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DRYING CLAY WARES

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PREFACE

The following articles which appeared serially in The Clay-Worker were inspired by the fact that there is no published literature on the subject of drying clay wares.

The various treatises on heating, ventilation and drying include only in a small measure data applicable to our clay drying problems. In our engineering work we have collected, modified and applied this data to our special needs, and the articles include such engineering data as we have found useful.

We have tried to make the articles not merely descriptive, nor yet too technical, and hope they will prove of some assistance to both the practical and technical clayworker.

Credit is due Mr. T. W. Garve, M. E., for all the pen and ink drawings and for the chapter on German clayworking plants. We also wish to acknowledge the assistance of Prof. C. B. Harrop, E. M., in numerous discussions of the problems involved and in checking over and correcting the mathematical work.

Credit has been given in the text to all authorities as far as possible, though in many instances the information is from our engineering data and so interwoven with it that it is impossible to trace it to any single authority.

ELLIS LOVEJOY, E. M.

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DRYING CLAY WARES.

By Ellis Lovejoy.

CHAPTER I.

Classification of Clays.

DRYING CLAY WARES is one of the most complex problems with which the clayworker has to deal, and one that is least considered and least understood. We are lacking in a proper classification of clays in their relation to drying and perhaps no accurate classification is possible.

Clays may be roughly classified as follows:

(1) Clays that may be dried in a few hours, starting with an initial high temperature and rapid drying condition.

(2) Clays that may be dried in twenty-four hours or less, starting at an initial low temperature in saturated atmosphere.

(3) Clays that can be dried in twenty-four to seventy-two hours, under conditions of No. 2.

(4) Clays that require over seventy-two hours under conditions of No. 2.

(5) Clays that must be slowly heated up in a saturated stagnant atmosphere before advancing into a moving drying atmosphere.

(6) Clays that cannot safely be subjected to conditions under No. 2 and No. 5, but must be dried slowly, starting under drying conditions.

(7) Clays that cannot be dried under any condition.

There are many clays and shales which will rate as No. 1; clays that can be dried in a pipe rack dryer; that will stand exposure to wind and sun; that can be placed in a periodic dryer in which a maximum temperature is maintained from end to end of dryer.

No. 2 contains a greater number of clays and the progressive dryers in which No. 2 conditions prevail, are the most numerous. No. 2 class shades into No. 3 and No. 4.

There are many tender drying clays that can be dried safely by first heating them in a saturated atmosphere, then moving them into conditions No. 2 and No 4. No. 5 is considered the method par excellence for very tender clays, but we have found some clays that can be safely dried under somewhat trying conditions, provided they are not first subjected to a moist atmosphere—the humidity treatment which prevails in No. 2, 3, 4, and especially in No. 5.

These classes include many clays, but there are many others, perhaps as many, that cannot be dried under any conditions in their raw state, but must first be subjected to some treatment which changes the physical conditions.

A weak point in any classification is that a clay which may be difficult to dry in one kind of ware becomes easy to dry in some other ware. We have frequently found clays which in bricks required thirty-six to forty-eight hours to dry safely, yet in drain tile would dry without a flaw in twenty-four, or even twelve hours. In safe drying, drain tile easily leads the list, then comes sewer pipe in small sizes, simple and small hollow ware especially in clays that laminate, bricks, perforated bricks, complex hollow ware, large sewer pipe, roofing tile, terra cotta, etc.

Water in Clay.

*Water in clay exists in three conditions:

(1) Moisture, (a) free water, (b) water of saturation.

(2) Hygroscopic water.

(3) Chemically combined water.

We might also add colloidal water.

Free water is the water which fills the pore spaces in the clay mass, and which serves as a lubricant, permitting the grains of clay to slip one on another, and gives the mass the mobility necessary for casting or moulding processes. This is the water with which we are chiefly concerned in

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*One authority classifies the water in clay as: Shrinkage water, pore water, hygroscopic water, and combined water. Another classification is: Water of dilution, water of plasticity, hygroscopic water, and combined or chemical water.

drying. When it is driven off the clay mass is rigid; it will no longer flow under pressure, but it still looks wet.

Water of saturation is that water clinging to the surfaces of the grains of clay after the pores have been emptied of their free waters. This water can only be removed by contact with some other substance having greater affinity for the water than that of the clay, or by vaporization from the surfaces of the clay grains.

We say clay wares are bone dry when they come from the dryer, showing no perceptible wetness. Yet we know that in the water-smoking, there is driven off from the dry wares a considerable volume of water vapor. This is hygroscopic water and also colloidal water. We have no hint of its presence either in the appearance or feel of the clay. We often use the expression "dry as dust" to express dryness, but dust contains hygroscopic water.

Combined water is a chemical constituent of clay and only appears when we disintegrate the mineral kaolinite by heat.

To recapitulate: Free water is sensible moisture entrapped in the clay mass, but which may be removed by mechanical means, such as filtering, pressing and capillarity.

Water of saturation is also sensible water removable only by evaporation but at normal temperatures.

Hygroscopic water is insensible and is removed only by evaporation at temperatures above normal.

Combined water is a chemical constituent of the clay minerals and can only be driven off by a destruction of the mineral characteristics.

How Drying Proceeds.

Clay is porous, and when wet, these pores are filled with water. The pores form zig-zag channels or capillary tubes from the center of the mass to the surface. When there is no drying at the surface, there is practically no movement of the water in the pores—osmotic movement not considered. Immediately, however, that drying begins on the surface, the water thus evaporated is replaced by capillarity, draining the numerous minute reservoirs which we call pores. There is no better illustration than a lamp and wick. As long as the lamp contains oil it will be drawn up by the wick by capillarity. When the oil is exhausted, the flow ceases, although there is some oil still clinging to the walls of the lamp. Similarly are the pore reservoirs in a clay mass drained. This is the first stage in drying and the stage in which shrinkage takes place, and if all parts of the clay mass are being drained at the same time, there are no unequal or local strains and the ware does not crack.

It is almost needless to say that the safety of drying during this first stage depends upon the relative rate of surface evaporation and replacement.

If we dip different substances in a colored solution and note the rise of the solution in the substances, we will have a clear idea of how in one clay mass, because of its pore channels, the included water will move from one place to another within the mass faster than in another clay mass with a different system of pore channels, to replace water removed by surface evaporation.

Now if the water is evaporated from the surface faster than it is replaced, there must be cracking to relieve the strains, either that or the wet core must be compressed by the dried and shrinking shell, which is very doubtful. To compress such a core will exceed the power of the strongest press, and clay, however strong, has not such strength. There are undoubtedly some strains introduced. It would be folly to claim that drying proceeds absolutely at the same rate throughout the mass, and whenever the strain exceeds the breaking strain of the dried clay, there must be cracking.

In overcoming minor strains, the physical character of the clay plays a part. Ordinary clays, practically all clays, are made up of a number of minerals—fragments of the rocks from which the clays were derived. If the grains are angular and coarse, they may be loosened, partly pulled out of the imbedding matrix, or under compression will rearrange themselves into greater compactness, in either case relieving the relieving the strain. Also we must admit that clay has some elasticity which will relieve minor strains.

The safe removal of the moisture then depends upon three factors:

(1) The relative rate of evaporation and interstitial movement of the moisture.

(2) The shape and size of the grains which make up the clay mass—viz., the interlocking power.

(3) Elasticity.

Having removed the reservoir water, as above described, there still remains the moisture clinging to the walls of the pore passages—the water of saturation. This can only be removed under the boiling point. Air will take up and hold orating the water by direct contact with it.

This brings us to the border land of the second stage of the drying, or more properly, we should make this the second step in the first stage.

When the drying medium has penetrated to the core of the clay mass, the latter is bone dry, as we say, but there is still the hygroscopic and colloidal water that cannot be removed under the boiling point. Air will take up and hold as vapor a certain amount of water for each temperature. We make this statement advisedly. (Without confusing the discussion with technical matters, let us say the air has absorptive power for the moisture, so, likewise, has other bodies, including clay, and which every body has the greatest absorptive power, will remove moisture from the other. We may say that the clay mass may not become dryer than the drying medium, and air is never absolutely dry. We know that this statement is open to attack, but, relative absorptive powers considered, it is true.)

There is then some moisture remaining, and especially is this the case when we have lining the pore passages various salts common to clay besides sulphuric acid. The latter and calcium chloride are commonly used as dessicators to remove moisture from the air, simply because they have greater affinity for moisture than air. Whatever the cause, some moisture remains in the "bone" dry clay mass which can only be removed by temperatures above the boiling point of water, or of the solution whatever it may be. Sulphuric acid, for instance, is only volatilized at 680 degrees Fahrenheit. The removal of this hygroscopic water is the second drying stage and is done in the kilns—water-smoking.

We are not concerned with chemically combined water, since it is never in the form of moisture, and is only expelled by the breaking up of the kaolin at a temperature of 800 degrees or higher. It correlates with the expulsion of carbondioxide from limestone, or sulphuric anhydride from sulphates, or sulphur from sulphides.

In the water-smoking stage of the drying there is considerable danger. We may generate the vapor so fast that there is considerable pressure, and while it may not rupture the mass as a whole, yet it may loosen the indiviual grains and thus cause a rather punky product which otherwise would have the steel-like ring so much desired. The grains are loosened in their sockets in the matrix and while they may not pull out entirely, yet they cannot conduct the vibratory motion which is essential if the ware is to ring like steel. A cracked bell or a cracked vase will not ring true, neither will a brick ring true that has an infinite number of minute cracks, or loosened grains. This is why steamed bricks are so often rotten.

CHAPTER II.

The Work to Be Done.

WE HAVE SHOWN how drying proceeds. It will be in order next to determine the work to be done and the heat required.

Clays vary in the amount of water they will take up in order to make them plastic. The following table, made up from various sources, gives the percentage of water required for the clays in question:

Missouri Geological Survey.

Brick clay	16—19 per cent.
Fire and potters' clay	15—33 per cent.
Flint clay	15—24 per cent.
Kaolins	18—35 per cent.
Shales	14—25 per cent.

Georgia Geological Survey.

Brick clays	15—30 per cent.
Kaolins	30—45 per cent.
Fuller's earth up to	90 per cent.

North Carolina Geological Survey.

All clays	16—40 per cent.

Illinois Geological Survey.

Paving brick clays	13—17 per cent.
Other clays	15—21 per cent.

Oklahoma Geological Survey.

Shale	10—32	Average	22.5 per cent.
Light burning clays,		"	25.1 per cent.
Fire clays		"	15.1 per cent.
Surface clays,	15—36	"	24.9 per cent.

The amount of water in clay ware depends upon the process as well as the clay. The dry or dust-pressed wares have very little water. In the semi-dry processes, the clay is damp enough to ball up in the hand, and this is the usual condition of the clay for dry-pressed bricks.

Stiff mud processes require more water—from 10 to 25 per cent. of the dry clay. The soft mud has a still higher per cent., and casting processes require that the clay be made up into a thin slip, but as this is absorbed by the plaster moulds, the ware itself has scarcely more water than would be required for soft mud.

In the several processes, but especially in the stiff mud, the softness of the ware has a wide range. Some clays can only be made into stiff mud wares by working them so soft that they easily dent by the fingers in handling them, and paddles or hand clamps are necessary for the handling. Other stiff mud wares are so hard that in bricks, for instance, they may be hacked ten to fifteen courses high. In several plants, for a number of years, stiff mud bricks have been set in the kiln six to ten courses high and dried therein. Experiments are being made, having in view setting the bricks eighteen to twenty courses high in the kiln, making this the maximum height of the setting and drying in the kiln followed by burning, thus eliminating the dryer just as in the dry-pressed bricks. Clays which will stand this setting must be suitable, and naturally will require little water.

In our discussion of the work of drying, we will assume that a standard sized brick weighing five and one-half pounds burned, will contain one pound of free water. This may seem low, but it must be remembered that there are three water conditions that enter into loss in weight in burning—chemical water, hygroscopic water, and moisture. In drying we are only concerned with the moisture.

Many people get the idea that because clay wares can be dried readily at normal temperatures in the open air, that very little heat is required for the drying. We wish to state emphatically that regardless of temperature, a certain number of heat units are required to vaporize water, and this heat must be supplied from some source.

(Note—We wish to encumber this discussion with technicalities as little as possible, and make this note to avoid the criticism of some technicist who concerns himself chiefly with technicalities. Water vaporizes at all practical temperatures. It will take less heat to vaporize water at 60 degrees Fahrenheit than 212 degrees or 325 degrees. First, the water is only heated to 60 degrees instead of 212 degrees or 325 degrees. This is the sensible heat. Second, it requires more heat to maintain the pressure, the greater the pressure.)

We are accustomed to say that air absorbs the vapor, and will continue to use that term. Water will evaporate at any temperature until the requisite vapor pressure for that temperature is reached, and this takes place in a vacuum practically as well as in air or in any gas mixture.

We readily appreciate this in boiler practice, where the temperature of the water must be advanced with every advance in gauge pressure. The same is true of temperatures below 212 degrees, only here the boiler is not in evidence, but the pressure is there just the same. We say the air is saturated, meaning the vapor pressure is satisfied.

For the benefit of those who wish to figure these questions closely, we insert the following table, giving the heat units of vaporization.

32 degrees—1092 B. T. U.
60 degrees—1100 B. T. U.
100 degrees—1112 B. T. U.
212 degrees—1147 B. T. U.
307 degrees—1176 B. T. U. 60 pounds pressure.
324 degrees—1181 B. T. U. 80 pounds pressure.
338 degrees—1185 B. T. U. 100 pounds pressure.
350 degrees—1189 B. T. U. 120 pounds pressure.

We will make use of this table in discussing steam dryers.

To vaporize a pound of water at 212 degrees Fahrenheit, at sea level, 967 B. T. U. are required. This is the heat that disappears—becomes latent. It represents the heat required to keep the pot boiling without any advance in temperature of the water in the pot. One hundred and eighty B. T. U. per pound of water are required to bring the water up to the boiling point from 32 degrees Fahrenheit, or 140 B. T. U. to advance the temperature from 72 degrees to boiling. Add this 140 to 967 and we have 1,107 B. T. U. to vaporize a pound of water at 212 degrees Fahrenheit from 72 degrees Fahrenheit. Let us say 1,100 B. T. U.

We must generate this heat or rob the atmosphere to the extent of the latent heat for every pound of water we evaporate from our wares.

A pound of coal may have from 8,000 to 15,000 (average 12,000) B. T. U., and nearly one pound of coal is required to evaporate ten pounds of water. Ten bricks then require one pound of coal; a thousand bricks require 100 pounds of coal.

But this is only part of the work. We put in 6,000 pounds of clay (1,000 bricks), at 60 degrees Fahrenheit and take them out at 130 degrees Fahrenheit perhaps. This takes 84,000 B. T. U. [6,000×.2 (sp. ht. of clay)×70,] or seven pounds of coal. We put in 800 pounds of iron cars per thousand bricks, which requires 6,260 B. T. U. (800×.11×70), or one-half pound of coal.

We may use 720,000 cubic feet of air in drying 1,000 bricks, or 57,600 pounds, which requires 967,670 B. T. U. (57,600×.24×70) or 80 pounds of coal.

Now we have in round numbers 188 pounds of coal. If the radiation loss is ten per cent., the total fuel requirement is 206 pounds, or practically one-tenth ton of coal to dry 1,000 bricks.*

These figures will be surprising to many, but there are many dryers using a greater quantity. In fact, a half more is common practice, and double is not infrequent. Our figures are on the assumption that we get all the heat from the fuel into the dryer.

If we are drying with steam, we must introduce the boiler losses.

If we use direct heat, we must allow for the loss in the products of combustion, for imperfect combustion, either through too much or too little air, loss in ash, etc. However we may do the work, there is an absorption of heat, and the fuel required to generate this heat will in some factories exceed the fuel used in burning the ware.

The fuel consumption in burning is frequently discussed in conventions, but we seldom hear any mention of the fuel used in drying.

The owners of open yards will often view with envy the modern drying plant of their competitors, its less labor, perhaps less drying loss, but if they could appreciate the fact that the gain is at an expense of ten to fifteen dollars per day in fuel, they would be more content with their old-fashioned process.

