$, K^2O, $2H^2O$, and the insoluble alkalies as orthoclase feldspar, $6SiO^2$, $4Al^2O^3$, K^2O, any soda being reckoned as an equivalent of potash. Thus, the proportions of the mixture of alumina hydrosilicate, quartz, feldspar, and mica, which make up the china clay are obtained.

It is also necessary to make a practical experiment in order to ascertain the plasticity of the body. The dimensions and probably

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[1] [There are many irregularities observed when this method of analysis is used. On the whole, a very full ultimate analysis, combined with a careful microscopical examination, is superior.—A. B. S.]

the shape of the grains of alumina hydrosilicate are, in fact, more variable in china clay than in the plastic clays, so that the higher its plasticity, as in the Cornish china clays, the nearer it resembles corresponding clays (kaolins) from China and Japan.

The non-plastic materials added are quartz, quartzose sand, or biscuit porcelain ; the fluxes are feldspar, Cornish stone or chalk. It frequently happens that a single china clay, especially when it is a lean one, cannot give the needful composition, and two or even three clays are, therefore, mixed together.

The following are typical analyses, the first eight being burned porcelains and the last eleven raw bodies.

		Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Potash.	Soda.	Water.	Carbonic Acid.
Burned Porcelain.	Meissen	58·5	35·1	0·8	0·3	0·6	5·0	—	—	—
	,,	60·0	35·5	—	0·6	—	2·3	1·6	—	—
	Vienna	59·6	34·2	0·8	1·7	1·4	2·0	—	—	—
	Nymphenburg	72·8	18·4	2·5	3·3	0·3	0·6	1·8	—	—
	Berlin	64·3	29·0	0·6	0·3	0·5	3·6	—	—	—
	China	69·0	23·6	1·2	0·3	—	3·3	2·9	—	—
	,,	70·0	22·2	1·3	0·8	—	3·6	2·7	—	—
	,,	73·3	19·3	2·0	0·6	—	2·5	2·3	—	—
Raw Bodies.	Sèvres body for table-ware	52·94	28·91	0·48	3·99	0·17	1·70	0·68	9·12	2·4
	Limoges (L. Pouyat) superfine body	64·28	23·49	0·87	1·77	tr.	1·11	3·07	5·48	0·6
	Limoges (L. Sazerat) ordinary body	60·42	26·47	0·52	1·37	tr.	2·75	1·60	7·19	—
	Limoges (Geurin et Cie.) superfine body	65·61	23·07	0·65	0·80	tr.	2·94	2·72	4·50	—
	Limoges (Geurin et Cie.) ordinary body	66·00	22·59	0·36	1·68	—	2·71	1·80	5·59	—
	Vierzon heavy porcelain	63·48	25·00	0·51	1·06	—	2·26	1·19	6·76	—
	Hal (Belgium) heavy porcelain	63·95	25·59	0·69	tr.	0·54	2·07	0·98	6·62	—
	Berlin table porcelain	63·07	24·67	0·59	—	0·40	4·25	—	7·00	—
	Japan	74·53	16·09	1·03	0·06	0·25	4·37	1·19	2·83	—
	,,	71·31	19·74	0·73	0·17	—	4·04	0·10	4·01	—
	,,	71·60	18·71	1·19	tr.	—	4·16	0·18	4·68	—

By comparing the foregoing numbers, Seger recognized four types of porcelain: (1) Sèvres porcelain; (2) heavy French porcelain, Hal porcelain, and Berlin porcelain; (3) French porcelain of superfine quality, and (4) Chinese and Japanese porcelains.

The respective compositions of these four types group themselves more clearly if Seger's average figures are taken for the burned bodies.

	Silica.	Alumina.	Iron Oxide.	Lime.	Potash.	Soda.
Type 1	59·6	32·6	0·6	4·5	2·0	0·7
,, 2	67·8	26·7	0·7	0·8	2·9	1·1
,, 3	69·1	24·0	0·7	1·6	2·3	2·3
,, 4	75·5	19·0	1·0	—	4·3	0·6

The comparison may be facilitated by representing the composition by the symbol mRO, R^2O^3, $n SiO^2$, in which mRO represents the fluxes (lime, magnesia, potash and soda), R^2O^3 the alumina and iron oxide, taken together, and $n SiO^2$ the proportion of silica.

Under these conditions, these typical porcelains correspond to the formulæ:—

Type 1	0·30 to 0·35RO, R^2O^3, 2·8 to 3·5SiO^2
,, 2	0·20 ,, 0·30RO, R^2O^3, 4·2 ,, 4·8SiO^2
,, 3	0·40 ,, 0·45RO, R^2O^3, 4·8 ,, 5·3SiO^2
,, 4*a*	0·40 ,, 0·45RO, R^2O^3, 5·5 ,, 6·0SiO^2
,, 4*b*	0·30 ,, 0·40RO, R^2O^3, 6·2 ,, 7·4SiO^2

At the high temperature at which porcelain is burned, the silica becomes a fusible element, hence the foregoing bodies are in the order of their fusibility. According to Vogt, the Sèvres body, which is the most refractory, is burned at Seger cone 15 and the Chinese bodies at cone 12.

The following table, based on rational analysis and on the calculations on page 432, is interesting:—

	Calcium Carbonate (Chalk).	Soluble in Sulphuric Acid.		Insoluble in Sulphuric Acid.	
		Alumina Hydro-silicate (Clay).	Impalpable Mica.	Quartz.	Feldspar.
Type 1	6·47	59·80	6·57	12·05	15·11
,, 2	—	48·89	6·28	24·34	20·49
,, 3	—	40·99	4·13	23·87	31·01
,, 4	—	33·13	9·56	42·60	14·71

Vogt has shown by experiment that the impalpable mica possesses a plasticity analogous to that of the true clay, and the high proportion of this material often found in Oriental porcelain bodies explains in some measure their remarkable plasticity; it must also be admitted that the alumina hydrosilicate in the kaolins from China and Japan is more plastic than that in the European china clays. Attempts have been made to produce European bodies as plastic as the Oriental ones by adding to them a certain proportion of plastic clay, but this result has only been obtained at the expense of their whiteness and translucency.

The raw materials used in France are principally the feldspathic clay from St.-Yrieix, with the addition of a quartzose stone found in the same beds, and a little grog obtained by powdering biscuit porcelain. In some cases, a little marble or chalk is added. In Germany and Austria, where the china clays contain very little feldspar, a special mixture of china clay, feldspar and quartz must be made.

The glazes employed for hard porcelain are silicates of alumina and other bases, principally lime and alkalies. According as the alkaline earthy bases or alkalies preponderate, the glaze is calcareous or alkaline (feldspathic).

The following table shows the chemical composition of some of the glazes :—

	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Potash.	Soda.	Loss in the kiln, etc.
Pegmatite used at Sèvres .	70·64	16·87	0·73	1·31	0·20	4·22	4·97	0·34
Pegmatite used at Limoges	76·11	14·61	0·66	1·44	0·42	2·99	3·03	1·23
,, ,, ,,	75·99	14·80	0·37	1·09	0·36	4·31	3·49	0·65
Glaze used at Berlin . .	73·24	13·97	0·31	2·57	0·51	4·81	1·71	3·83
Japanese glaze . . .	61·97	12·92	0·39	9·59	tr.	4·17	1·12	10·21 (1)
,, ,, . . .	64·96	12·74	0·80	8·78	tr.	1·95	2·30	9·35 (2)
Chinese sea-green glaze .	64·80	14·33	1·39	10·09	1·55	5·61	0·81	1·39 (3)

(1) 0·30 of phosphoric acid is included in it.
(2) 0·16 of phosphoric acid is included in it.
(3) Titanic acid.

The first analysis is by M. Vogt, the other six by Seger.

The first four glazes are alkaline, the last three calcareous ones; they may be represented by the following formulæ, in which RO indicates the fluxes, R^2O^3 the alumina and iron oxide :—

Pegmatite used at Sèvres .	$1{\cdot}0RO$,	$1{\cdot}07R^2O^3$,	$7{\cdot}45SiO^2$.
,, ,, Limoges	$1{\cdot}0RO$,	$1{\cdot}00R^2O^3$,	$8{\cdot}91SiO^2$.
,, ,, ,,	$1{\cdot}0RO$,	$1{\cdot}24R^2O^3$,	$10{\cdot}84SiO^2$.
Glaze used at Berlin . .	$1{\cdot}0RO$,	$1{\cdot}12R^2O^3$,	$9{\cdot}58SiO^2$.
,, Japanese . . .	$1{\cdot}0RO$,	$0{\cdot}55R^2O^3$,	$4{\cdot}42SiO^2$.
,, ,, . . .	$1{\cdot}0RO$,	$0{\cdot}59R^2O^3$,	$5{\cdot}04SiO^2$.
,, Chinese . . .	$1{\cdot}0RO$,	$0{\cdot}52R^2O^3$,	$3{\cdot}82SiO^2$.

The relative proportion of silica and alumina varies little, but there is double the amount of fluxes in the Oriental glazes, which accounts for their greater fusibility.

In France, pegmatite from St.-Yrieix is almost exclusively used as a glaze. It closely resembles a mixture of feldspar, quartz and china clay. Its fusibility may be regulated by the addition of quartz.

In Germany and Austria, the glaze is composed of a mixture of the last three substances. In those countries for a long time, and even now to a great extent, calcareous glazes were used, the lime being introduced in the form of marble, chalk or whiting or as a burnt sulphate of lime. The following are some of these compositions (Prossel) :—

Quartz	34·5	32·0	27·0	50·0	44·0
China clay	9·5	7·0	8·0	37·5	30·0
Feldspar	32·5	37·0	32·0	—	—
Carbonate of lime	12·0	11·0	16·5	12·5	—
Sulphate of lime	—	—	—	—	13·5
Grog (biscuit porcelain)	11·5	13·0	16·5	—	12·5

In the East, the glaze appears to be made of a stone similar to pegmatite (Cornish stone) finely powdered and diluted in milk of lime.

The calcareous glazes are usually more transparent and penetrate into the body better than the alkaline glazes, which are more milky and need to be applied in a thicker layer. But, as the latter give a more velvety and agreeable appearance to the porcelain, they are generally preferred. The burning of the body and the glaze is done simultaneously, so that there must be a complete agreement between the temperature needed for vitrifying the body and that for burning the glaze. The foregoing analyses show the ordinary limits within which the respective proportions of alumina, silica and fluxes may be varied to attain this end.

The body is always prepared in a slip state. The china clay is first sorted and carefully washed, unless bought ready for use as is now customary ; the quartz and feldspathic rocks are also sorted and then ground to powder. As stated on page 92, the body may be prepared by two methods. In the first, the measuring is done when the materials are dry and they are afterwards mixed with water and ground, while in the second, the measuring takes place when the materials are in a liquid state, as they have been separately mixed with water before or after grinding.

The first method is used at Limoges ; the second in England, Germany, and Austria. Whatever the method of grinding and measuring, the liquid body (slip) is afterwards sifted, submitted to the action of electric magnets to remove any iron particles and is then made into a firm cake in a filter press. These moist cakes are placed in cellars, where they are kept for some time before being used. In some cases, the bodies are prepared in special factories.

Previous to moulding, the cake of body is put into a kneading machine, water being added to it if necessary to get rid of any air-bubbles it may contain (see pp. 99 and 100).

The moulding of porcelain presents much greater difficulties than that of any other ware, as the body, which is nearly always a very short one, lends itself very badly to all methods of moulding based on the use of a plastic material. Then, as the ware softens in the firing, and consequently tends to collapse under its own weight, it is necessary to give it a variable thickness, strengthening the parts on which they will rest in the kiln and diminishing the other parts. Lastly, on account of the considerable shrinkage which takes place during vitrification, porcelain tends to lose its shape if the body of which it is moulded is not of an absolutely uniform density in all its parts. It is often sufficient to compress the body, even only with a touch of the hand, to make the ware warp. Nevertheless, the methods already mentioned (Chapter V.) may be used for moulding porcelain, if the following precautions are taken:—

Throwing can only produce a rough form, because the low plasticity of the body necessitates the walls being of an undesirable thickness. The ware must, therefore, be finished off by the body being turned when partially dried, or even when quite dry. As the quantity of body to be taken off during this latter operation is large, many scraps are formed, and are used again. A thick dust is also obtained which is inconvenient and injurious to the health of the workman, who must wear a mask and be provided with a good mechanical ventilator.