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*Note—The above figures are general, but approximately correct for a direct fired dryer. The heat consumption will vary with the method of application and will be considered in detail in the discussion of the several types of dryers.

CHAPTER III.

The Relation of Air to Drying.

WE HAVE USED the expression, "the air absorbs moisture," and yet stated that the air plays no part in absorption. We wish to set ourselves right in this matter and have a clear understanding of it.

Scientists hold that water as vapor is absorbed by air, that it goes into solution just as salt may go into solution in water. Such problems in physical chemistry do not concern us.

From our standpoint of drying clay wares, we may consider that air does not absorb moisture because air is not an essential factor in vaporization.

If we could inclose a cubic foot of air saturated with moisture and then could remove the air, the moisture would remain suspended in the space as vapor.

If we fill a long tube closed at one end, with mercury, and invert it in a mercury bath, the mercury in the tube will drop to about 29″ or barometric pressure. The space above the mercury in the tube is a vacuum. Now suppose we introduce a drop of water in the tube; the mercury will quickly drop, and this fall is not due to the weight of the water, which is insignificant, but to the vapor from the water which fills the upper part of the tube and which exerts a pressure upon the mercury and depresses it, or in other words, partially overcomes atmospheric pressure, which supports the column of mercury. If all the water passes into vapor, the saturation of the vacuum may not be complete, and the introduction of more water will cause further depression of the mercury, but finally a point will be reached when saturation is complete and no more water will evaporate, and no further change will take place in the mercury level. Suppose we now introduce some other liquid. The space is saturated with water vapor, but not with the vapor of this other liquid, and the latter evaporates and the mercury level is still further depressed. The pressure exerted by these vapors is called vapor pressure. If we cool the tube some of the vapor condenses and the mercury rises, but if we raise the temperature, we increase the vapor pressure (volume of liquid vaporized), and the mercury falls. If we introduce air, the mercury still further falls, and additional vapor is taken up in consequence of the greater space, and perhaps in consequence of the introduction of the air.

Suppose we could take a cubic foot of saturated air from a dryer at 60 degrees, and remove the moisture by dessicators, by cooling, or in any way, we would have a cubic foot of rarefied air, but less than a cubic foot at atmospheric pressure. Repeat the experiment at 120 degrees, and our remaining air will occupy a much smaller volume, and at 212 degrees there may be no air whatever.

In other words, while air in a closed space does not interfere with the weight of moisture taken up, and indeed may be in some slight degree an aid, yet in free space the water vapor displaces air and at the boiling point or above the air may be entirely driven out.

From this it will be seen that practically air has nothing to do with evaporation. Evaporation is a function of vapor pressure, and vapor pressure is influenced by temperature.

The part air plays is mechanical, and very important. Referring again to the mercury tube, suppose we have a stopcock in the top of the tube opening into a larger vacuum. When the mercury has reached its lowest level, due to the vapor pressure, if we open the stopcock the mercury will rise and force out the vapor. Closing the stopcock reproduces the former conditions and the water will evaporate as before and force down the mercury. With air we can create a draft and sweep away the vapor as fast as it is taken up by space. If it were not removed, drying would cease when the vapor pressure was attained. As the temperature rises, the vapor pressure increases, and at 212 degrees equals the pressure of the atmosphere. We now no longer need any air because the steam will overcome atmospheric pressure and forces itself out, not because of the air, but in spite of it. Steam will rush out of a boiler with great force, pushing the air away.

If we are working at a low temperature, we must introduce a large volume of air because each cubic foot has space for only so much vapor and must be removed when saturated if the drying is to continue. As we increase the temperature, the capacity to take up moisture increases, and we need less volume to carry it away. Above 212 degrees we theoretically need no air whatever, but in practice it serves as a convenient medium to conduct the heat from the source to the ware. We say convenient—not essential.

The question may arise, does not the volume of air increase with temperature in equal ratio with the vapor pressure, and if so, will there not be required the same volume of air for all temperatures?

Let us glance at this.

The following table from Seger's formula for vapor capacities has been especially calculated for this paper. Seger's formula is:

$$V = 1.293 \times \frac{p}{760} \times \frac{.623}{1+at} = \text{wt. of vapor in kilos per cu. meter of air}$$

$1.293 =$ wt. of 1 cu. meter or dry air at temperature t.
$p =$ tension of vapor at temperature t.
$a = 0.00366 =$ co-efficient of expansion of gas.
$t =$ temperature.
$0.623 =$ specific weight of water vapor where dry air equals 1.

We have changed the formula to pounds, Fahrenheit, etc., and we have assumed an altitude of 800′ or 29″ of mercury instead of 760 millimeters.

Our formula becomes:

$$V=1.293 \times 0.062 \times \frac{p'}{29} \times \frac{0.623}{1+0.002(t'-32)} \times 100 = \text{wt. of vapor in lbs. per 100 cu. ft. of air}$$

The column on the left gives the value of p′ for the several temperatures. In the table itself, the first column gives the temperature; the second column is for 100 per cent. or complete saturation; the third column is 90 per cent. saturation, etc. See table on opposite page.

Now as seen in the second column, in advancing from 100 degrees to 200 degrees, the capacity for moisture increases more than ten times—namely, from 0.292 pounds to 3.024 pounds.

The volume of air increases according to the ratio 1+.002 t to 1+.002 T=1.17.

This is an increase of 17 per cent. in the volume of air, or rather the air is rarefied to this extent while the carrying capacity of equal volumes has increased over 1,000 per cent. About one-eighth of the air volume is required at the higher temperature to do the same work.

We will have occasion to refer to the above table in the discussion of some of the types of dryers.

Having explained the relation of air to vaporization, we shall continue to use the term "moisture absorbed by the air," rather than "moisture in space."

VAPOR CAPACITY OF 100 CU. FT. OF AIR.

p′	Deg. Fahr.	Percentage of Saturation						
		100	90	80	70	60	50	40
0.361	50	0.060	0.054	0.048	0.042	0.036	0.030	0.024
0.518	60 -	0.085	0.077	0.068	0.059	0.051	0.043	0.034 -
0.733	70	0.117	0.105	0.094	0.082	0.070	0.059	0.047
1.024	80 -	0.161	0.145	0.129	0.113	0.097	0.081	0.064 -
1.410	90	0.218	0.196	0.174	0.153	0.131	0.109	0.087
1.918	100 -	0.292	0.263	0.233	0.204	0.175	0.146	0.117 -
2.578	110	0.384	0.346	0.307	0.269	0.230	0.192	0.154
3.425	120 -	0.502	0.452	0.402	0.351	0.301	0.251	0.201 -
4.503	130	0.650	0.585	0.520	0.455	0.390	0.325	0.260
5.859	140 -	0.830	0.747	0.664	0.581	0.498	0.415	0.332 -
7.545	150	1.051	0.946	0.841	0.736	0.631	0.526	0.421
9.628	160 -	1.320	1.188	1.056	0.924	0.792	0.660	0.528 -
10.850	165	1.476	1.328	1.181	1.033	0.886	0.738	0.590
12.180	170	1.644	1.480	1.315	1.151	0.986	0.822	0.658
13.650	175	1.826	1.643	1.461	1.278	1.096	0.913	0.730
15.270	180 -	2.029	1.826	1.623	1.420	1.217	1.015	0.812 -
17.060	185	2.250	2.025	1.800	1.575	1.350	1.125	0.900
19.000	190	2.486	2.237	1.989	1.740	1.492	1.243	0.994
20.260	195	2.631	2.368	2.105	1.842	1.579	1.316	1.052
23.460	200 -	3.024	2.722	2.419	2.117	1.814	1.512	1.209 -

Effect of Lamination on Drying.

Lamination, as we know, is due to the slipping of the clay on itself, forming planes or "slickensides" in the clay mass.

We can hardly conceive a porous plastic mass being slipped on itself without closing up the pores. Where such closing up takes place the effect in drying is serious.

We have said that safe drying can only take place when the water in the mass is brought to the surface as fast as evaporation on the surface takes place.

Now if the clay mass is made up of a series of plates as would be the case when laminated, the passages for the water are broken and closed along the planes of the laminations. In order to dry such masses safely, the rate of evaporation should only be the same as the rate of the passage of the water across the laminated planes. Suppose the evaporation rate should be faster than this, let us say at a rate which would be safe if the clay were not laminated, the water in the outer shell is drawn to the surface at a faster rate than the water can get into this shell from the inner core.

The outer shell becomes leather hard and finally bone dry. In becoming so, it must shrink or crack, and it naturally cracks. The tendency to shrink and the cracking causes the shell to creep more or less on the core and breaks whatever bond there may have been.

The air enters the cracks and begins work upon the second shell and the result is duplicated and a second ring or shell is dried, cracked and loosened from the core. The final dried mass is a series of cracked and loosened concentric shells, or, as we say, badly shattered. In order to make such a clay safe drying, or to get a solid product from it, the first step is to overcome lamination.

Grog.

Lamination is often discussed and we will not enter into it except as it relates to drying.

The usual remedies for lamination are lubrication, grog, lamination bars, etc. Grog plays quite a part in drying as well as in lamination. It reduces lamination simply because of its granular character. It acts as a binder, as a lot of teeth, as a drag to prevent the clay slipping on itself. To serve this purpose it must be relatively coarse and angular. Its effect on drying is first to increase the pore space so the water will flow faster to the surface; second, to reduce shrinkage, thus reducing the degree of strains; third, it increases the strength of the clay because of its binding action and enables the clay to withstand the strains. The coarser and more angular the grog, the better it serves as a binder, and the larger the pore spaces.

Sand, which is most commonly used as a grog because it is most available, is far from the best material. It is deposited from the water, and in consequence it is made up of rounded instead of angular grains, through the rolling and tumbling it gets from its source to the final deposit. The density and smoothness of the surface of the grains do not permit the plastic clay to cling as closely to it as to a rougher and more porous material. Finally in the burning there can be no bond between the clay and the sand except at high temperature, but this does not concern us in the drying problem.

Crushed quartz or quartzite is a better material than sand because of its angular character, but this is available in very few yards.

The best grog is crushed burned clay, and often there is enough waste about the plant to make sufficient grog. Another good material is crushed clinkers from the kiln and boiler furnaces, but it can only be used in common wares.

Such materials have the advantage of being rough and angular, and in drying have the further advantage of being porous. If we have lamination planes bound together with a lot of porous grog, the water can get across through the binding material if it cannot find its way through the interstitial spaces.

The porous grog, because of its pores acting as a lot of suckers, draws the plastic clay into close contact and forms a much better bond than could exist between clay and sand.

Where sand suffices nothing further need be said, but where sand fails, as it often does, it is well to know that there is a much better material.

Preheating Clay.

Prof. A. V. Bleininger deserves great credit for his work on preheating clays as a means of overcoming drying troubles. Preheating a clay makes it more porous and permits the moisture to escape to the surface.

The peculiar condition of many clays which makes them difficult to dry is the subject of much study and discussion at the present time and brings us to the borderland of our knowledge. The colloid theory is now generally accepted by clay technicists. Briefly, we assume that the clay contains a great number of cells or sacs which absorb water through their walls, swell and close up the interstitial pore spaces. This puts a stop to any flow of water to the surface, and when the surface dries, it must crack to relieve the strain. The air gets into the cracks and continues the drying process which at the same time deepens the cracks. The drying cracks in a colloidal clay are irregularly hexagonal in shape and are characteristic.

The preheating bursts the sacs and sets free the included water, driving it off, and at the same time so destroys the structure of the sac that it cannot take up water and hold it except by surface tension which applies in any case, nor can the colloids now swell and close up the pores in the clay mass.

Clayworkers have been slow to take up preheating, and there may arise a number of practical difficulties.

The temperature must be carried considerably above the drying degree, and it remains to be proven whether we have a practical preheating range, otherwise it becomes of questionable value. Clays differ in the degree of preheating required, and the variation ranges from 250 degrees C. (450 degrees F.) to 450 degrees C. (810 degrees F.). Suppose a clay is not sufficiently heated at 500 degrees Fahrenheit and too much plasticity is lost at 600 degrees Fahrenheit, then we must keep within this range, else we will get some cracked ware in drying on one extreme and some loss through weak bonding on the other extreme. Therein lies the uncertainty of preheating—the range may be less than we can work within.

In testing one material, we found that the addition of burned clay grog to the raw clay served the same purpose as preheating, and, if it applies in all cases, will greatly simplify the problem.

It is analogous to the trouble with the Bessemer converter in making steel. Originally, it was intended to stop the process when the impurities in the metal had been burned out to a required degree, but it was impossible to stop at the right point, and successive blows differed widely in the character of the metal. The process became successful when the overburning was resorted to and the overburned metal corrected by the addition of a reducing element which could be added in definite proportions.

We may not be able to preheat clay to the proper degree of uniformity, but if grog will serve the same purpose, we can add it in any determined amount. We think that the part that burned clay grog plays is not only that of opening up the structure mechanically, but, by the absorptive power of its pores, it will draw the water from the colloids, and collapse the cells which clog the pores of the mass.

CHAPTER IV.

Shrinkage.

BEFORE TAKING up a description and discussion of dryers, we wish to consider the question of shrinkage. Why do wet clays shrink? It seems almost a foolish question, but if we could properly answer it we would understand the cause of our drying trouble and perhaps more easily eliminate it.

What is shrinkage? The answer is easy. It is a drawing together of the particles of clay toward a common center, each particle pulling the next beyond. When the chain of particles is too long, it breaks, causing a crack in the ware. Every break establishes a new center with a shorter chain of particles and we have safe drying only when the mass around each center is proportionate to the forces pulling the particles together.

There are several forces at work though they all may be grouped under the head of gravitation. It is the attraction of one molecule for another in the same material (cohesion), of a molecule in one material for a molecule in a different material (adhesion), of differential cohesion (surface tension), of adhesion in minute passages (capillarity), that cause a clay to shrink.

The surface of a liquid is stronger and more difficult to rupture than within the liquid. It is, as it were, an elastic skin or coating, which will support bodies that will not float once the surface is broken and the body submerged. A needle may be floated on water, but sinks immediately when submerged. This surface force, or skin to retain the simile, is called surface tension. In any liquid each molecule attracts all surrounding molecules. It is pulling and being pulled in every direction and may be said to be in equilibrium. Being balanced, little force is required to start it in motion. At the surface, however, there are no molecules above, and in consequence the surface molecules are not balanced. They are held down by the attraction between them and the molecules below, and it requires more force to move them than the submerged molecules. Thus we explain surface tension.

Citing again the floating needle, it remains on the surface because the only forces acting are terrestrial gravity pulling the needle down and surface tension resisting this pull. The water is depressed under the needle, and there is a stretching apart of the surface molecules, but not beyond the limit of elasticity, or more properly, not sufficient to overcome the forces of surface tension.

Iron is nearly eight times as heavy as water, and it is evident that surface tension which supports such a weight is a force worthy of consideration. The needle must be oiled or waxed to make it float. There must be no adhesion, because if the water can stick to the needle it will immediately begin to climb by capillarity, and we have this force added to gravity to pull the needle down.

Capillarity is a much greater force than gravity. Witness the sap rising in the trees to heights of three hundred feet or more (sequoia trees) directly or indirectly by the force of capillarity acting against gravity and overcoming friction. Here we have a force of ten atmospheres, with apparently no decrease in the acting force. Again if a porous body is placed in a closed vessel and submerged in water, capillarity will take up the water and drive out the air from the body to develop in the vessel a pressure of four to five atmospheres.

Who knows the power of capillarity?

Of course, capillarity is merely an application of adhesion, and the latter is a force inestimable. Government tests show that nearly 50 per cent. of the water in a clay is retained against a force three thousand times the force of gravity.

We do not appreciate the power of these forces in connection with time.

We can tear a mass of wet clay apart with our hands, but no mechanical power can pull the water loose from the clay grains. We may tear the mass apart, but how much power will be required to compress the mass to the degree of natural shrinkage? But, you will say, the mass is full of water and water cannot be appreciably compressed. True, but if there were no clay, the water would run out the smallest orifice by the force of gravity alone. In a mixture of water and wax, or water and mercury, or any mixture in which there is no adhesion and consequently no capillarity, we could easily squeeze out the water; but in clay it is impossible, except in small degree.