Expression is made difficult by the low plasticity of the body and so is seldom used, except for taps, or for special pieces.

Moulding by hand in plaster moulds needs special care so as to press the body equally into all parts of the mould and in making the joints. The batts of body must themselves have been made with equal care and they should be cut out in such a way as to correspond exactly when put together with the mould. They should be made on a cloth or piece of damp leather (p. 124) which is used to lift them and convey them to the mould. When they are in a suitable position, the cloth is taken away, and the body is pressed lightly by means of a sponge, any necessary joints being made at the same time. The body being dried, this moulding is followed by a trimming, in which the ridges are removed, the edges are rounded, etc. This operation also produces a large amount of dust, and may need the use of the same methods of prevention of disease as the turning.

Moulding on a jolley is the most usual method of working porcelain, as it is not only the most convenient, but because most of the porcelain goods are of a shape which lends itself to it. It is always preceded by throwing a batt for flat pieces; covers for hollow ware are made on the wheel, giving them a very regular form and smoothing the surfaces, as this is an indispensable condition. The batt, or shape, having been applied on or in the mould, it is pressed down by means of a sponge beginning at the centre. For narrow vases, into which the hand cannot be placed, the sponge is fixed on a stick.

The piece having thus taken its definite shape from one side of the mould, the other face can sometimes be simply moulded by the sponge, but it is usually necessary to have a second special moulding. In Britain, Germany and Austria, this is chiefly done with templets as already described (pp. 124 and 388). In France, the stiffened body is turned on vertical or horizontal lathes according to the shape of the pieces, the body being still in the mould, though some pieces can wait until they are sufficiently dry to be put direct on to the wheel. Each method has its own advantages and disadvantages; the second one makes pieces better as to quality, but needs very skilful workmen.

For flat pieces, the following method of *jiggering* may also be used. It was invented by Faure at Limoges and allows all open hollow goods to be moulded on the jigger with templets. There are four operations:—

(1) Making the batt.
(2) Putting the batt in the centre of the plaster mould.
(3) Making the outside shape with a templet.
(4) Turning the edges.

As already stated, the batts are moulded on a skin stretched over a copper ring, and fitted on to the head of the machine (see p. 124). In the centre is placed a lump of clay of a definite size, and the machine is set in motion; the templet descends and ascends automatically. The batt, when finished, is taken up with the skin and the disc, and the whole is placed under the circular plate of the shaping machine. This plate is lowered in such a way as to place the batt on the plaster mould; it is then taken off by putting between it and the leather a wooden knife. The plate is raised, the wheel started by leaning on the pedal, and the batt is pressed on to the mould with a sponge, working from the centre to the circumference, to prevent any air remaining between the mould and the batt.

The mould is then placed on the head of the jigger (Fig. 302) and the latter is started by depressing the pedal at the left. A tool first starts from the centre and going outwards forms the bottom, then it is raised to shape the foot, and descends again along the edge. This kind of forming being finished, a second tool, which is really a templet, is lowered and gives the final shape.

This machine makes about sixty plates an hour. It may be used to obtain all round forms (plates, dishes and shallow bowls) by regulating the course of the templet by means of an upper screw and by using templets with different profiles. A more modern machine for the same purpose is shown in Fig. 303.

The ware thus cut by the templet is finally placed on a third wheel, where the edges are rounded off and made thinner.

Faure also constructed a machine, shown in Fig. 304, for making oval dishes. The batt having been made as described, is shaped by means of a plate balanced and guided by two stems; then, this plate having been raised again, the frame carrying the templets is made to revolve; these are put in contact with the batt, and the wheel, which is furnished with an arrangement to give it an oval motion, is started. The templets are arranged as in the preceding machine, but with this difference, that the part of the templet which forms the edges is moved with a slightly oscillating motion, made necessary by the greater width of the edges on account of the large axis of the dish, as this

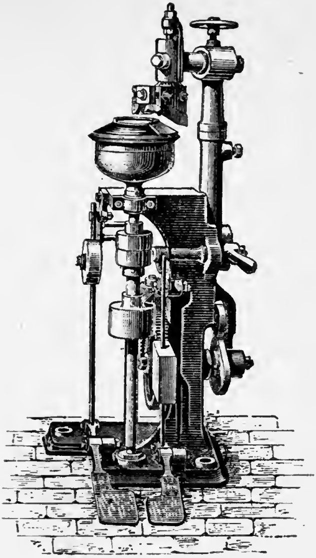


Fig. 302.—Jigger for plates.

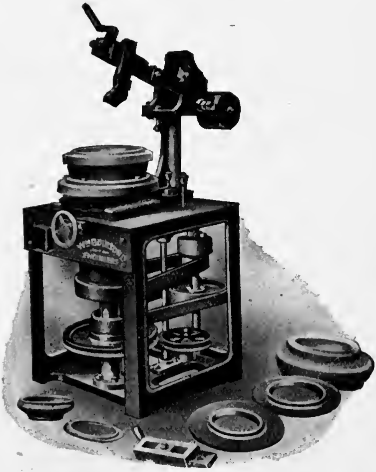


Fig. 303.—Flat-ware jigger.

necessitates the inclination of them being modified. This oscillating motion is transmitted to the templet by a series of levers worked by a roller, under which turns the rim of a large plate placed under the mould. This rim has various heights; being raised more in the parts which correspond to the long axis, so that it raises the roller progressively to let it ascend again and thus modify the slope of the templet.

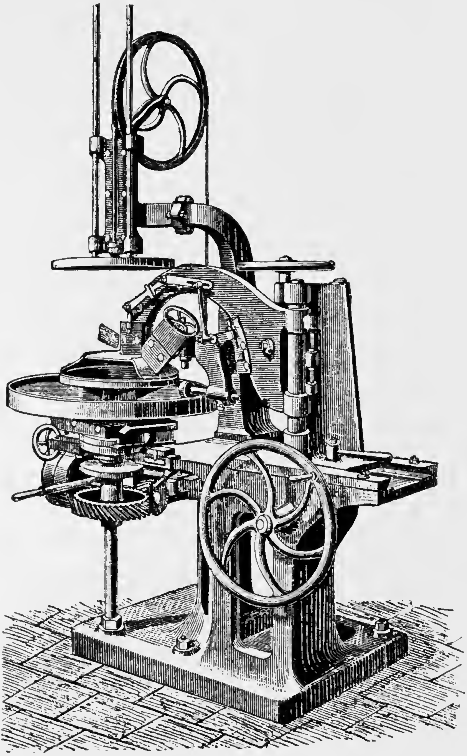


Fig. 304.—Jigger for oval ware.