Adhesion, cohesion, capillarity and surface tension—these are the forces that cause shrinkage, and if we give them the proper assistance they will do their work faithfully. The trouble is that we ask too much of them. We set one force against another, and in the equilibrium which follows our ware ruptures.

Let us consider a clay body. In a slip prepared for dipping or casting the clay grains are in suspension in the water. The larger or coarser particles settle quickly, but the finer grains may float for days. Here we have widely separated grains of clay in a water matrix. They are moving about, but hardly can come in contact. As two particles approach, the space between decreases, capillarity increases, and a current of water is drawn up between them driving them apart. If two plates of glass are placed on edge in a shallow vessel of water and held like a slightly opened book, it will be noticed that the water will rise highest at the hinge or back edge and will drop in a curve to the natural water level toward the open edges. Closing the angle sends the curve upward, opening causes it to drop. Similarly when grains of floating clay approach or fall apart, the currents set in motion counteract the movement.

A bed of quicksand looks solid, but the grains are quiescently afloat in water. Puddle the bed in the slightest degree, and we set the grains of sand in motion in their watery beds. A beach sand, on the contrary, is solid, and one may follow the waves out, scarcely leaving a footprint on the wet sand. The difference is due to size of grain and surface area. We may float a needle on water, but not an iron shot, though they have the same weight.

In clays we have a large percentage of very fine material (some authorities hold that plasticity is due to fineness of grain, and the flotation of these grains gives the mass its mobility). This fine material, vibrating back and forth through the varying capillary currents, will materially aid in keeping the coarser material afloat.

If we could greatly magnify a drop of slip we would observe a condition something like sketch No. 1. On the surface we would have the wavy conditions as shown. The grains of clay, being heavier than water, do not float, but are held suspended at the surface by adhesion of the water to the grain surfaces and surface tension of the water. Should two particles approach each other, as at "A," a capillary current is set up between them, the tendency of which is to carry the column of water to a higher elevation, and the pressure thus developed forces the particles apart. Thus No. 1 particle will be driven toward No. 2. Momentum carries it beyond the point of equilibrium and back it goes toward No. 3.

If we let the slip settle, equilibrium will finally be reached, but if we draw off the supernatant water we still find our clay mass afloat.

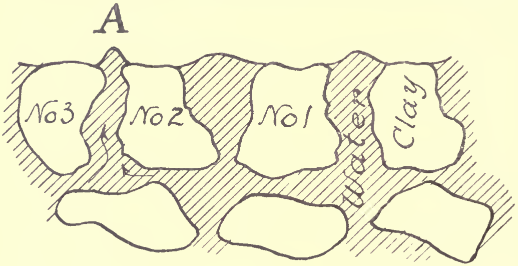


Fig. 1

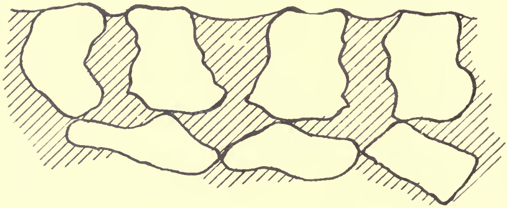


Fig. 2

Let us take some of the material and dry it. In the first stage we reach the condition as shown in No. 2 sketch, differing from No. 1 only in that the grains are closer together.

In sketch No. 3 they are fully in contact and the top grains are kept moist by capillarity from the pools below. As the outer grains are drawn together by surface tension, they exert a compresive force on the mass below, squeezing together and forcing the water outward.

In sketch No. 4 we are approaching the final stage. The water is constantly being drawn to the surface and evaporated and the water in the pores is being drained just as if a wick had been inserted into each pore. The end is reached in sketch No. 5, where all the pores are drained, and there only remains to be removed the water clinging to the surface of the grains.

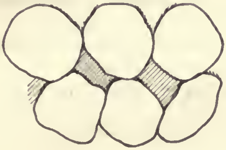


Figure 3.

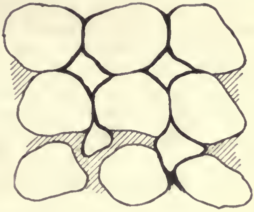


Figure 4.

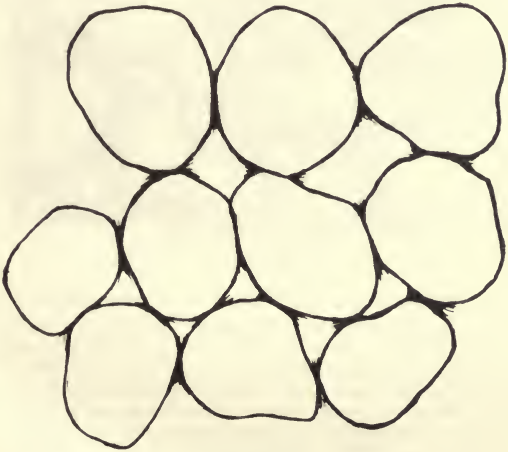


Figure 5.

This is removed by the air entering the pores and the evaporation takes place from the surfaces of the grains. Even then the drying is not complete. The clay particles cling tenaciously to the water and the last traces of the latter can only be removed by temperatures above the boiling point, but this is done in the kiln and does not concern us in the drying.

We have illustrated the grains as uniform in size and shape, but in reality they are widely varied, as illustrated in sketch No. 6. As compression takes place the angular grains arrange themselves into greater compactness and the finer grains are forced into the interstices between the larger grains.

The bond or strength of the dried ware depends upon the surface area in contact and the forces of adhesion and cohesion. A lot of marbles, or shot, or rounded grains or washed sand will have little or no bound. There is too little surface in contact. Crush the marbles and mix with them a quantity of infinitesimally fine materials and we will get a bond. Add to this some soluble salt which as evaporation of the water proceeds will crystallize and interlace the mass with its crystals and we get a still stronger bond.

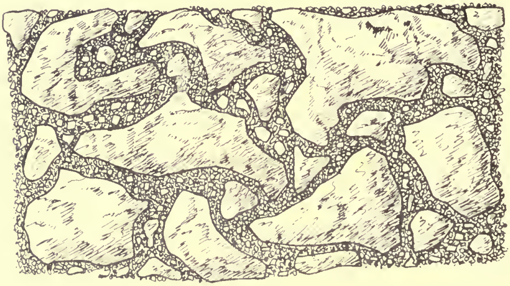


Figure 6.

We think of gummy clays which are so difficult to dry as being chemically different from other clays, but the difference is largely a physical one, and by some excellent authorities is considered simply a difference of fineness of grain. The fine grains necessarily involve small pore spaces and the water travels very slowly from the center to the surface of the mass and in consequence is troublesome to dry. Others hold that these gummy clays and in fact plasticity in all clays are due to cells or sacs enclosing water and the cells must burst to allow the water to escape and also to provide passageway to the surface of the mass, since the sacs not only hold the water back, but pack the pore spaces through which the water must escape. These amorphous sacs, glue like in their character (colloidal), as drying proceeds coat the larger grains and cement them together. When colloids are abundant (gummy clays) drying is difficult, but the dried ware is very hard. As colloids (colloidal condition) decrease drying is safest with corresponding falling off in the strength of the dried ware.

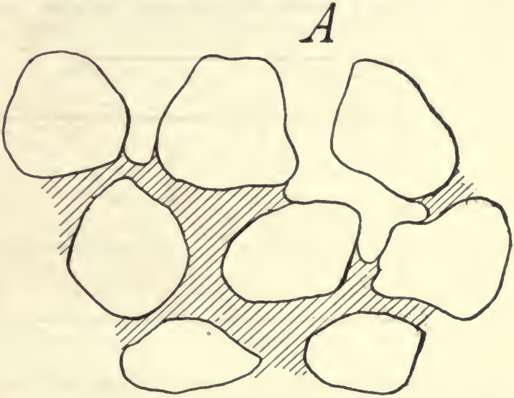


Figure 7.

After all, these colloidal sacs are built up of molecules and held together by cohesion, and so far as we are concerned, fineness of grain, in connection with angularity, soluble salts, cohesive and adhesive forces, suffice to explain the difference in the bond of dry clay ware.

Why do clay ware crack in drying? Suppose we illustrated in sketch No. 7, that the rate of evaporation is greater at the surface than the rate at which the water is brought to the surface by capillarity. The air will follow the surface of the water into the brick as at "A." The surface particles can only draw together as the entire mass shrinks, and the mass can only shrink as the water is driven out. Consequently there is a rupture between the surface grains. The crack started at "A" will go deeper and deeper into the ware as drying proceeds, and will only cease when sufficient pores have been opened by the crack to supply the rate of evaporation.

The cracks in such instances are irregularly hexagonal in shape (see sketch No. 8) and the size of the separate masses depends upon the difference in the rate of evaporation from the surface and the rate of the progress of the water to the surface.

Many wares, such as bricks, tiles, fire clay blocks, etc., of simple rectangular shape, develop straight cracks across the narrow face, which extend into and across the ware. Such cracks are due to the load being in excess of the forces. As noted the particles, one acting on another, are all being pulled toward the center of the mass. When the load becomes greater than the strength of the chain, a break occurs, and the load is divided into two sections, or three, or a dozen, as the case may be.

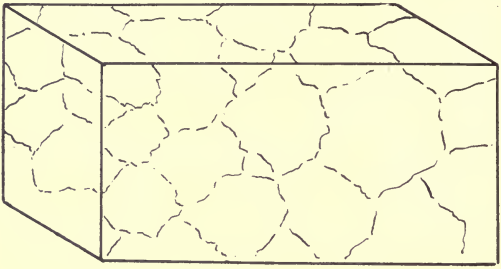


Figure 8.

Time is an important factor. If we tie a string to a load, and give it a quick jerk, we break the string, but if we pull gradually we may move the load. Similarly in drying, if we give the acting forces time, we can safely dry any ware.

Irregular shaped ware develops cracks in the weakest points, due to the shrinkage forces acting in opposite directions. For example, sketch 9 shows a shape that would be difficult to dry. The forces pulling the two halves together are greatly reduced in the neck with a heavy load on each side to be moved toward the center. An "L" shaped piece will crack in the angle because each leg is pulling toward its center and away from the angle.

Many cracks which develop in drying are due to faulty structure. Lamination, for instance (sketch 10), which has been previously discussed, is really a core within a shell. The structural fault between the two causes a break in the flow of water from center to surface and cracking occurs.

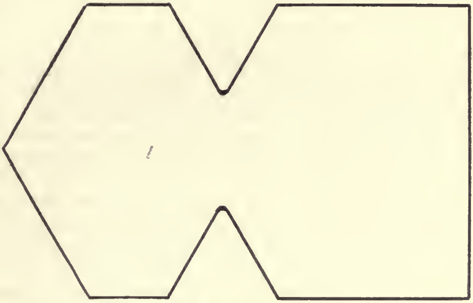


Figure 9.

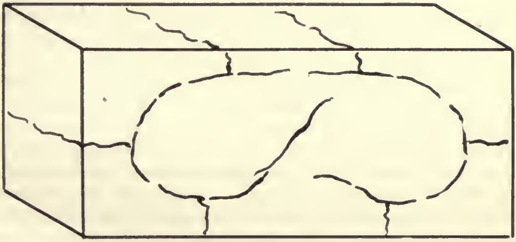


Figure 10.

Hollow ware often develops straight cracks the length of the ware, due to weak structure. The cracks may occur in the corner where we have the effect of the "L" shaped ware cited above, and in such cases the trouble is not necessarily due to faulty structure.

When, however, the longitudinal cracks are in the sides of rectangular ware, and also in circular tile, the trouble is generally due to structure. The core bridge splits the ware and while the split is closed up in coming from the die, yet not to have the strength of the other parts of the ware. It is the same condition as sketch 9—the weak neck is present but not visible in the ware as it comes from the die.

This structural weakness has been experienced in changing from one product to another.

Many manufacturers who have installed new dryers discredit the dryer because it will not dry in the time specified. When told to increase the heat or circulation they say it cracks the ware. What they wanted was a dryer that would do the work in a specified time without cracking the ware. The trouble is in the clay, in the shape of the ware, or in some structural weakness rather than in the dryer.

We have discussed methods of overcoming structural weakness, and also methods of improving the drying qualities of a clay, and will not go into that here.

A few words about drying mediums other than air, and we will close. As seen from the table previously published, the capacity of air for moisture increases very rapidly with advancing temperatures. We can not safely increase the temperature in a tender drying clay, because we soon reach a point where the surface evaporation is greater than the internal movement of the water. Suppose, now, that we introduce moisture to vapor pressure or saturation. We may then advance the temperature to any degree without harm to the ware. Many tender drying clays become safe drying under this treatment. There can be no cracking, since no drying can take place, and in consequence no shrinkage can occur so long as the vapor pressure is maintained. Meanwhile the heating up of the ware sets the water in motion and pore spaces are cleared for the subsequent escape of the water to the surface when drying begins. Moreover, the grains of clay are being softened and put in condition to adjust themselves more readily to drying strains. We have only to adjust the degree of pressure of vapor to correspond with the rate of flow of water to the surface of the ware to insure safe drying.

This humidity treatment to insure safe drying has been extensively used in terra cotta work and has been applied to common wares with gratifying results in a number of instances.

CHAPTER V.

Air Drying.

AIR DRYING of clay wares is both ancient and modern. The oldest cities of the world, now merely mounds in the plain they once adorned, even the names of which are questions of historical dispute, were built of air-dried bricks, and the modern city of New York is likewise largely built of the same product.

By air drying is meant drying without the expenditure of heat except such heat as is naturally in the air, or such as may be derived from radiation from burning and cooling kilns. There are many adaptations of air drying.

Open Yard Drying of Soft Mud Bricks.

The original and at the same time the simplest, is to lay the ware on the ground exposed to wind, sun and rain. It is limited to soft mud bricks, and there are many clays which will not stand such severe drying test. It seems strange that in the New England States, New York and New Jersey, where weather conditions are least favorable, we should find the largest and greatest number of open yards, while in the south and west where conditions are extremely favorable, open yards are the exception. Perhaps the clay has much to do with it. Direct exposure of a green piece of ware to the sun's rays is a very trying test, and open yard work is only possible where the clays will come through the ordeal safely.

The Hudson river district is the most notable instance of open yards. For many years open yards only were to be found in this district, but recently the artificial dryers are coming into use.

The arrangement of open yards is much alike. See Fig. 11. The soft mud machines are widely separated and each has its clay mixing rig, thus making a complete plant of each machine. In front of the machine is a broad, practically level space, sufficiently large to hold the daily output of the machine with space for hacking.

Usually the work begins very early in the morning and the daily task is on the yard before noon, oftentimes by 8 or 9 o'clock in the forenoon.

The molds of bricks from the machine are placed on trucks and run to the yard, and are there dumped on the ground, thus covering the ground with bricks laid flat and spaced the thickness of the sides and divisions of the mold. The early start is necessary in order to get the bricks dried before night. As soon as the bricks are stiffened so they will hold their shape they are edged up with a wooden tool called an edger. See Fig. 12. The divisions of the edger correspond to the divisions in the mold. The edger is placed over six bricks, and by a dexterous twist the six bricks are turned on their edges.

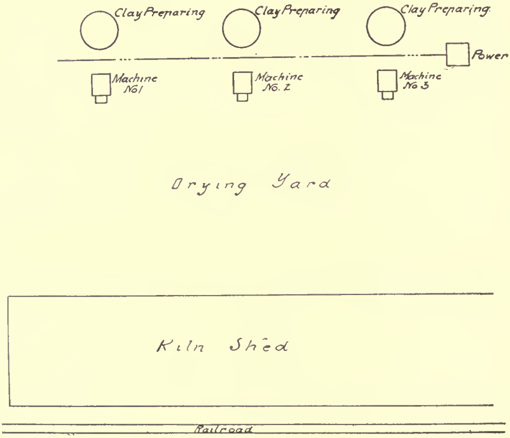


Figure 11.