Moulding in a press is only used for small objects. The body is first thrown or shaped by hand and is then compressed between two plaster moulds. The stiffened body may be repressed if desired.

Moulding by casting is very suitable for lean bodies such as porcelain, and it is largely used for making objects with thin sides which it would be difficult to obtain with any other processes. This method of fashioning them is described on page 132. The thickness of the body can be varied by diminishing the absorption of the plaster in certain parts, or by adding a little body by hand while the piece is still in the mould.

The *finishing* of porcelain is more important than in any other ware. The different operations that it needs are described on page 134.

The drying, burning and application of the glaze to thin and porous pieces such as porcelain bodies does not present any special difficulty. They are usually dried in the places where they are moulded, which are provided with heating apparatus, though artificially heated drying-sheds similar to those employed in faience works may be used, especially for drying the moulds.

In order to facilitate the application of the glaze, the bodies are first fired at a temperature of 800° C., using the waste heat from the glost kilns. The body must be guarded from too high a temperature, which would diminish its porosity too much, and so make it incapable of fixing the glaze. The first heating is done in saggers, the pieces being packed in bulk until filled.

The biscuit ware so produced is carefully brushed and then covered with glaze. This latter is in the form of a slip, of a consistency which may be varied according to the thickness of the layer desired. It is nearly always applied by dipping; only very fragile pieces being sprayed or dusted. The layer of glaze in contact with the porous body dries rapidly and after a short time the goods may be taken to the glost kiln.

Burning.—Round kilns with up-draught and heated by wood were, for a long time, exclusively used for burning porcelain. The wood was later replaced by coal, and down-draught kilns substituted. Fig. 152 shows the arrangement generally used at the present time. The dimensions of these kilns vary greatly, but in order to obtain a suitable distribution of the heat it is wise not to have the interior diameter more than 16 to 20 feet. The height of the burning space should be a little less than the diameter. The number of fireplaces varies from three to eight.

Fig. 153 represents a kiln of the same kind, but in this the second chamber is below the fireplace, thus necessitating an independent chimney. This type of kiln has several theoretical advantages over the preceding one.

The slow firing is relatively short and easily managed on account of the very small amount of moisture in the goods. The same applies to the hard firing, up to about 1200° C. From that time, the atmosphere of the kilns must be reducing in order to avoid a yellow colour due to the peroxide of iron in the body and which should be replaced by the slightly bluish colour of the protoxide. This reducing action would not be difficult if there were no risk of the hydrocarbons diffusing through the walls of the saggers (see p. 235) and, by decomposing, leaving a deposit of carbon on the ware. When the vitrification takes place, this carbon would be incorporated in the mass and would give it a red smoked colour. When, in the course of the burning, it is noticed that the atmosphere in the kiln is clouded by the presence of these hydrocarbons, which have a tendency to accumulate under the dome at the place where the circulation of the gases is least active, the reducing action must be stopped for a time, and the fires made oxidizing to burn up the deposited carbon. The firemen call this "washing" the kiln.

It is not easy to find the true mean between an oxidizing atmosphere or a neutral one and an atmosphere which is excessively reducing, especially where the fireplaces are difficult to regulate. It is also very necessary that the atmosphere of the kilns should be as uniform as possible, that there should not be parts where it is extra reducing. This condition can only be obtained by a rational arrangement of the fireplaces. It is equally indispensable that all the burning space should be under pressure to prevent air leaking in through cracks in the walls. For this reason, the openings for letting off the gases are made of rather narrow section, and the flues for the smoke are made wider.

The dimensions of the grates depend upon the volume of the burning space, and especially on the fuel; so that it is impossible to give precise directions in relation to them. As a general rule the fireboxes used are too small. The duration of the burning varies from eighteen to thirty-six or even forty hours. Naturally, it pays to hasten it as much as possible, without passing certain limits necessitated by the sensitiveness of fireproof materials to a rapid rise in temperature.

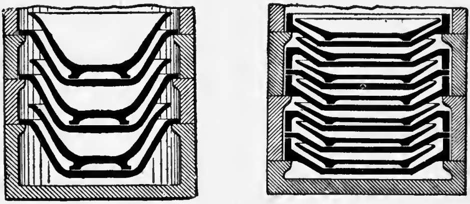
The first part of the cooling should be in a reducing atmosphere, until the glaze is solidified. After that, the atmosphere may be neutral, and below 800° C. it may be oxidizing without any bad effects.

The thermic balance sheet in this class of kiln may be set down as follows:—

Heat produced by combustion .	100	Heat theoretically needed . .	10
		Heat used in the furnace . .	6
		Heat lost in heating saggers .	38
		Heat lost by the heating of the walls	12
		Heat lost by radiation . . .	10
		Heat lost through the chimney .	20
		Heat lost by the reducing atmosphere	1
		Heat lost by incomplete combustion	3
	100		100

At the chief Berlin manufactory a continuous kiln, constructed on the Mendheim system and represented in Fig. 290, has been used for a long time. As the general working of continuous kilns is always decidedly oxidizing, it has not been possible in this kiln to get the powerful reducing atmosphere necessary for burning porcelain, except by various expedients, the principal one consisting of rather rapidly cooling the compartment in which the burning has just been finished, so as to solidify the glaze and thus protect the body against the oxidizing action of the air. The results attained by this kiln are, for this reason, only partially satisfactory for porcelain, and for this class of ware it seems unlikely that, in the present state of the porcelain industry and of the knowledge of industrial physics, burning in a continuous kiln can be used to any great advantage. The reader interested in this subject is referred to the argument used in burning faience (p. 396), but the economy would reach scarcely 10 or 15 per cent, and would be counterbalanced by the annoyances of a much longer burning and important modifications in existing factories. It would be better to copy the Chinese and use semi-continuous kilns. The author believes that more progress may be made by better construction of the present single kilns, and by using gas instead of solid fuel.