The bricks on edge dry until later in the day, and are then hacked up in long hacks across the yard from machine to kiln.

The advantage of open-yard drying is in initial cost of installation and in that no fuel is required. The disadvantages are, short operating season with lessened capacity on account of bad weather, and increased labor cost.

An open yard ware is limited to common bricks, the demand for which is light during the winter season, especially in the north, and the summer operation is not a serious handicap, since the initial cost of the plant is not large compared with a modern plant of equal capacity, and the overhead cost is correspondingly low. The yards are built in several units and a yard of 50,000 brick capacity may have machine and drying capacity for 100,000 brick.

During the busy season the output may be pushed above the normal capacity. Usually one or more machines are idle all the time in order to keep down the labor cost. For instance, in Fig. 11, machines 1 and 2 will be operated when setting to the left of the center of the kiln shed and machines 2 and 3 when setting to the right. This gives minimum wheeling distance from the hacks to the kiln.

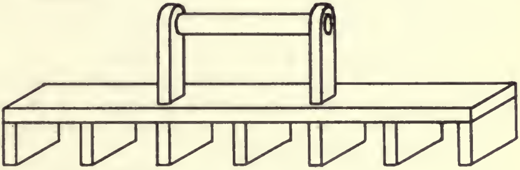


Figure 12.

It can be shown that the cost of putting the bricks on the yard, edging and hacking, on the basis of $2 labor will not exceed 25 cents per thousand. It is also evident that the cost of getting the bricks from hacks to kilns in view of the minimum distance ought not be greater than from a mechanical dryer however centrally located it may be.

The fuel cost in an artificial dryer may exceed the total cost of labor incident to drying on an open yard and in the most economical operation will equal one-half the open yard labor cost.

An artificial dryer, however, does not eliminate labor cost entirely, but does reduce it. We are safe in saying that the labor cost will not be less than one-half the cost on an open yard. The labor putting the bricks into the dryer, taking them out, handling pallets, making repairs, etc., will on many plants equal the cost on open yard. Then the cost of equipment must be considered—tunnels, fans, heaters, piping, racks, cars, tracks, pallets—and the total cost of artificial drying will exceed that of natural drying.

The great advantage of the artificial drying is that the manufacturer is independent of weather conditions and may keep the plant in continuous operation throughout the season, or throughout the year if desired. The work may start early in the season and the early product catches the early market when left-over stocks are exhausted, and the late fall operation insures a stock to last until the new product comes in. Thus the artificial drying increases the yearly output and reduces the overhead cost per thousand to more than offset any increase in the actual cost of drying.

It will generally be found that artificial drying costs more than natural drying, but we hold that in the majority of instances the net advantage will be in favor of the artificial operation.

Stiff Mud Bricks in Open Yards.

The open yard drying is occasionally used for stiff mud bricks. The bricks from the machine are placed on foot pallets—60 to 80 bricks—and these are carried to the drying yard by lifting trucks and set in rows.

They are covered with boards as occasion may require to protect them from the direct rays of the sun or from rain. When dry they are picked up by the lifting trucks, taken to the kiln and the pallets returned to the machine.

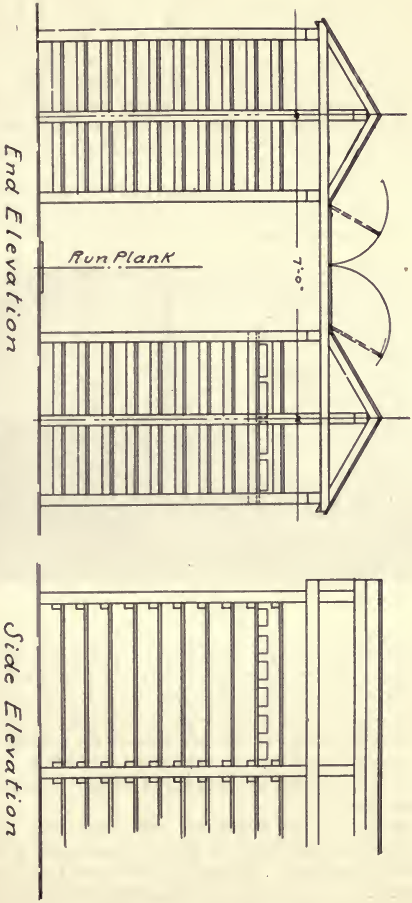
The pallets and covers are the only equipment over the soft mud open yard and there is an advantage in that the bricks are handled in larger units. All that has been said relative to the soft mud open yard applies to the stiff mud, with the exception that the bricks originate at one place, and in drying must be left on the yard several days to one week. The ground area required for each day is much smaller than for soft mud, since the bricks are hacked on edge eight to ten courses high.

Rack and Pallet Yard.

By far the larger number of summer common brick yards use the rack and pallet system. This is necessary because the clay will not stand the severe test of the open yard work.

Long sheds, commonly called "racks," are built as shown in Fig. 13.

The uprights are spaced the length of the pallets, each pallet holding one mold, 6 or 7 bricks. To the uprights are nailed



End Elevation

Side Elevation

Figure 13.

horizontal cleats spaced vertically the width of the bricks plus the thickness of the pallet plus clearance. The length of the cleats is sufficient to hold four pallets—two on each side.

The racks are roofed over as shown in Fig. 13, and the space between is covered by hinged doors which may be opened or closed as weather conditions demand. The racks are built ten cleats in height and each section holds forty pallets, or 240 bricks. The pallets are about 35 inches long, making the section over three feet on centers. A rack 100 feet long will have 32 to 33 sections and will hold 7,920 brick. Seven racks are required for a day's run of 50,000 brick, or 42 racks for the week's run.

Figure 14.

As the racks are spaced 7 feet on centers, the total space required is 29,400 square feet—something over half an acre.

The above described racks (Fig. 13) are extensively used in this country in air drying soft mud bricks, but in foreign countries where labor is cheaper other types of buildings are used. For instance, three or more racks may be put under one roof, but the advantage in quick and uniform drying is with the single rack.

In Germany large sheds are often used with the racks across the shed (See Figs. 14 and 15), and space is provided for storing the dried or partially dried bricks until kiln space is available. This involves extra handling, but it saves space, and what is more important, it insures a supply of bricks at all times for the kilns—a consideration not to be overlooked where the burning is done in continuous kilns.

In German practice continuous kilns are more commonly used for common bricks than in this country, and to keep the kiln in operation it is necessary that there be a supply of dry bricks, regardless of weather conditions, which requires not only excessive drying space, but space must be provided to store dry bricks in order to take advantage of good drying weather and tide over periods of bad weather. The atmospheric conditions in Germany are also less favorable for air drying than in this country, which accounts for the more permanent structures used in that country.

Figure 15.

The German bricks are nearly five inches wide and ten inches long (2½ centimeters by 25 centimeters). Their racks are usually built to hold only two pallets, one on each side, while ours hold four. They also use higher racks than we, which requires that the workmen stand on benches in filling the upper racks.

In order to economize space, the German sheds are often built two stories high which is never done in this country.

Because of the unfavorable atmospheric conditions, and in order to protect the ware from early and late frosts, thereby getting a longer drying season, the Germans have largely adopted the method of constructing the drying sheds over the continuous kilns, thus taking advantage of the radiated and waste heat from the continuous kilns. This will be fully described in a following article. We are beginning to adopt this method in this country, and it is likely that with the adoption of the continuous kiln for common bricks this method of drying will largely replace the open yard or yard rack work. Now we used scove kilns which are independent of drying conditions. We may build several arches in one day or allow the kiln to stand an indefinite period, as the making and drying may require.

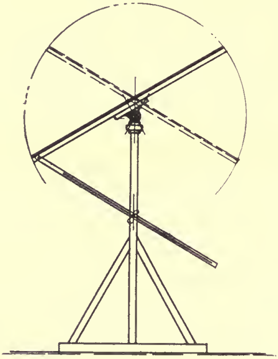


Figure 16.

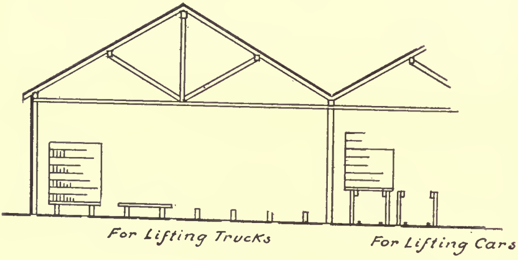


Figure 17.

Returning to the subject of racks—at the machine the bricks are dumped on flat pallets, usually on a turntable, and the loaded pallets are trucked to the racks and placed on the cleats. As soon as the bricks are hardened so they will stand handling, they are edged up by hand. When the bricks are dry they are removed from the pallets to barrows and wheeled to the kiln.

The time of drying varies from two to three days up to ten days, depending upon the weather.

Compared with the open yard work, there is a slight advantage in labor in favor of it over the rack system, but this is more than offset by the less loss in the rack on account of the protection from inclement weather. The latest development in the rack system is to use rope conveyors from the machine along the front of the racks with cross conveyors down each aisle.

Figure 18.

Air Drying Stiff Mud Bricks.

In place of the movable covers for stiff mud bricks on open yards we occasionally find a shed with a swinging roof as shown in Fig. 16. Such a shed economizes the labor in handling the covers.

A more permanent structure, however, is usually built for stiff mud bricks. The shed structure, a section of which is shown in Fig. 17 and Fig. 18, covers all the drying ground and is a permanent structure. Runners about four inches to six inches high are placed through the shed spaced to receive the pallets and to serve as guides for the two-wheeled lifting trucks. Eighty to one hundred bricks are placed on pallets at the machine and run to the drying shed, and when dry are removed to the kiln. The same method is followed in handling larger units with lifting cars, only the pallet supports (stanchions) are higher.

In the latter case several stanchions on turntables are placed along the take-off belt. The empty pallets are placed on the stanchions and as soon as one side is filled the table is turned 180 degrees, bringing the empty side to the belt. When the pallet is full—400 to 500 bricks—the lifting car is run on the turntable under the load and the latter is picked up and carried to the dryer, and thence, when dry, to the kilns.

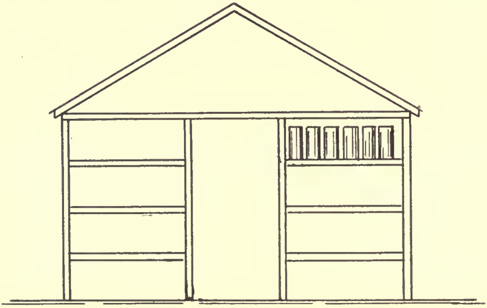


Figure 19.

The chief advantage is that the bricks are handled in units of 400 to 500 bricks, and we have the economy of handling which comes from these larger units.

Occasionally steam pipes are installed under the racks to hasten the drying but more particularly to protect the green bricks from frost in early spring and late fall months.

It is not uncommon practice to keep off frosts by the use of smudge fires, and the large sheds used in Germany are better adapted to this than our open racks. It is well known that pure air absorbs little or no radiated heat either from the sun or from the earth. Air is heated by conduction in contact with the earth and is distributed by convection (circulation or mass movement). Particles of dust in the air, however, can be heated by radiation and in turn give up their heat to the air by conduction.

By surrounding the bricks with smoke particles, if we may so express it, we collect the radiant heat from the earth and from objects on the earth and retain it as a blanket protecing the bricks.

Drain Tile Sheds.

Sheds for drain tile for natural drying are built more substantially than brick racks. A common type is a shed about fourteen feet wide with racks. The racks are on either side with a passage way through the center of the shed.

The pallets to hold the tile are four to five feet long and are placed in the racks, just as brick pallets are racked. The tile, however, are trucked to the shed and placed on the pallets in place. As each pallet is filled, the next pallet is placed, and so on until the rack is full. Fig. 19 shows a section of a drain tile shed.

There are many modifications of tile sheds—often some old building being adapted.

Very little can be said in favor of natural drying for drain tile. The best market is in the late fall, winter and early spring and a tile plant equipped for natural drying only is badly handicapped. A good combination for a small yard is open yard drying for bricks during the summer, when the demand for bricks is greatest, and an artificial dryer for tile during the winter. Many tile makers have found the need of artificial drying and have added to the sheds some system of heating. Sometimes steam pipes are placed along the floor under the racks, and we have seen tunnels or flues of sewer pipe built under the racks and heated from a furnace at one end of each tunnel, with draft stack at the other end, or, if the shed be long, the stack is placed midway, with a furnace at each end of the tunnel.

Such methods of heating are makeshifts and very crude. They art not to be recommended in a new construction and will not be considered in connection with artificial drying.

CHAPTER VI.

The Drying Above Continuous Kilns.

IN DRYING ABOVE a continuous kiln, as it is done quite generally in Germany, and to a limited extent in this country, there are two main problems involved, viz: the drying and the handling of the ware.

Prior to the introduction of the continuous kiln, drying was almost exclusively done in sheds or in the open air by sun and wind, but following the successful operation of the Hoffman kiln it was quite natural and logical to go a step farther in the economical performance of this kiln by utilizing its radiated heat to assist the natural air in drying the ware.

The first dryers thus constructed did not use any other heat source, but merely took advantage of the heat radiating from the kiln and the bricks were stacked all around and above it.

Such dryers, one, two and even three stories high can still be found in Germany on a number of yards.

Theoretically, as will be seen later, there is nearly enough heat from a continuous kiln to dry the ware to be burned in the kiln, but practically so much of it is lost in the application, in sufficiently heating and maintaining the temperature of the air to carry the moisture taken up, in radiation loss from the buildings, in heating the ware itself, etc., that it falls far short of the requirement.

It has been shown that the radiation loss from a continuous kiln is 32 per cent. of the fuel consumed in the burning. If we assume that 200 pounds of coal per thousand bricks are used in the burning, then we will have the value of 64 pounds in radiated heat. On the basis of 12,000 B. T. U. per pound of coal, we have 768,000 B. T. U. in radiated heat. If the bricks (American size) contain one pound of water each, which requires 970 B. T. U. to evaporate, then the evaporation of the water in 1,000 bricks will consume 970,000 B. T. U. The available heat, if all of it could be used in drying alone, will suffice to dry 800 bricks out of each 1,000 to be burned, but we undoubtedly lose more than half of the heat from the kiln. As the fuel required for burning increases, we have corresponding increase in the available radiated heat, and it may be possible in factories with high fuel consumption and properly constructed buildings, together with the best application of the heat, to dry the ware during the summer season without auxiliary heat supply.

It has been demonstrated that in the majority of instances the radiated heat by no means suffices to dry as much ware as the continuous kiln can burn, and it has been found that factories depending entirely upon radiated heat cannot operate during the winter. It is necessary, therefore, to have additional drying facilities, either in outside sheds or by means of other sources of heat than that radiated from the kiln.

Figure 20.

Fig. 20 shows a factory with outside sheds contiguous to the kiln. Even with such outside sheds for additional drying, on many yards the bricks are taken from the racks as soon as practicable and are racked on the ground around the kiln, and near to it, as seen in the illustration, where they may become fully dry. Thus advantage can be taken of favorable drying weather and a stock of dry bricks accumulated to keep the kiln in full operation during bad weather. The photograph is of a German brick plant of average size making 12,000 to 15,000 (German size) bricks per day.

The outside drying racks hold about 130,000 bricks; 50,000 bricks are placed in racks around the kiln, level with the top of the kiln, and get the heat radiated from the kiln walls and wickets, besides more or less circulation from the kiln top; an additional 50,000 are placed in portable racks, forming tunnels above the kiln, which will be described later.

The temperature above the kiln during the summer varies from 20 degrees C. to 40 degrees C. (68 degrees F. to 104 degrees F.) and the time required for drying is from five to ten days.

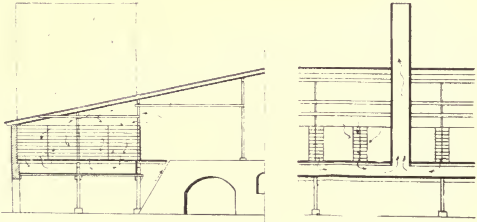


Figure 21.

In this plant we have 100,000 bricks dried by heat from the kiln and 130,000 bricks dried in outside sheds, with storage space in which to accumulate dry bricks during good weather, yet the need of additional drying facilities is urgently felt.

In such kiln dryers the air regulation is effected by opening or closing the windows, according to the wind direction. It can readily be seen that the drying, besides being slow, is also quite irregular. Sometimes in order to distribute the heat more uniformly a sheet metal lining with openings is placed below the drying floors and the results have often been bettered by doing so. Usually the floors under the ware are slotted and only left solid in the aisles to compel the rising heat to pass through the ware before escaping through the windows or louvres of the monitor above.

The updraft is slow and where condensation occurs under the roof there are placed a few steam pipes below the monitor to heat up the air, prevent condensation and increase the speed of the rising air. In such cases the main updraft will naturally be directed towards the center and the drying of the ware in the side racks will be neglected. One, or better, two suction fans in the monitor are doubtless more effective. With a stronger draft throughout which the fans will give, it is possible to force the air to the side racks by closing floor openings under the center racks.

In Fig. 21 we have a system devised and built by Cohrs about thirty years ago. The drying racks are placed on both sides level with the top of the kilns, thus relieving the kiln walls of the dryer load. Vapor stacks are placed intermittently between the racks, being connected with ducts below the ware. The heated air, coming from over the kiln, is drawn down through the ware and escapes through bottom openings into the under ducts, thence to the stacks. The drying space is confined to the kiln top level, and hence, if possible, the ware should be delivered from the machine on this floor, so that, after drying, the ware only needs to be lowered.

Most of the modern kiln dryers make use of the exhaust steam from the engine. There may be pipes under the floors and the natural updraft system be used, or there may be used steam heating coils in connection with a fan or a combination of a heating tank with a hot water system.

We must mention the fact, however, that European plants do not have the amount of exhaust steam available in our American plants. Their engines do not require over 10 pounds of steam per h.p. hour—from one-half to one-fourth of the consumption in this country—and hence the heat derived from this source is comparatively small.

Other kiln dryers make use of the heat from the cooling chambers by means of a small fan. Many plants use both exhaust steam and the heat from the cooling chambers. Any heat taken from the kiln, however, is not gratis; it must be replaced in some way and more fuel in the burning is the result.

It furthermore is a fact that the so-called radiated heat is not always to be considered as being gratis. Whenever an artificial updraft above the kiln is created by fans or any other means and the air taken from the top or surroundings of the kiln, there is bound to be a fall of temperature of the kiln walls and thus indirectly of the chambers and the heat taken must be replaced by more fuel in the kiln. The actual

Figure 22.

amount of radiated heat, therefore, which has no value in the kiln operation and which is an absolute loss except as it may be recovered in drying, is much less than is generally claimed, but at the same time it may be turned into profits provided its value is not more than offset by increased labor cost.

As regards the handling of the ware there are several systems in vogue. Frequently a tray elevator is used for getting the ware from the machine below to the upper drying floors. This elevator is located close to the cutter, as we can see from Fig. 22. One man takes off two or three bricks at a time and places them upon the tray at hand. The loaded trays go up and on their downward movement, after passing the head sprockets, are unloaded. It is essential that emptying and filling the racks keep pace with the progress of the fires in the kiln as far as possible in order that the bricks in greatest need of heat shall be over the hottest part of the kiln. Where the drying room has two floors a man on the upper floor unloads alternate trays, leaving the intermediate trays for the man on the lower floor, thus the racks in both floors are equally filled at the same time.

Figure 23.

There are several ways of conveying the ware about the drying floor, the most common perhaps being the car system, of which there are several in use. We have a series of illustrations before us of one such system, not necessarily understood to be the best. In Fig. 23 we see the upper part of the tray elevator. The man in front of it is taking off the bricks and placing them in the frame to the left, which is standing on two wooden blocks, or footings, on top of a turntable. The frame consists of seven shelves, each made up of four narrow strips of wood, so that a brick is always resting on two strips. After one side is filled the turntable with frame is swung around 180 degrees and the other side is filled.

As soon as this is done a man pushes a car of special design under the frame between the footings and, by lifting a lever, catches the frame under the upper shelf on two projecting arms. In Fig. 24 we see the frame just being taken off, while in Fig. 25 we have the car with its leverage to the rear and the two projecting arms to the front, ready to be pushed under the frame.

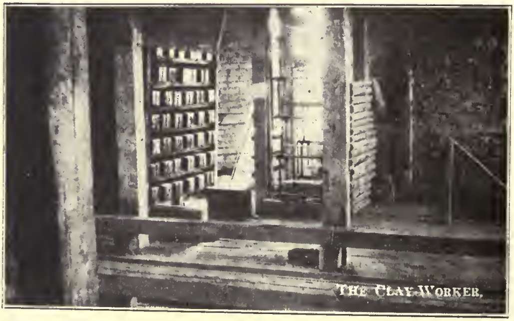


Figure 24.

The loaded car is moved to the transfer car and with it is pushed along until opposite the space being filled. The car is run off the transfer, pushed into the space and, by lowering the lever, the frame is set down on two projecting floor beams. In Fig. 26 we see the man setting down the last frame and thus filling the space or so-called tunnel.

After the bricks are dried they are loaded on wheelbarrows and lowered on a double gravity elevator to the ground and wheeled into the chambers of the kiln. The frames remain on the drying floors, and when empty are returned to

THE CLAY-WORKER.

Figure 25.

the turntable. The location of the gravity elevator can be seen in Fig. 20.

Instead of this system the frames may be filled in front of the cutter on the ground floor, then the loaded frames are elevated to the drying floor, where they are put into place by lifting cars as described, or by similar cars of a better design, and, after the bricks contained therein are dry, are taken down on a gravity elevator. A better plan, which will be described later, eliminates the portable frames, and the pallets only are handled by the lifting cars.

Again, another way is to use a combination of tray elevator and tray conveyor with the elimination of cars entirely.

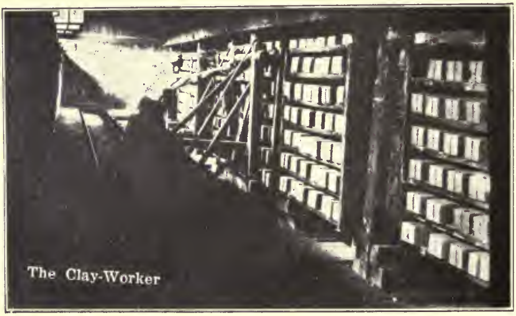


Figure 26.

There are numerous arrangements adapted to special conditions and to take advantage of different methods of handling the bricks and distributing the heat.

Fig. 27 shows an underground continuous kiln with dryer on the ground level on either side. The bricks are partially dried in the racks around the kiln and are then stacked on the cooling burned bricks for the final drying. They do not need to be elevated; they are delivered by the machine to the racks on the ground floor, thence removed to the kiln, and later lowered into the kiln for burning. This scheme requires a second handling in the drying. In Fig. 28 we have the same kiln with a dryer building above.

Fig. 29 illustrates a continuous kiln with three drying floors above. It is evident that in this case the load of the dryer upon the kiln walls and piers is rather excessive and first quality masonry and good foundation work are essential.

Fig. 30 illustrates an arrangement first designed by Schaff and later taken up and now built by Rudolf Witte of Osnabrück, Germany, for drying bricks and especially roofing tile. The tiles are delivered on the upper ends of inclined chutes and gradually slide down as drying proceeds and as the dried ware is removed from the lower ends of the chutes along the outer aisles. Schaff originally used the natural updraft of the hot air within closed chutes, while Witte blows in hot air from the side, taken from the cooling chamber or a heater. The original idea may not be more effective, but it certainly is more interesting on account of its scheme by which the drying medium (the air going up) and the conveying feature

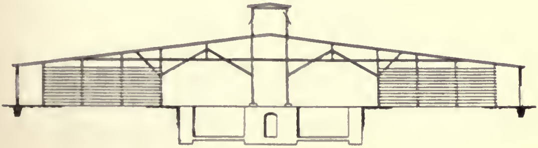


Figure 27.

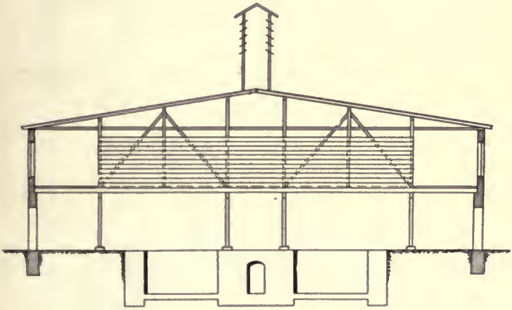


Figure 28.

(the ware coming down) carries out a logical idea which has been so successfully applied in our progressive tunnel dryers.

In Fig. 31 we have the bricks in racks around the kiln at the kiln top level and similar to the Cohrs system shown in Fig. 21, which relieves the kiln of the excessive weight in other systems where the bricks are above the kiln. This system only uses radiated heat from the side walls of the kiln and

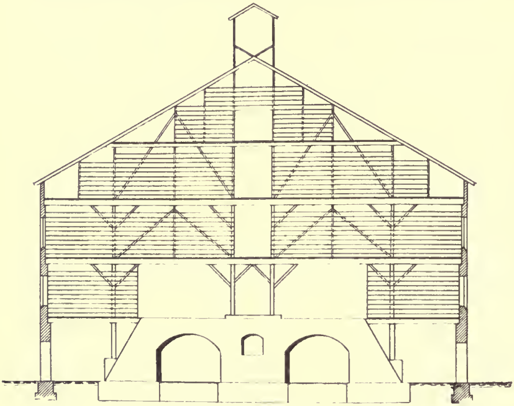


Figure 29.

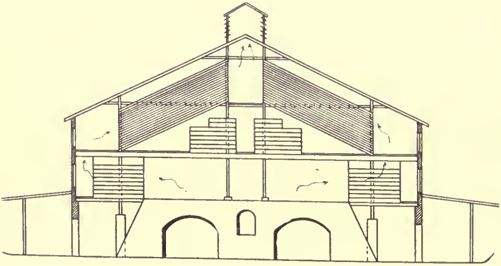


Figure 30.

that escaping from the wickets. Under the racks are placed steam pipes enclosed in a box, with admission for air on the sides next to the kiln, and outlets into racks on the opposite

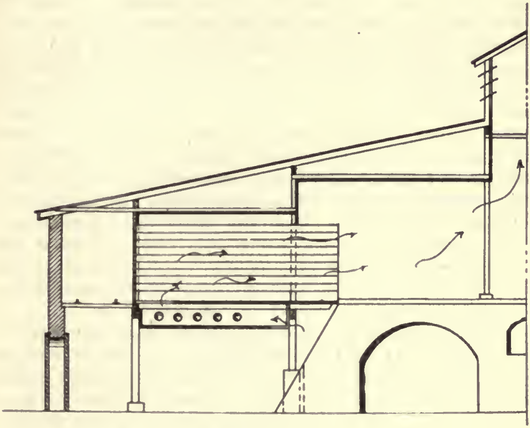


Figure 31.

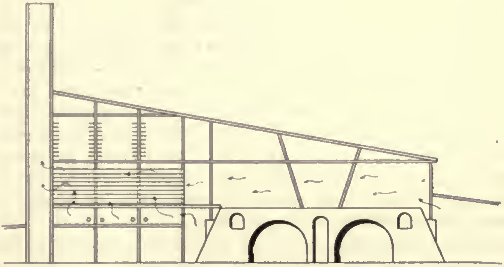


Figure 32.

upper side. The principal source of heat in this instance is from the steam pipes, and not from the kiln. The radiated heat from the top of the kiln is used to produce draft through the monitor of the building and is not available for drying.

Fig. 32 gives the arrangement as built by F. L. Smith & Co. of Copenhagen and Berlin. There are certain features in the drying as well as in the handling worth describing, and we will follow the ware as it leaves the machine. The bricks are cut from the end of the bar of clay, three at a time, without waste, by a hand cutter operated by one man and a capacity of 40,000 to 50,000 German size bricks is attained per day—a remarkable output for a hand cutter operated by one man. Such a cutter is shown in Fig. 25. The bricks are taken off by another man and placed on a pallet which is level with the cutter. There are ten such pallets, each of which will hold fifteen bricks, resting loosely on the frame of an elevator and the filling starts with the lowest pallet. As soon as the bottom pallet is filled the elevator drops the height of one pallet, bringing the second pallet level with the cutter and thus repeating until the frame is full. A pit receives the elevator as it descends. A woman on the opposite side of the elevator frame spaces the bricks on the pallets.

After the frame is loaded the woman shifts the lever of the coupling and the elevator rises to the floor where the bricks are to be dried. Two elevator frames at right angles to each other forming a letter V, the angle of which encloses the cutter, are used. Thus the take-off is at equal distance from both elevator frames and has to make only a quarter turn to place the bricks on either frame.

When the first frame has reached the upper drying floor the elevator is stopped automatically and a man with a special car takes off the row of pallets from the elevator by pushing the car with its ten sets of projecting arms into it and raising the pallets from the frame supports by the movement of a lever on the car. After the car is loaded and pulled back the elevator frame is filled with (ten) empty pallets and lowered to the first position at the cutter. The drying sections or tunnels are provided with projections to receive the pallets corresponding to the projections on the elevator pallet frame, and the loaded pallets are placed in position by a single movement of the car lifting lever. One man on the dryer can easily handle 30,000 bricks.

Turning again to our illustration, Fig. 32, we see the drying floor located to one side of the kiln to avoid any load upon the kiln walls. Outside air is coming in from the opposite side, passes over the top of the kiln and becomes heated by contact with the kiln top and by commingling with hot air

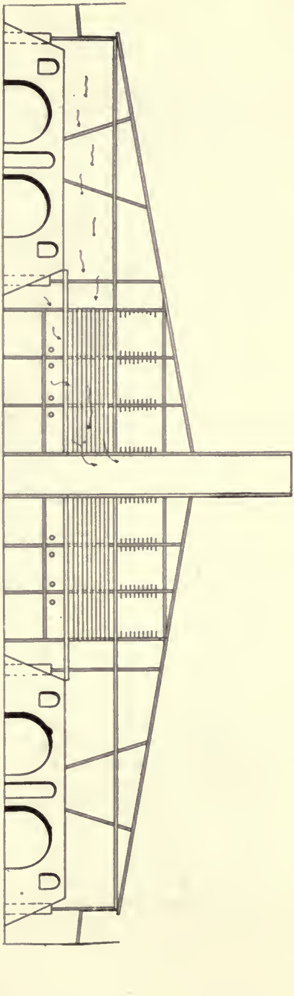


Figure 33.

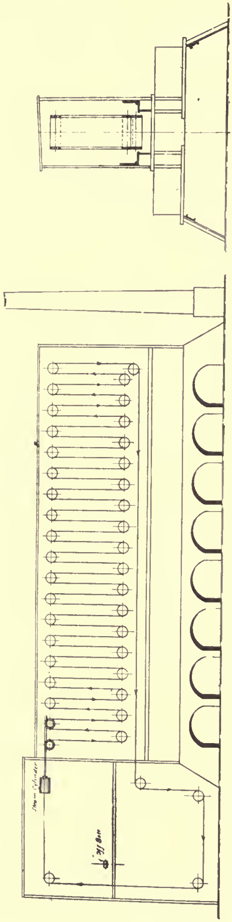


Figure 34.

rising from the kiln. An air-tight ceiling prevents the heat from escaping into and through the roof, thus forcing it to enter the dryer on the side facing the kiln. The heat, after having passed through the ware, enters a vapor stack provided with regulating dampers and escapes to the open air.

The speed of the air in the dryer is about 60 meters (197 feet) per minute. The exhaust steam from the engine is also used for drying purposes. The steam is forced into a well insulated hot water tank, which supplies ribbed pipes under the dryer. The circulating water will gradually cool off and return to the tank by its own weight through separate piping.

The drying chambers are made as small as possible to utilize all the space and to avoid losses of heat.