Saggering is the great trouble in burning porcelain, as nearly all the pieces have to be supported separately, so that it is necessary to use supports in the saggers; this increases the dead weight as compared with the useful weight. The high temperature at which they are burned necessitates the use of the saggers and supports made of fireproof materials of superfine quality and the wear and tear of them is very considerable. As the dead weight is usually four times the weight of the pottery, and the supports must be set so that the ware will not get out of place, it is easy to understand the importance of saggers in the manufacture of porcelain.


Figs. 305 and 306.—Methods of saggering.

The piles of saggers are arranged in the kilns in the same way as when burning faience, but the saggering is entirely different. In theory, each sagger is composed of an outer part, usually circular, and of an article suspended inside, so that there is only one piece in a sagger. Fig. 305 shows an arrangement of this kind. For very flat objects such as plates, three pieces may be placed in a sagger, by using the arrangement shown in Fig. 306. In these two examples, some of the wares rest on their feet, the lower surface of which can remain unglazed without any disadvantage. They can be prevented from sticking by powdering the bottom of the sagger with a little quartzose sand, or by smearing the parts in contact with a little fireclay. In special cases it may be better to put the objects on their upper edges, but these edges, being necessarily left without glaze, should afterwards be gilded. Larger pieces, or those in which the foot is too small, should be supported to prevent them getting out of shape or sinking down. The parts in contact with the supports must remain unglazed, and be decorated later. In some cases the ware must be held up from the inside by means of pieces or supports of unburned body, which can, naturally, be used only once. For goods of very large dimensions, it is necessary to construct muffles in the kiln, these being sometimes placed on the top of several piles of saggers.

Such is a very brief summary of the principles of saggering porcelain. The application of them needs much practice, much care, and the knowledge of many special expedients.

Burned ware, the foot of which is slightly out of shape, may be trued up on rapidly rotating horizontal plates of cast-iron, covered with sand and water, similar to those used for polishing stove tiles. Polishers are also used for removing small grains of sand or pieces of the saggers which fall on to the ware while it is being burned and become incorporated in the glaze. These polishers, like those used in glass-making, are of hard stoneware, or of a mixture of porcelain body and quartz which has been heated thoroughly.

The Decoration of hard porcelain presents special difficulties. For *decorative moulding*, the slight plasticity of the body makes it very difficult to manufacture many objects, the execution of which would on the contrary be relatively easy in faience or stoneware. The Chinese discovered some expedients in moulding, but the body they used is more plastic than ours, and labour is cheaper.

Decorating with colour presents difficulties of another kind, as on account of the high temperature at which the burning must take place there is only a small number of colouring materials which can be employed.

The body may be coloured by the following materials:—

Blues.—Cobalt oxide, the shade being modified by a mixture of chrome oxide or uranium oxide. It is necessary to frit the cobalt oxide with zinc oxide before mixing it with the body.

Grey.—Iridium oxide and platinum. The tone can be improved by adding cobalt oxide.

Yellow.—Uranium oxide.

Browns.—Mixtures, in various proportions, of iron chromate and manganese oxide.

Rose.—Mixture of alumina and chromate of potash, first heated in the hard fire with an oxidizing atmosphere, and afterwards added to the body.

The introduction of these colouring materials into the body has the effect of varying its fusibility, and it is necessary to modify its composition by the addition of china clay or feldspar.

Under-glaze colour is little used on account of the small number of colours which can be employed. Only one, cobalt oxide, is much used, though the oxides of uranium, chrome and iridium, a mixture of chromate of iron and manganese oxide, etc., might also be employed. These oxides are generally mixed with the body, heated in a hard fire, and then put on the biscuit. It is then necessary to fix the colour by warming the body before the glaze is applied. Generally, the colours thus obtained are rather dull, as no glaze is completely transparent.

It is difficult to apply the colour to the unburnt glaze and this process is seldom employed.

Over-glaze colouring may be obtained on *hard fired ware* by putting the colour on the vitrified glaze and heating it a second time in saggers, with an ordinary burning. The colours thus used have a flux (ordinary glaze modified by the addition of some alkaline-earthy bases) added to them.

Theoretically, in order to prevent the action of the flux on the colour, it is necessary to combine a protoxide with a sesquioxide. The colour may then be represented by the formula RO, R^2O^3, in which RO represents a colouring protoxide or an alkaline-earthy base, and R^2O^3 alumina or a colouring sesquioxide. The most popular combinations of this kind are:—

Aluminate of cobalt	CoO, Al^2O^3.
Aluminate of zinc and cobalt	$\left\{\begin{matrix} ZnO \\ CoO \end{matrix}\right\} Al^2O^3$.
Aluminate of chrome	CrO, Al^2O^3.
Chromate of cobalt	CoO, Cr^2O^3.
Chromate of iron	FeO, Cr^2O^3.

These compounds, having been heated in the hard fire, are ground and mixed with a flux. Very stable oxides, such as those of titanium, uranium, platinum, iridium, may be used direct.

The colours thus obtained are black, blue of different shades, emerald green, yellow, various browns, rose, brick red. This method of decoration in the hard firing, though lacking the brilliancy of transparent faïence enamels, is of a much richer and more brilliant colour than that obtainable with muffle firing.

Over-glaze colouring with muffle firing is, however, much more used. It is based on the employment of vitrifiable colours mentioned on page 262, the burning being done in a muffle at the test for gold.

These vitrifiable colours are usually manufactured in special works, and can easily be procured in commerce, though some factories prepare them themselves. The colouring oxides are mixed with fluxes; the following being the composition of the principal ones, with the names given to them in the vitrifiable colour trade:—

Rocaille Flux.

Lead oxide	75
Silica	25

(Used for blues and for reds from iron.)

Flux for Carmine.

Red lead	11
Silica	33
Melted borax	55

(Used for carmine and light purple.)

Flux for Violet.

Red lead	67·5
Silica	5·0
Melted borax	27·5

(Used for violet.)

Flux for Turquoise.

Red lead	35
Melted borax	65

(Used for turquoise blue, sea green.)

Flux for Greys (1).

Red lead	66
Silica	22
Melted borax	11

Flux for Greys (2).

Red lead	60
Silica	15
Melted borax	25

(Used for greys, yellows and light browns.)

Flux for Purple.

Red lead	37·5
Silica	12·5
Melted borax	50·0

(Used for purple and the violets made from gold.)