A test of such a dryer some years ago during the month of November gave the following data:

The temperature of the outside air was 11 degree C. (52 degrees F.) and its degree of saturation 90 per cent. The temperature of the air entering the dryer was found to be 15 degrees C. (59 degrees F.) and its degree of saturation 65 per cent. The temperature rising in the dryer was 23 degrees C. (73 degrees F.). The temperature in the vapor stack was 15 degrees C. with a saturation of 93 per cent. The sectional area of the stack was 4.2 square meters (45.2 square feet) and the speed of the air 60 meters (197 feet) per minute. Each of the sixteen chambers contained 7,500 bricks and it took four days for drying. At 59 degrees F. saturated air contains 4.75 grains of moisture per cubic foot. In the above data the air entered at 59 degrees F. 65 per cent. saturated and came into the vapor stack at 59 degrees F. and 93 per cent. saturated. Sixty-five per cent. and 93 per cent. of 4.75 give us, respectively, 3.08 and 4.41 grains, and the difference, 1.33 grains, represents the amount carried out by each cubic foot of air. The stack being 45.2 square feet and the air moving at the rate of 197 feet per minute, we get an air movement of 8,904 cubic feet per minute, carrying 11,842 grains of water. In one hour, therefore, about 123 pounds of water are carried out, and in four days 11,808 pounds, which fairly represents the water in 7,500 (German size) bricks.

Fig. 33 shows the same system for two continuous kilns, for which it works out especially well by getting the dryer in the center.

In Fig. 34 we have a system of drying which has been in successful operation in this country for a number of years.

The bricks are set on long trays, which are fastened to a

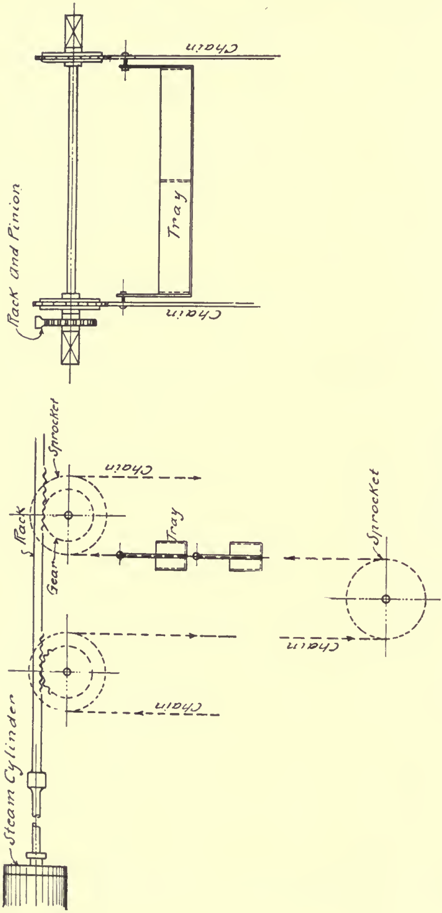

Rack and Pinion
Chain
Tray
Chain
Sprocket
Chain
Rack
Gear
Tray
Sprocket
Chain
Chain
Steam Cylinder

Figure 35.

continuous double chain conveyor, which passes over and under sprockets the full length of the continuous kiln, as shown in the illustration, and returns to the ground floor, where the dry bricks are removed and wheeled to the kiln. The conveyor is operated by rack and pinions driven from a steam cylinder, as seen in Fig. 35. Alongside one wall steam radiators are placed and the whole dryer is operated at pretty high temperature, higher than in German practice. The bricks are handled three times in small units—once from machine to tray, once from tray to barrow and once from barrow to setter.

From our experience with cars and transfers into and out of dryer tunnels and kilns, we believe there will be some economy in labor in the above system. Our continuous kilns are not insulated as are the German kilns, and we will have a greater value in radiated heat, but still far from sufficient to dry the product burned in the kiln. As our kilns are constructed, operated and maintained they are not adapted to carry heavy loads, especially loads of moving machinery equipment, which must be kept in perfect alignment.

In a number of plants drying floors have been established over periodic kilns, but the consensus of opinion is that such combination of kilns and drying floors is not satisfactory.

There have, perhaps, other attempts been made in this country to dry the ware above kilns, of which we do not know. The tendency of our day is directed towards economy in fuel, and we believe that the methods of drying above kilns will in the future more and more be taken into serious consideration.

In conclusion we briefly wish to recapitulate the advantages and disadvantages of the drying methods above described:

Advantages.

Utilization of space.

Compactness of arrangement. (Eventually the whole plant under one roof.)

Economy in fuel.

Disadvantages.

Elevating and lowering of the ware.

Load upon the kiln walls. (The outer kiln walls should not be loaded under any circumstances.)

High buildings.

The radiation alone not sufficient for drying and in consequence extensive and scattered auxiliary equipment.

CHAPTER VII.

Artificial Dryers.

AMERICA LEADS in the development of artificial dryers for clay ware, and her advance in this feature of clayworking is due to greater need, or more properly, to greater variety of needs. A need leads to an invention to supply it. No two clays are exactly alike and in the variety of clays, America has all the needs in the world. The alluviums of the coasts border and overlap the tertiary and cretaceous deposits, which in turn, extend to the foothills of shales, adjacent to the mountains of schists, quartzites and hard shales. In and beyond the mountains come the rich shales and fireclays of every kind laid down in Paleozoic times, and these overlap the calcareous shales of the Devonian age. The great glacial cap stretches in a broad belt from coast to coast, nearly three thousand miles. In the broad valleys are the deep terrace and lake deposits of the Champlain period. The mountains are ribbed and seamed with disintegrated dikes of every description. In the Middle West are vast deposits of white cretaceous clay, overlapped by tertiary shales the drying difficulties of which are beyond the ingenuity of the dryer man. Over the plains are found the wind-tossed beds of loess, and the troublesome joint clay. In the South are the washings of the continent, ancient and modern, shales and alluviums, kaolins, Fullers earths, fire clays, bauxite.

The development of the dryer is also influenced by climatic conditions. We have the frozen North and the sunny South, the arid plains and the dripping west coast, and all kinds of climate in between.

Fuel also must be considered. In a smaller country the variation in cost is less wide than in our broad land where a difference of 1,000 per cent, is not unusual. In the coal districts, where coal and clay often come from the same pit, the cost of fuel is of slight consideration, while in the distant districts it must have every consideration.

High priced labor must be reckoned with, and every effort is made to develop a mechanical operation.

These conditions in every extreme have led to a wide development of mechanical dryers.

All dryers can be placed in two general classes:

1. The periodic dryer, in which the ware is stationary and the heat and circulating air are brought to it.

2. The progressive dryer, in which the ware is being advanced from a low temperature, usually humid zone, to a high temperate dry zone.

The periodic dryers may be separated into: Floor dryers, rack dryers, tunnel or compartment dryers.

The progressive dryers are limited to the tunnel or compartment type.

A further classification introduces the source of heat as follows:

- Combustion—
  - Introduced direct.
  - Radiation.
  - Convection.
- Steam—
  - Direct radiation.
  - Convection.
- Waste Heat—
  - Steam.
  - Cooling kilns.
  - Burning kilns.

The possible variations, the combinations and the modifications, to adapt dryers to all kinds of ware and all varieties of clays, gives us a long list of artificial dryers.

It is not our purpose to go into a full description and discussion of all the modifications, but instead we will take up the general types and follow with some of the best known and most widely used modifications, but we will not attempt to follow any definite classification. In fact, the division is not always sharply drawn. It is but a step from hot floors to ordinary drying floors in one direction and to radiated tunnel dryers in the opposite direction. Periodical dryers in some instances approach very closely to the progressive type, some being periodical in construction and progressive in operation.

General Principles.

Before taking up the individual dryers, we wish to review briefly the general principles of drying even though we repeat what has been said in a previous chapter.

1. It is important to bear in mind that drying cannot take place without the consumption of heat, and the same amount of heat is required in every instance for equal amounts of water evaporated. The efficiency of a dryer depends upon the application of the heat.

2. Air has nothing whatever to do with drying in a strict sense. We speak of the volume of air required and it is convenient to do so. It is true that we use air in drying, but not for drying. The air is simply a vehicle to carry away the water vapor, or more properly speaking, it is used to create a current, or a draft, to sweep away the moisture vapor as fast as it is formed. As a matter of fact, instead of air absorbing vapor, the latter, as fast as it forms, displaces air by its pressure, until at the boiling point there is theoretically no air present in a vessel containing the boiling water. Some types of dryers have small air inlets and equally small outlets with no other force moving the air than natural draft. Other types use fans to force the air in through large ducts in which one may walk without inconvenience, and at the exhaust end of the dryer is another fan drawing away the air and moisture through another large duct. These dryers may have equal drying capacity yet there is no comparison in the volumes of air passing through them.

3. Other things being equal, the greatest economy will come with the shortest connection between the source of heat and the drying ware.

A direct coal fired combustion dryer will give greater return in heat than a dryer in which the fuel is used to generate steam a hundred or more feet away and the heat value recovered from the steam in or adjacent to the dryer, on the other hand, where the combustion gases cannot be used direct, but instead the heat from the combustion must be conducted through walls thence by radiation to the ware, the amount of heat which may be led to the ware may be less than by the more complicated steam operation.

4. Meteorologists tell us that air cannot be heated by

radiation, but becomes heated by contact with hot bodies (conduction), and the movement of the air carries the heat from place to place (convection), and gives it up by conduction, to the bodies with which it comes in contact. They also inform us that heat waves radiating from a hot body will raise the temperature of any solid body with which they come in contact without, as above stated, heating the intervening air. The Fery pyrometer is perhaps an illustration of this. We focus it on a glowing body in the center of a kiln and it will register the temperature in a galvanometer, but instantly a screen is intervened the temperature drops back, which would not be the case if the intervening air were heated by radiation from the glowing body. We sit in front of a fire and are comfortable so long as a screen is held between us and the fire but without the screen our face will burn. It is evident that the burning sensation does not come from the air.

5. Dryers, then, must be constructed to get the air in contact with the heated body in the greatest degree and then be brought in contact with the ware to be dried, or if we are relying upon radiation from the hot floor to the ware there should be as little movement of the intervening air as possible because to whatever degree it comes in contact with the hot body and ware it will carry away heat from both, but on the other hand, after the heat has driven the moisture from the ware there should be a current of air to remove the vapor. Herein lies the difference in the quantity of air required for different types of dryers. In one type the air is heated by contact with the hot body and is then brought into contact with the drying ware. In the other type, the ware is heated and the water evaporated directly by the heat radiated from the hot body to the ware and it is only necessary to maintain the vapor condition and sweep it away either by its own expansive force or by a current of air.

Floor Dryers—Hot Floor.

Clay wares were originally dried on the ground without cover. Shelter was next provided which raised the drying space to the dignity of a floor. It was but a step farther to provide some method of heating the floor and this led to the development of modern hot floors.

The hot floor, so called, was first used in the manufacture of fire bricks and is still the chief drying equipment in such factories. It consisted of a floor of any width and one hundred feet or less in length. At one end was a firing pit below the floor level, and at the other end a stack. The floor was underlaid by a series of parallel flues connected directly with coal-fired furnaces in the firing pit, and with the stack by a cross head flue.

In order to equalize the temperature of the floor, it was made thicker near the furnaces, gradually decreasing in thickness toward the stack. The flues were spanned with bricks, then the thickness was built up with rammed ashes and paved, or with rammed crushed furnace slag without paving, or with concrete finished to a smooth surface. Even at best it was impossible to get the temperature uniform nor was it considered desirable to do so, because some wares required slower drying than others and a suitable temperature for all the product could be found on such a floor.

The size of the floor per thousand bricks depends upon the time required to dry, and varies from 700 square feet to 1,250 square feet.

In the hand molding process the bricks in the molds are carried by boys from the molder and are dumped flat on the hot floor just as common bricks from soft mud machines are placed on the open air drying ground.

The bricks are left on the floor from twelve to twenty-four hours or until dry enough to repress. If they show signs of becoming too dry before the repressing gang gets them, they are hacked into piles, or in some instances, simply edged up. This is one instance where the drying may be retarded by edging up the bricks, where usually edging is resorted to in order to hasten the drying process.

Where the bricks set sufficiently for repressing in eight or ten hours it is the custom for the molders to begin work about 4 a. m. and finish their task by noon, while the repressing crew will begin at noon or as early as the drying will permit, and continue until the day's output is complete.

From the repress the bricks are again placed flat on the floor, four to eight high, and allowed to remain until completely dry, when they are taken up and wheeled to the kilns.

The tunnel dryer is being introduced in fire brick manufacture, as an adjunct to the hot floor, and in fact has been in use on a few yards for many years. It is used for the repressed product and for any struck bricks which do not have to be repressed.

The advantage of the open floor is that the bricks can be watched and repressed when in the proper condition, and it is retained in all fire brick plants, but the crude direct fired hot floor, expensive in fuel consumption and at best not very efficient, has been replaced by the modern exhaust and live steam heated floor.

Figs. 37, 38 and 39 show a section, plan, and detail of a

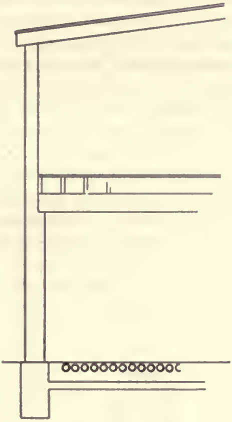


Figure 37.

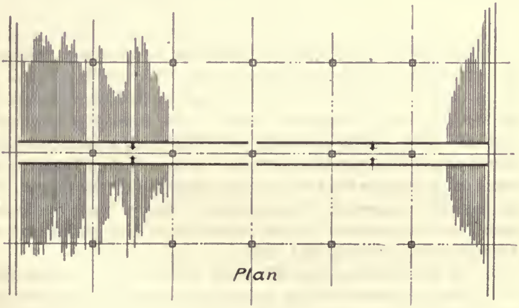


Figure 38.

modern hot floor. The floor is divided into sections so that each can be heated independently. It has a base of concrete upon which are laid 4-inch hard-burned drain tiles or electrical conduits imbedded in and covered with concrete, which is finished to a smooth surface, with the tiles as near to the surface as practical.

The hot floor is adapted only for low pressures and the size and number of tiles under the floor is such that the steam pressure is virtually atmospheric pressure. Exhaust steam is used during the day and low pressure live steam at night, which reaches the floor at a gauge pressure less than five pounds. The main header is connected with the under tiles by ¾-inch nipples and though the pressure in the header be five pounds the drop will be practically to atmospheric pressure in the tiles, being merely sufficiently in excess to carry the steam to the exhaust end of the floor.

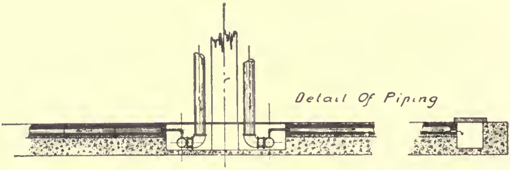


Figure 39.

The tiles have a grade sufficient to carry away the condensation and the floor surface follows this grade.

In modern plants there is a second slatted floor, as shown in Fig. 37, upon which are molded and dried the large and intricate shapes which require careful drying treatment. The temperature is lower in the second floor and the ware cannot come in contact with the hot radiating floor. Moreover, the air is partly saturated with moisture from the ware on the hot floor, and in consequence the progress of the drying on the second floor is slower and safer.

It is also evident that all ware dried on the second floor is without expense for fuel and further that the hot floor can be kept at a maximum operation on ware that will dry safely under such conditions, so that the combination of a hot floor and upper drying floor is an economy which should not be neglected.

In a number of yards, waste heat is drawn from the cooling kilns by a fan and distributed through the building in galvanized iron pipe so that blasts of hot air can be turned on the stacks of bricks that have reached a drying stage, where they will stand rapid finish. This is the only use in fire brick plants of waste heat from cooling kilns, but with the advent of the tunnel dryer in the fire brick factories, a greater use of this valuable heat will be made.

Hot floors are sometimes built with brick flues covered with cast iron or steel plates. The steam pressure may be so low that the leakage through the lapped joints of the plates is hardly noticeable.