Flux for Green.

Red lead	73
Silica	18
Melted borax	9

or

Red lead	70
Silica	10
Melted borax	20

(Used for chrome greens, blue greens, and yellow greens.)

At the low temperature of muffle firing, any colouring oxides may be employed. The colour is applied either with a brush or else by chromo-lithography (p. 263).

The type of muffle kiln in general use is shown in Fig. 168. For large quantities a series of muffles side by side are sometimes used, so as to obtain a heating with continuous or semi-continuous firing. For small quantities, or for heating pieces that need special care, little muffles as shown in Fig. 307 are used.

The atmosphere in a muffle is always decidedly oxidizing.

(*b*) *Refractory or Fire-proof Porcelain.*

This name includes porcelain objects used for heating liquids in chemical industries, in laboratories, and for domestic purposes, such as basins, retorts, crucibles, tubes, stewpans, dishes, coffeepots, etc.

The composition of the body scarcely differs from that of the other hard porcelains, but it is often less silicious and more aluminous. For example, the refractory porcelain, from Bayeux, which is much valued in France, is composed of—

Silica	61·61	per cent.
Alumina	30·01	,, ,,
Oxide of iron	1·56	,, ,,
Lime	3·56	,, ,,
Potash	3·26	,, ,,

This body, when burned, is less translucent than that of table-ware porcelain, but it resists sudden changes of temperature better. It should be made of a plastic china clay, or by the addition of a certain proportion of plastic clay to a leaner one. It is manufactured as has just been described, but the more plastic body lends itself better to moulding. As many of the objects must be thin they are frequently cast (p. 132).

(*c*) *Porcelain for Electrical Insulators.*

The non-conductibility of porcelain makes it valuable for making insulators for electrical purposes (Fig. 308). The bodies employed should be rather plastic, so as to be readily moulded into complicated shapes, the translucency being quite a secondary matter. They are usually cast in a mould and repressed, when stiffened, in lever presses.

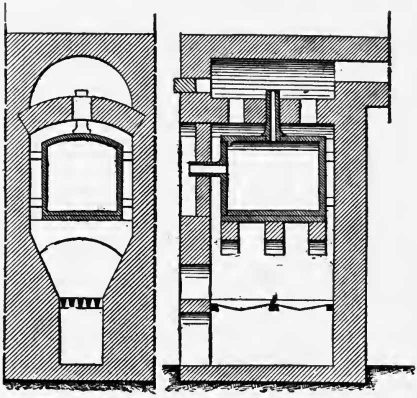


Fig. 307.—Muffle kiln.

The filleted parts are sometimes finished on the lathe, as for some purposes it is necessary for them to be so exact that they may fit other machinery.

The manufacture of these goods is a speciality of some factories in Germany, France and England.

(*d*) *Porcelain for Mechanical Purposes.*

The hardness of porcelain and its resistance to cracking permit it, in some cases, to be employed for mechanical purposes, principally for grinding, as porcelain mortars, and for lining ball mills and Alsing cylinders. As it is necessary to have a very hard article of accurate shape, this kind of porcelain is made as just described for the porcelains used for electricity. After being moulded, the stiffened body is repressed in hydraulic presses. The burned ware is turned to shape very exactly by means of emery or black diamond, the only materials available whose hardness is greater than that of the porcelain.

There are still many other cases in which the remarkable qualities of hard porcelain could be used with advantage in machinery.

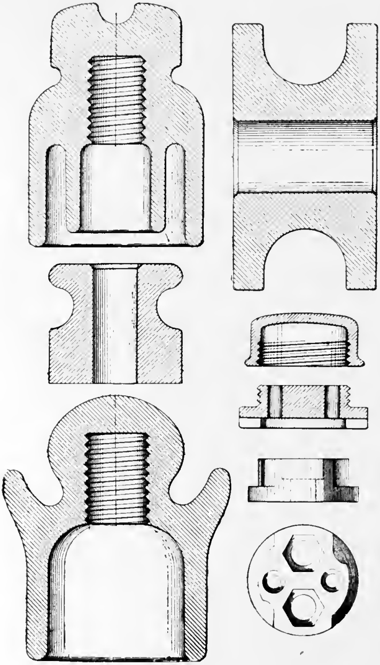


Fig. 308.—Electrical insulators, etc.

(*e*) *Architectural Porcelain.*

The Chinese used porcelain in architectural decoration and even in the construction of walls as far back as 954 A.D., though this material is not suitable for making thick articles in consequence of its great shrinkage and its cost.

For architectural decoration, porcelain may be used, but has no advantage over stoneware, while its high price and the difficulty of making it are serious drawbacks. Extreme hardness and translucency, which make hard porcelain the most perfect material for table-ware, lose their importance in monumental pottery.

(*f*) *Dull Porcelain* (*Biscuit Porcelain*).

The body of hard porcelain may, naturally, be without a glaze. It is then called "biscuit" porcelain, though this term is unsatisfactory.

The most plastic porcelain body, called "body for sculpture," is used. It has a composition similar to that used at Sèvres.

Seger recommends a body formed of 54 parts of Zettlitz kaolin, 45 parts of Norwegian feldspar, and 1 of marble, mixing 30 parts of the burned mass (grog) to 70 parts of the raw body. The burning should take place at Seger Cone 9.

The moulding, saggering and burning of these dull porcelains are done in the same manner as for glazed porcelain. The only thing to be noticed is that the body must remain dull and not commence to vitrify, which would give it a disagreeable, greasy appearance.

2. *Bone China, or English Porcelain.*

The only kind of tender porcelain of any industrial importance is phosphated porcelain or bone china, manufactured almost exclusively in England. This porcelain requires a much lower temperature for burning than hard porcelain, and consequently is less costly and easier to decorate. The body is moderately translucent and milky white, resembling alabaster. Its chief disadvantage, which hinders it being made outside England, is its lack of hardness and its low durability. It is very curious that the English prefer this porcelain when hard porcelain could be so easily manufactured.[1]

The body varies somewhat in composition. The following are due to Prossel[2]:—

China clay	30	28	23	—	23	30
Cornish stone	18	30	31	23	27	7
Plastic clay	—	—	—	23	—	4
Quartz	—	—	—	14	—	3
Biscuit (grog)	5	—	—	—	—	—
Calcined bones	47	41	46	46	46	50
Alkaline frit	—	—	—	—	3	6

This frit is composed of—

Cornish stone	56 to 60
Quartz	20 ,, 30
Soda	8 ,, —
Borax	8 ,, 10
Zinc oxide	8 ,, —

[[1] Bourry does not appear to appreciate the special advantages to the potter offered by bone china. These include its plasticity, the lesser difficulties in "saggering," and the wide range of colours available.—A. B. S.]