The use of hot floors is not uncommon in brick and tile plants. The bricks may be handled on pallets and dumped directly on the floor as with fire bricks, or they may be placed on foot pallets and delivered to the floor by lifting trucks, the bricks remaining on the pallets until dry—or flat pallets, lifting cars and supporting stanchions may be used as illustrated under air drying, or the dry floors may be equipped with tracks and standard dryer cars. The latter, however, would hardly be considered. The hot floor is not the most efficient type of dryer, and if a car equipment is to be used, a better type of dryer should be adopted. The advantage of the hot floor is that it lends itself readily to the use of pallets and lifting trucks or lifting cars. A good feature of it is that after once in full operation there is a large mass of concrete and earth heated up, which, in a number of plants, suffices to carry the operation through the night without the use of steam, or, in other words, we store up enough heat in the day time to run the plant through the night.

The hot floor dryer has some advantages in small yards where the operation is not continuous throughout the year, and where no waste kiln heat is available, but is hardly to be recommended for large capacity plants, except in the fire brick industry, where it is necessary to watch the progress of the drying.

Compared with other types of modern dryers the cost of installation is low, which is usually a consideration; the labor cost is not excessive, especially in small yards where the distances are short; a combination of brick and drain tile very common in small yards, works nicely with the hot floor, since the more easily drying tile may be dried on the upper floor.

CHAPTER VIII.

Sewer Pipe Floors.

THE DRYING ROOMS for sewer pipe, drain tile and fireproofing hardly need any description. Manufacturers of drain tile, fireproofing and other hollow ware that do not need to be finished after leaving the machine or press are adopting tunnel dryers for the small sizes of ware, but retain the dry floors for the large sizes.

A sewer pipe dryer is a large building with three to four floors, including the ground floor. The customary plan in the past, and still largely followed, has the steam piping under the second floor. The press is placed to deliver the ware on this floor, and the large sizes which have to be turned as the drying progresses are lowered by gravity to the ground floor. The steam pipes being overhead, all this ware is heated by radiation from above, and the top of the ware dries first, as it should, and the finishing work is done when the pipes are in the best condition for this work. It is necessary that little or no drying take place in the large pipe at the floor level, because the weight of the pipe would prevent shrinkage and the pipe would crack to relieve the shrinkage strains. As soon as the top is dry, sufficiently so that the danger of cracking from any drying which might occur at the floor level is obviated, the pipe is turned, bringing the bottom to the top, and is then left on the floor until the drying is completed. The pipe leaves the press with the socket down, but it is turned at the machine and placed on the shod (pallet) with the socket up and so placed on the floor for the initial drying.

The upper floors are always slatted where a single piping system is used, but in some sections the floors are made solid and there is an overhead pipe system for each floor. The slatted floors are made of four-inch strips spaced about one-half inch. The second floor in a single heating system plant is the most rapid drying floor, and upon it is placed, or should be placed, the small ware which will stand rapid drying.

The hot air from the lower floors rises through the slatted floors to the upper floors, gathering moisture in its course and finally escapes through monitors on the roof.

A frequent annoyance is the condensation under the roof and constant dripping on the ware. Steep roofs (one-fourth pitch or more) covered with shingles will not "sweat," but such roofs are not regarded with favor on account of fire risk. To prevent dripping from flat roofs, a ceiling is put in, thus giving air space, and an occasional steam pipe under the roof maintains a temperature sufficient to prevent condensation.

An average one-press shop has a capacity of from sixty to seventy-five tons per day, and the dry floor space required is from 800 square feet to 1,000 square feet per ton of ware. This means from 50,000 square feet to 75,000 square feet of floor, and the dimensions of a three-story factory will be in round numbers, 100x200 feet.

It is desirable to have the building rectangular rather than square; first, on account of light, and second, to distribute the ware in front of the kilns in which it is to be set.

The press is preferably placed in an annex midway of the length of the dryer.

The green ware from the press is lowered to the ground floor on gravity drops, and elevated to the upper floors on power elevators. When dry, the ground floor product is wheeled or trucked direct to the kilns, and the upper floor product is lowered on gravity drops, which at the same time return the empty trucks to the floor in question.

In most instances no provision is made for the admission of air, and the supply depends upon leakage, open doors, elevator shafts, etc.

There is no data in regard to the quantity of piping. Originally the single pipe system used one-inch pipe spaced 12 to 15 inches under the entire second floor except around elevator, etc. This would require from 15,000 to 18,000 feet of piping, or 5,000 to 6,000 square feet of radiating surface, not counting mains and headers, verticals and returns, roof piping, etc., which materially increase the radiating surface. It is arranged in sections and all of it is not necessarily in operation at the same time. Later plants have put in 1¼-inch pipe without increasing the spacing beyond 15 inches, which would give in excess of 6,000 square feet of radiating surface, not counting the mains, etc.

In determining the radiating surface required to heat a given building, R. C. Carpenter used the following formula:

$$H = \frac{NC}{55} + G + \frac{W}{4}$$

in which H = heat units per degree difference in temperature; C = cubic content of the building; G = glass surface; W = wall surface; N = number of times air is changed per hour. We estimate that a building 100x200 feet, three stories high, has 600,000 cubic feet content, 15,000 square feet wall surface and 2,700 square feet glass surface. For winter work, let us assume the outside temperature as 32 degrees F. and the room temperature 92 degrees F.

N can be obtained from the volume of moisture to be removed. Sixty tons of clay made into pipe will contain fifteen tons, or 30,000 pounds of water, which must be removed every twenty-four hours. If the air enters 70 per cent. saturated and leaves fully saturated, each cubic foot will remove .002 pound of moisture, and therefore there must be 15,000,000 cubic feet of air pass through the building each day, or air in the building must be changed

$$\frac{(15,000,000)}{(600,000)} = 25 \text{ times in 24 hours.}$$

$$\frac{\frac{25 \text{x} 600,000}{24}}{55} + 2,700 + \frac{15,000}{4} + \frac{20,000}{10} = 19,810.$$

$$19,810 \text{x} (92 - 32) = 1,188,600 \text{ B.T.U. per hour.}$$

We add to the wall surface the approximate roof area on the the basis of wood construction. In ordinary building heating the roof need not be considered, because usually an attic intervenes between it and the rooms to be heated; but there is no attic in a sewer pipe plant. Carpenter assumes a radiation value of 280 B.T.U. per hour per square foot of steam radiating surface:

$$\frac{1,188,600}{280} = 4,245 \text{ square feet radiating surface.}$$

Assume that summer conditions are 82 degrees F. outside temperature, air 70 per cent. saturated. We determine in the same way that 1,295 square feet of radiating surface will be required. In the last determination each cubic foot of air takes out .00108 pound of moisture and 27,800,000 cubic feet will be required daily, or, in round numbers, the air in the building must be changed twice per hour.

These calculations do not take into consideration the working conditions in a pipe dryer. We are heating up seventy-five or more tons of clay and water from some lower temperature to 92 degrees F. and evaporating 30,000 pounds of water. We may neglect the sensible heat in the mass, so far as the dryer is concerned, because it presumably heated up in preparation and pressing. There remains 30,000 pounds of water to be evaporated at 92 degrees F. The latent heat at 92 degrees is 1,041.1 B.T.U. per pound, and the total heat required per day will be 30,000x1,040.1=31,203,000 B.T.U., or, in round numbers, 1,300,000 B.T.U. per hour. The radiating surface required will be

$$\frac{1,300,000}{280} = 4,643 \text{ square feet.}$$

Adding this to the radiation losses, we find 8,888 square feet of radiating surface required for winter work and 5,908 square feet for summer work.

The problem is merely illustrative, and we have made no attempt to work out the niceties of it, which would only confuse the main points which we wish to bring out.

It is evident that a radiating surface of 6,000 to 9,000 square feet will be required, depending upon climatic conditions.

It is also evident that the older factories with 6,000 to 7,000 feet of radiating surface were not fully efficient under unfavorable weather conditions, and this probably accounts for the increase in piping in the more recent factories. As an offset to this the older factories were wood structures, the conductivity of which is less than one-half that of brick, and $\frac{W}{4}$ in the formula becomes $\frac{W}{10}$ or less, depending upon the insulation.

There is no published data in regard to the power required to operate a sewer pipe dryer. One-press shops usually install three to four boilers with a rated power of 400 to 450-h.p., but when occasion requires one of these can be cut out for cleaning or repairs without shutting down any part of the operation.

An approximation of the power required for drying may be made from the preceding problems. In the winter problem we have 1,188,600 B.T.U. per hour to maintain the factory temperature, and 1,300,000 B.T.U. per hour for the evaporation of round numbers, 1,300,000 B.T.U. per hour. The radiating sur- the water, making a total of 2,488,600 B.T.U. per hour. A boiler horse power is rated at 30 pounds of water from 100 degrees F. steam at 70 pounds pressure, and this requires 33,450 B.T.U. The boiler horse power therefore for the above requirement would be 75, but this is unquestionably too low. There are boiler losses, pipe losses in transmission to the dryer, frictional losses in moving the steam and water through the piping, leakage losses, steam losses in the return mains and vacuum pump. Allowing 10 per cent. for these losses brings the boiler requirement for drying alone to about 83-h.p. We have no data to determine whether 10 per cent. is even an approximation of these losses. The boiler radiation losses alone have been carefully calculated and even determined direct, and when the boilers are properly protected, are reckoned at 4 per cent. Besides the actual work of drying, there is the heat required for the plaster and molding rooms, clay preparing room,. press room, etc., which cannot be separated from the actual boiler requirement.

Waste heat from cooling kilns is not largely used in sewer pipe drying. Three or more plants were built to use waste heat in connection with steam piping, but in one instance at least the method was abandoned. The steam piping was placed under the second floor, as usual in older plants. Figs. 40 and 41 show the methods of introducing and distributing the air in two factories. A plate fan collects the hot air from the cooling kilns, or from sectional steam heating coils, and forces it into the building through galvanized iron pipes (Fig. 41). From the verticals, under each floor, are four small distributing pipes, so placed and of such an extent that each riser suffices for six sections of the floor, or about 1,500 square feet. Fig. 40 shows the distributing outlet in another plant. In this instance the heat was distributed under the lower floor only. Each perforated pipe was enclosed by a galvanized iron pipe, also perforated to mate with the perforations in the inner pipe. When it was desired to shut off the heat in any section, the outer pipe was turned so the holes missed connection. We believe the hot air system in the latter plant was abandoned. and also in one plant using the distributing pipe system. The difficulty in such hot air system is to get even distribution of the heat. Sections of the floor immediately over and adjacent to the heating pipes will get greater heat than intermediate sections, and if the clay is at all tender there will be excessive loss in cracked ware in the vicinity of the distributing pipes.

Another method of working out this waste heat problem which is in successful operation, is to have a deep basement under the lower floor, with steam pipes under the first floor. The hot air from the kilns is simply blown into the basement,

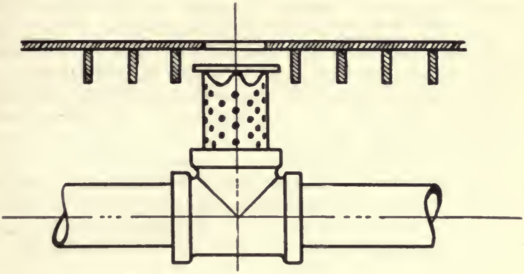


Figure 40.

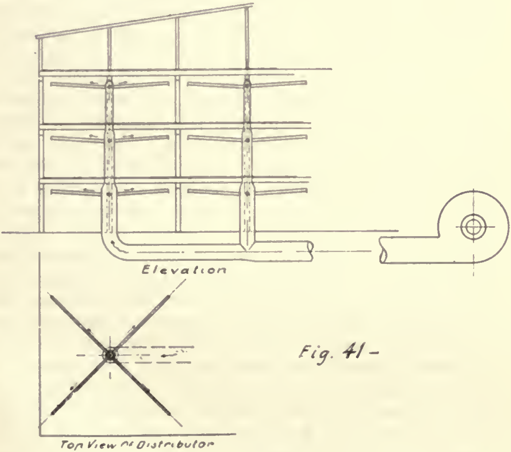


Fig. 41-

in which there is ample space for diffusion before its passage among the steam pipes and up through the slatted floor. There could be no marked changes in temperature from one section of the floor to the next, and one could easily learn what portion of the floor must be reserved for tender drying ware. No ware is placed on the basement floor.

This recalls another point previously mentioned in regard to sewer pipe plants; namely, that in very few plants is any specific provision made for ventilation. Leakage is relied upon for inlet air and windows in monitors for outlet.

The use of a fan as above mentioned insures any desired volume of air, and it is practical to distribute it uniformly through the several floors. Natural exhaustion at the top is perhaps satisfactory, but we believe a forced exhaustion by suction fans would be better.

Many people have the erroneous idea that moisture ladened air is heavier than dry air and attempts have been made to adapt down comer ventilators. This is a mistake. The more moisture air takes up the lighter it becomes, and completely satured air has the least weight per cubic foot, temperature of course remaining the same. Water vapor is lighter than air, and instead of being taken up by the air, displaces it. A cubic foot of dry air when saturated with vapor will occupy more than a cubic foot of space, and the moisture has a lower specific gravity. As air cools, however, it becomes heavier, and the cooling effect should be counteracted by secondary heating, which at the same time prevents condensation of the moisture. The air rising from the first floor, whether the floor be heated or not, is partly saturated with moisture. Passing the pipes under the second floor, it becomes heated and its capacity for moisture correspondingly increased. The ware on the second floor gives up moisture to the air without saturating it, but, in passing through the third floor and the fourth floor, both in taking up moisture and cooling, the air becomes saturated, and may have little or no capacity for moisture in the upper floor, and, because of its greater weight through cooling, it acts as a blanket or damper. With steam pipes under the third and fourth floors, we maintain the temperature and the air is lighter in consequence of the vapor and becomes lighter with each increase of vapor. Of the capacity of the air to take up moisture, 25 per cent may be used in the first floor, 25 per cent in the second, 25 per cent in the third, and complete saturation reached in the fourth. The air becomes more buoyant as it rises and we only need to maintain the temperature by steam pipes under the roof until the air can reach the exits, where it will discharge itself fully ladened with moisture and carrying materially more moisture than if heated only by a single system of piping under the first or second floor.

We recall only one instance in which a tunnel dryer for small ware was used in connection with dry floors for large pipe, and the operation was not satisfactory. On drain tile, however, which does not have to be rolled and finished, the modern plant uses a tunnel dryer for small sizes and the dryer floors for large tile.

CHAPTER IX.

Periodical Dryers.

ANY DRYER, in which the ware remains stationary during the drying, is periodical, and the open air and the kiln dryers previously described belong in this class. There are two distinct advantages in the periodical dryer:

1. It is adapted to the use of lifting cars or trucks, or a conveyor system for delivery of the ware into the dryer and removing it when dry.
2. In some types it permits slow heating up with as little or as much air as may be desired, and when the ware has reached a condition where it will stand rapid drying, the temperature may be advanced to any degree within the limits of the heating equipment and any required volume of air may be introduced.

Steam Pipe Dryers.

A combined radiation and convection periodical dryer consists of a series of tunnels with steam pipes under the tracks or runways, and sometimes along the sides. With the air inlets and outlets closed, the ware can be heated up by radiation with no convection except such air currents as may be occasioned by leakage. When the ware has been heated up and thus put through any desired degree of humidity treatment, the air vents may be opened and the drying finished rapidly. With the steam pipes in the dryer tunnels we have no radiation loss except that from the dryer building itself, which is unavoidable in any dryer.

As will be seen under the description of the progressive type of waste heat dryers, a large volume of air is required to bring in sufficient heat to do the drying.