[[2] W. Burton (*Porcelain*, p. 19) states that the average English bone china is made from 4 parts of bone-ash, 3½ parts of china clay, and 4 parts of china stone; the glaze having a basis of feldspar and china clay rendered more fusible by the addition of borax, lime or lead oxide. The limits of composition are, however, exceedingly wide.—A. B. S.]

Plastic clay is only added to the body to increase its plasticity. It thus makes the goods easier to mould, but at the expense of translucency and whiteness, so that it is only used for making ware of inferior quality. The special characteristic of this porcelain is the large proportion of calcined bones (see p. 39), which are composed chiefly of calcium phosphate, a little calcium carbonate and some magnesia.

The composition of the glaze is very similar to that for feldspathic faience, viz. alkaline boracic plumbiferous.

Frit.			
China clay	34	—	12
Cornish stone	—	38	20
Quartz	14	24	15
Chalk or marble	18	11	18
Borax	34	27	35

Glaze.			
Frit	70	60	65
Cornish stone	9	20	11
Quartz	—	—	11
White lead	21	20	13

The body is made up from liquid slips, though in many factories the raw materials are measured in a powder and not in slip. The body is only slightly plastic and presents the same difficulties in moulding as that for hard porcelain. The most usual methods are casting and jolleying, and, more rarely, pressing by hand in plaster moulds. The first firing is also done in the "domes" (Figs. 152 and 153), the pieces being placed in bulk in saggers. For the best qualities, i.e. those richest in phosphate and alkalies, it is necessary to dust over portions of the surfaces with quartz, to prevent them sticking. The biscuit is burned at the same temperature as that used for feldspathic faience [according to W. Burton, 1250° C.], and the two wares are sometimes burned simultaneously.

As the biscuit is not very porous, the glaze must be rather thick; it is applied by dipping. The thickness of the layer of glaze is less than for hard porcelain.

The glaze firing is the same as for hard porcelain,[1] but the saggering is easier (Fig. 277).

The colouring may be under-glaze as for feldspathic faience, or over-glaze as for hard porcelain. Lithographic printing over-glaze is also frequently employed, the decoration being touched up with vitrifiable colours put on with a brush. The backgrounds may be made by covering the glaze with a lithographic varnish and dusting on some vitrifiable colour. The methods of decoration are more numerous than for hard porcelain and the muffle colours are more brilliant, because the glaze, which is more fusible, agrees better with the vitrifiable colours. Yet all these advantages are acquired at the expense of solidity, so that these decorated English porcelains are objects of luxury rather than articles for everyday use.[2]

The manufacture of English bone china, faience and fine stoneware is concentrated in Staffordshire, where some factories produce all three kinds of ware.

[1] [W. Burton states 1050° to 1100° C.—A. B. S.]

[2] [See first footnote on previous page.]

3. *Soft Vitreous Porcelain* (*French Porcelain*).

This porcelain, sometimes termed "fritted porcelain" or "Reaumur porcelain," was the first to be made in France. Its manufacture was abandoned shortly after the discovery of hard porcelain, but from time to time new attempts at making it are taken up, though they are generally of short duration. This material is not really a ceramic product, but a glass (heated to a temperature which is not sufficient to melt it, but enough to give it a milky transparency, and covered over with another soft glass), though its use, appearance and the processes of its manufacture, caused it to be classed among pottery. The body was composed in the following manner:—

Frit.		*Body.*	
Fontainebleau sand	60·0	Frit	75
Saltpetre	22·0	White chalk	17
Grey sea salt	7·2	Calcareous Argentevil marl	8
Rock alum	3·6		
Alicante soda	3·6		
Montmartre gypsum	3·6		

Only the vitrified parts of the frit were used; these were ground and added to the chalk and marl, then ground again in water, in such a way as to obtain an impalpable paste. This was dried, and made into a paste by the addition of water, green soft soap, and parchment size. Its composition is almost exactly the same as that of plate-glass.

The moulding, on account of the almost entire absence of plasticity, could only be done by putting a thick layer of body into a plaster mould which had the outside form of the object, and compressing it with a plunger, also of plaster, which roughly represents the form of the inside space, only smaller. The dried piece was finished by turning.

The burning consisted, as in the case of faience, of a first heating to vitrify the body, and a second burning at a lower temperature to fix the glaze. For the first burning, the placing in saggers was very difficult on account of the softening and great shrinkage of the body, and articles had to be held up with supports made of raw body, which would shrink the same as the ware.

The glaze was composed of—

Litharge	38
Fontainebleau sand	27
Calcined flint	11
Potash	15
Soda	9

It was melted, ground, made into a slip and put on by pouring. In the second burning, the pieces were simply stood on their bases, either in glazed saggers or in muffles.

The colours, with the addition of a small proportion of alkaline fluxes, were over-glaze, rather brilliant, and harmonized remarkably well with the glaze.

4. *Soft Vitreous Porcelain* (*New Sèvres Porcelain*).

In 1884 the pottery at Sèvres, after many attempts to find a porcelain which would lend itself better to decoration than hard porcelain does, and especially one which would produce a turquoise blue from copper, brought out a new kind of ware, to which the name of New Sèvres Porcelain was given. According to Lauth and Dutailly, the body is composed of—

Frit.		*Body.*	
Sand	77	Fontainebleau sand	49·02
Soda	8·5	Frit	27·45
Saltpetre	16·5	Chalk	16·66
Chalk	18·4	Plastic clay from Dreux	6·86

This composition is similar to that of the preceding porcelain, from which it differs only in a larger ratio of lime to alkalies, and a slightly greater amount of alumina and silica as compared with the fluxes.

The body, although slightly more plastic than that of French porcelain, is still very weak, and the moulding presents some difficulties which are more easily overcome when objects of luxury are manufactured than when commercial products are to be made.

The first burning (at Seger Cone 9) is intended to vitrify the body, and not, as in hard porcelain, to convert it into biscuit. The saggering is the same as for burning glazed, hard porcelain.

The glaze is composed of—

Sand	25·52	or	35·15
Chalk	8·60	,,	7·43
Cornish stone	65·98	,,	7·43
Feldspar	—	,,	57·42

This corresponds to RO 0·64 Al_2O_3 6·77 SiO_2 and clearly distinguishes the new porcelain from the French soft porcelain, the glaze of which is an alkaline plumbiferous one.

It is applied either by dusting or by dipping.

The decoration, which is the essential feature of this class of ware, may be under-glaze, stained glaze, and also over-glaze. The temperature of the glost firing is sufficiently low to allow the production of the blue from copper and of reds from iron.

5. *Argillaceous Soft Porcelain* (*Seger's Porcelain*).

This porcelain has been manufactured since 1886 in the factory in Berlin. Seger's object in seeking a soft porcelain was the same as that followed by the Sèvres pottery when the new porcelain was invented, but the different starting-points led to very different results. The people at Sèvres started with French soft porcelain. Seger took as his pattern Japanese porcelain. The following are the different compositions of the body at which he stopped :—

Plastic clay	31·0	15·5	15·5
Zettlitz kaolin	—	—	13·0
Sennewitz kaolin	—	19·0	—
Feldspar	30·0	30·0	30·0
Powdered Hohenbocka sand	39·0	35·5	41·5

	Pure clay.	Sand.
The plastic clay contains	81	19
Zettlitz kaolin	97	3
Sennewitz kaolin	65	35

The chemical composition is approximately the following:—

Silica	77·0 to 77·5
Alumina	17·0 „ 17·5
Lime	0·30
Magnesia	0·20
Potash	3·75 to 3·80
Soda	0·65 „ 0·70

which can be represented by the formula $0{\cdot}38RO, R^2O^3, 7{\cdot}7SiO^2$, and is almost identical, as to rational analysis, with the composition of Japanese porcelain.

The glaze is similar to that of the Japanese glazes, viz.:—

Sand	27·3	21·0
Zettlitz kaolin	13·0	—
Sennewitz kaolin	—	19·2
Feldspar	42·1	42·1
Marble	17·7	17·7

It corresponds to the formula—

$$\left.\begin{matrix}0{\cdot}7CaO\\0{\cdot}3K^2O\end{matrix}\right\} 0{\cdot}5Al^2O^3,\ 4SiO^2.$$

Seger thus completely imitated the Japanese porcelains from a chemical point of view, but in physical properties Seger's porcelain is less translucent, less hard, more fragile and of a slightly yellowish tint. The body should be plastic enough to lend itself easily to moulding; like hard porcelain, it is heated to convert it into biscuit, then glazed and burned at a temperature sufficient to bend Seger Cone 9. This comparatively low temperature for burning (the same as the new Sèvres porcelain) and its slight hardness, has caused this ware to be placed among the soft porcelains.

6. *Dull Soft Porcelain* (*Parian Porcelain*).

The various kinds of soft porcelain may, like the hard porcelains, be hard fired without any glaze. Up to the present time, only French porcelain has been used for this purpose, and this gives dull ware of beautiful appearance. Dull, phosphated porcelain is less satisfactory, and has been replaced by a special body, which, when burned, has a slightly yellowish colour, with a dull brilliancy, reminding one of the beautiful marble from Paros, whence its name of "Parian".

Parian body is chiefly composed of a mixture of china clay and feldspar; the latter, under the influence of the high temperature, becomes semi-fused, giving the ware a milky appearance. According to Prossel, its composition is[1]:—

Frit.			*Body.*				
Kaolin	11	—	Frit	15	9	—	—
Feldspar	25	—	China clay	39	28	33	37
White sand	58	83	Feldspar	39	42	44	63
Potash	6	18	Cornish stone	—	14	22	—
			Flint glass	6	7	—	—

The body may be coloured so as to produce imitations of ivory or different natural stones, whence the names of "carrara," "malachite," "lazulite," "porphyry," and "obsidian" ware.

The plasticity being so slight makes the moulding rather troublesome, so it is often cast. The ware is fired at the same temperature as phosphated porcelain (bone china), but the shrinkage, as well as the softening of the mass, necessitate the placing being very carefully done, the projecting parts being held up by supports made of raw body.

7. *Dull Feldspathic Soft Porcelain.*

Small objects, buttons and imitations of pearl and agate, are made of this material. This manufacture was invented about 1840 by Prosser, who used the English porcelain body, then simply a mixture of feldspar and bone ash, to which plasticity was given by the addition of a greasy body, which was destroyed when burned.

Bapterosse introduced this industry into France, and by the use of special processes and very perfect machinery entirely "killed" the English trade, and his factory at Briare, with another at Fribourg (Baden), are the only ones which make this kind of ware exclusively at the present time.

The body is formed of feldspar, which is powdered and treated with sulphuric acid to separate part of the impurities (iron oxide). To the purified feldspar is added some colouring oxides, or sometimes a little bone ash or chalk. Milk or an emulsion of caseine in a solution of boracic acid is next added so as to give the material a consistency firm enough for it to be moulded in a press. Five hundred buttons are moulded with one stroke. They are arranged automatically on a sheet of paper, which is used to carry them on to a fireproof plate. This is first heated, so that the paper is burnt up; then the plate is put into a muffle, where it remains for about ten minutes. It is then drawn out, the buttons on it are taken off with one stroke of a rake and it is covered with a fresh sheet of paper. The muffles are arranged to

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[[1] W. Burton (*Porcelain*, p. 20) states that Parian ware was apparently invented by Copeland and Garrett of Stoke-on-Trent, about 1845, and that English "Parian" is composed of one part of china clay to two parts of feldspar. It is fired at 1150° C. to 1200° C. and is sometimes glazed with the ordinary lead glazes used for English china-ware.—A. B. S.]

the number of thirty in a rectangular down-draught kiln. The burned buttons fall into a series of boxes fastened to a pivot, where they finish cooling, and from which they are taken out through a movable bottom. They may be then decorated, if required, by chromo-lithography with vitrifiable colours, or gilded. Cameos and small cubes (mosaics) have also been manufactured by this process.

THE END.

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