In the periodical steam dryer we need very little air, merely sufficient to sweep out the moisture as it is developed. The problem figures as follows:

An ordinary tunnel is 100 feet long and holds 7,000 brick. If each brick contains one pound of water, and the drying period is twenty-four hours, we have 7,000 pounds to evaporate and remove from the dryer in that period. Assume that the air enters at 60 degrees F. and 70 per cent. saturated, then from the table of vapor capacities, page 19, we find that each cubic foot of air brings in .00059 pounds of moisture. If the dryer is heated to 200 degrees F., which can easily be done with high pressure live steam, the incoming air and moisture expands to

$$\frac{1}{491+(60\text{-}32)} = \frac{x}{491+(200\text{-}32)}$$

From which we find $x = 1.27$

from Charles' law that the volume of gas is proportional to the absolute temperatures and a cubic foot of the expanded air will contain

$$\frac{.00059}{1.27} = .00047 \text{ pounds of moisture.}$$

From the same table of vapor capacities we find that saturated air at 200 degrees contains .03024 pounds per cubic foot, and therefore each cubic foot of air will remove from the bricks $.03024 - .00047 = .02977$ pounds. To remove 1,000 pounds of water in twenty-four hours, we must have in round numbers 33,600 cubic feet of air at 200 degrees, or 26,450 cubic feet at 60 degrees.

We determine the radiation loss as follows:

A tunnel is 3 feet 6 inches wide, 4 feet 8 inches high and 100 feet long, and contains 1,630 cubic feet, from which we deduct 346 cubic feet for brick and cars, leaving 1,288 cubic feet, and since the air required per tunnel for drying is (7×33600) 235,200 cubic feet, the air in the tunnel must be changed (235,200/1288) one hundred and eighty-two times in twenty-four hours, or 7.6 times per hour.

In a battery of six tunnels there will be 867 square feet of exposed wall, 233 square feet of iron doors, and 2,500 square feet of well-insulated roof, the radiation from which may easily be reduced to one-twentieth that of glass. The radiation from iron is 1.1 times that from glass, and the other factors have been given in the discussion of sewer pipe drying.

Using Carpenter's formula, we get for radiation loss from one tunnel

$$\frac{7.6 \times 1288}{55} + \frac{233 \times 1.1}{6} + \frac{867}{4 \times 6} + \frac{2500}{20 \times 6}$$

= 277 B. T. U. per degree difference of temperature per hour. The difference in temperature is 200 — 60 = 140, and the total radiation loss per tunnel will be 277 × 140 = 38,780 B. T. U. per hour, or 930,720 B. T. U. in 24 hours, or 930,720/7 = 132,960 B. T. U. per 1,000 pounds of water evaporated.

It may be noted from what follows that the radiation loss as determined is about 9 per cent. of the total heat requirement. It has been customary to estimate dryer losses at 10 per cent., and it was also formerly customary to estimate kiln radiation losses at 10 per cent., but some commercial tests have shown kiln radiation losses up to 70 per cent. It is probable that a well-insulated dryer will have a radiation loss less than 10 per cent., and our calculations confirm this.

The value of such calculations in which there are a number of assumed factors may be questioned, but we hold that any calculation is a better basis for the exercise of one's judgment than a mere guess.

In the drying we have the following heat requirement per thousand bricks:

1,000 pounds of iron to be heated from 60° to 200°.

6,000 pounds of clay to be heated from 60° to 200°.

26,450 cubic feet, or 26,450 × .075 = 1,984 pounds of air to be heated from 60° to 200°.

1,000 pounds of water to be evaporated at 200°.

15.6 pounds of water vapor originally in the air, to be heated from 60° to 200°.

The specific heat of iron is taken as .12; of clay, .2; the sensible and latent heat required in changing water at 60° to vapor at 200° is 1118; the mean specific heat of a gas is k + s (T + t). For water vapor the value of "k" is .42 and of "s" is .0001, while for air "k" is .234 and "s" .000012. "T" and "t" are the temperatures less 32°.

1000 × .12 × 140 =........................ 16,800 B. T. U.
6000 × .2 × 140 =........................ 168,000 B. T. U.
1984 × [.234 + .000012 (168 + 28)] 140 =... 65,650 B. T. U.
1000 × 1118 (Heat in vapor at 200—60)=...1,118,000 B. T. U.
15.6 × [.42 + .0001 (168 + 28)] 140 =...... 960 B. T. U.

1,369,410 B. T. U.

Adding the radiation loss as previously determined, we have a total heat requirement of 1,502,370 B. T. U. per thousand bricks dried.

The next problem is to determine the amount of piping required.

Carpenter's factor of 280 B. T. U. radiation per square foot of radiating surface may be used, but it is only applicable to problems in which the current of air passing over the piping is very slow.

The rule of thumb, in which the quantity of heat given off from steam pipes varies from 1.25 to 3.25 B. T. U. per square foot per hour per degree difference, gives us a basis upon which to exercise our judgment, but it makes no separation of radiation and convection.

The amount of heat given off depends upon radiation and convection. The radiation value is constant for each temperature, but the convection value depends upon the size of the pipe and the number of changes of air.

It is evident, as will be seen in the discussion of indirect heating, that with increased circulation we get greater condensation and in consequence greater heat return from a given amount of piping. Richards' "Metallurgical Calculations" adopts the basis that the heat given off varies as the square roots of the velocities and uses the formula,

$$2+\sqrt{v} : 2+\sqrt{V}.$$

A familiar illustration of the advantages of circulation is that of a heater which is insufficient to heat a closed room by natural circulation, but which becomes sufficient if a fan is placed to force the air in contact with it. There is no change in the conditions except greater circulation, which increases the convected heat taken from the heater.

We can readily calculate the radiation and convection values for natural ventilation, but when we attempt to correct these values for increased changes of air we get into difficulties which make the calculations of little or no value.

We have the assurance, however, that the piping required for natural ventilation, other things being equal, is in excess of that required for greater velocities of air among the piping.

We have found the following method the most satisfactory in determining radiation and convection losses. It is based on Peclet's experiments, upon Newton's law of radiation, and upon Dulong's corrections for Newton's law. The data for the calculation will be found in one form or another in several treatises on heating and ventilating (Box "Treatise on Heat," Kent's "Mechanical Engineer's Pocket Book," Carpenter's "Heating and Ventilating Buildings"), but as a rule it is not in convenient form for ready calculation.

According to Newton's law, the radiation from steam piping varies with the difference in temperature, namely, .64 × difference in temperature = radiation, but this has been found incorrect for wide differences in temperature.

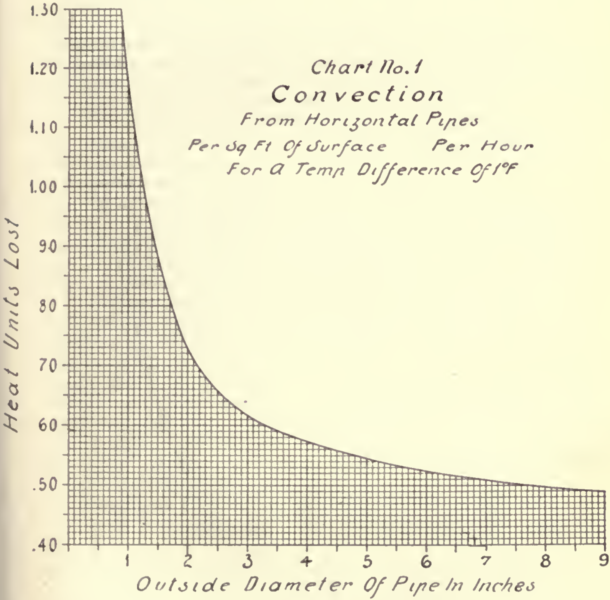
Factors For Reduction To Dulong's Law Of Radiation

Difference In Temp's Betw. Radiating Body And The Air, °F	Temperature Of The Air In Degrees Fahrenheit												
	32°	41	50	59	68	77	86	95	104	113	122	131	140
18°	1.00	1035	1.07	1.12	1.16	1205	125	1305	136	1415	147	1525	1.58
27	1.015	1052	1.090	1.140	1185	1230	1.275	1327	1380	1437	1495	1.552	1.610
36	1.03	1.070	111	116	1.21	1255	130	1.350	140	1460	152	1.580	164
45	1.050	1.092	1.135	1180	1.230	1277	1.325	1375	1425	1487	1.550	1.610	1670
54	107	1115	116	1.20	125	1300	135	1400	145	1.515	158	1640	1.70
63	1.095	1.137	1.180	1225	1275	1325	1375	1427	1480	1545	1610	1.670	1730
72	1.12	1.160	1.20	1.25	130	1350	140	1455	151	1575	1.64	1.700	176
81	1140	1182	1.225	1280	1.330	1380	1430	1487	1.545	1610	1675	1737	1800
90	1.16	1.205	1.25	1.31	1.36	1410	146	1520	1.58	1645	1.71	1775	184
99	1185	1.232	1280	1335	1.390	1440	1.490	1552	1615	1680	1745	1812	1880
108	121	1.260	131	136	142	1470	152	1585	165	1715	178	1850	192
117	1235	1.285	1335	1390	1450	1500	1550	1617	1685	1752	1820	1890	1.960
126	1.26	1310	136	142	148	1.530	158	1650	1.72	1.790	186	1930	200
135	1290	1340	1.390	1.450	1510	1562	1615	1685	1.755	1827	1900	1970	2040
144	1.32	1.370	142	148	154	1595	165	1720	179	1865	194	2010	208
153	1345	1397	145	1.510	1.570	1630	1690	1757	1.825	1902	1980	2052	2.125
162	137	1.425	148	154	160	1665	173	1795	1.86	1940	2.02	2.095	2.17
171	1.405	1460	1.515	1.575	1.640	1.705	1.770	1.838	1905	1.985	2.065	2.142	2.220
180	1.44	1495	1.55	161	168	1745	1.81	1.880	1.95	2.030	211	2190	2.27
189	1.470	1527	1.585	1650	1715	1.782	1850	1.922	1995	2077	2.160	2.247	2.325
198	150	1560	1.62	169	175	1.820	189	1965	204	2125	221	2.295	238
207	1.535	1.595	1.655	1.725	1790	1.860	1.930	2007	2.085	2.175	2265	2.347	2430
216	157	1.630	169	176	183	1.900	197	2050	213	2225	2.32	2400	248
225	1605	1667	1730	1.806	1865	1.940	2.015	1.975	2180	2277	2.375	2.455	2.535
234	1.64	1.705	177	1.84	1.90	1980	2.06	2.145	2.23	2.330	2.43	2510	259
243	1675	1742	1.810	1880	1945	2025	2.105	2192	2280	2.380	2480	2.565	2650
252	1.71	1780	1.85	1.92	1.99	2070	215	2240	2.33	2430	2.53	2.620	2.71
261	1.750	1.820	1890	1965	2.040	2122	2.205	2.295	2.385	2.485	2.585	2680	2775
270	1.79	1860	193	201	209	2175	2.26	2.350	2.44	2.540	264	2740	2.84

The factors for correction are given in the following table, and it will be sufficiently accurate for practical purposes to take the factor nearest to the required temperature and determined difference of temperature.

Chart No. 1 gives the convection losses of different sizes of piping for one degree temperature difference per square foot of surface and Chart No. 2 gives the factors for correction necessary in wide differences of temperature.*

In our problem we have a temperature difference of 247°, the nearest to which in the first column of the table is 243°. The factor for this difference of temperature and for an air temperature of 59°, which is nearest our assumed air temperature (60°), we find to be 1.88. The heat given up by radiation then is .64 × 1.88 × 247 = 297 B. T. U. By interpolations to get the exact factor, we find the radiation to be 301 B. T. U., which shows that the table is sufficiently extended



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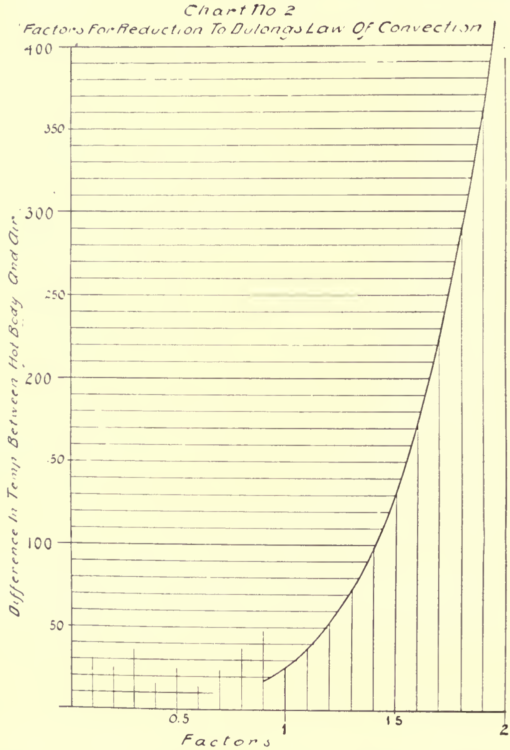
*Our problem is based on the use of live steam at 60 lbs. pressure, which has a temperature of 307° F.

for practical problems. Figuring the same problem from data given in "Heating and Ventilating Buildings" (Carpenter), we get 322 B. T. U.

Convection is determined from the charts No. 1 and No. 2.



Our problem assumes that 1-inch pipe will be used, which has 1.315 inches outside diameter.

From Chart No. 1 we find that piping with diameters of

1.3 inches strikes the curve opposite .97 heat units lost. From Chart No. 2 we find that 247 difference in temperature projected to the curve and thence to the base co-ordinate gives a factor of 1.73.

The convection loss, therefore, is $.97 \times 1.73 \times 247 = 414$ B. T. U. From the data given by Carpenter, the convection value for the assumed conditions is 380 B. T. U. The total radiation and convection loss from our table and charts is 711 B. T. U. and from Carpenter's data 702 B. T. U.

From our table and charts it is possible to figure the problem for any difference of temperature, for any outside air temperature and for any size of piping, and the results are sufficiently accurate for any practical problem. The result we obtained above, reduced to B. T. U. per degree difference, gives us 2.87 B. T. U. per square foot per hour.

With a heat development of 711 B. T. U. per square foot per hour, or 17,064 B. T. U. per day, we will require for the estimated heat requirement of 1,502,370 B. T. U. for 1,000 bricks, 88.2 square feet of heating surface.

The average capacity of a tunnel is 7,000 bricks, and therefore 616 square feet of heating surface will be required per tunnel, or 1,848 lineal feet of 1-inch pipe.

Low-pressure steam—let us say 5 pounds—will have a temperature of 227° F. and the difference in temperature will be 167°. From the table of factors we find that the factor for a temperature difference of 171° and air temperature of 59° is 1.575 and the heat given off by radiation will be $1.575 \times .64 \times 167 = 168$ B. T. U.

From Chart No. 1 we get for 1-inch pipe the factor .97, as before, and from Chart No. 2, for a temperature difference of 167, we get the factor 1.58. The convected heat then is $.97 \times 1.58 \times 167 = 256$ B. T. U., making the total heat loss 424 B. T. U. per square foot per hour, or 2.54 B. T. U. per degree difference per square foot per hour.

The piping required under such condition would be

$$\frac{1,502,370}{424 \times 24} = 147.6$$

square feet per thousand bricks, or 1,033 square feet per tunnel, or 3,099 lineal feet of 1-inch pipe per tunnel.

The above determinations of convected heat are for natural ventilation, and do not take into consideration the increase which comes from increased circulation essential in natural draft dryers. The solution of the problem for natural draft dryers requires too many uncertain assumptions to give results of any value, as the following discussion will show:

In a coil heater we space the pipes 2¾ inches and the free area will be 1.435 inches. If we have eight pipes in a row we may count nine spaces or 12.915 inches of free area in the row, and for a square foot of free area we must have a section (144/12.915) 11.15 inches long, in which there will be 11.15 × 8 = 89.2 inches of piping, which is equivalent to 2.48 square feet of heating surface. We require per tunnel 26,450 (page 79) × 7 = 185,150 cubic feet of air per day, or 7,715 cubic feet per hour. If the tunnel is 100 feet long we have

$$\frac{100 \times 12 \times 12.915}{144} = 107.6$$

square feet of free area. The velocity of the air is

$$\frac{7715}{107.6} = 71.7$$

cubic feet per hour through each square foot of free area. A cubic foot of air requires .018 B. T. U. to raise the temperature one degree—the formula is $[.018 \times .0000009\ (T + t)]\ (T - t)$—and 71.7 cubic feet will require 1.29 B. T. U. to raise the temperature one degree.

Under natural ventilation we have, as previously determined, 414 (page 84) B. T. U. convection value, or since each square foot of free area has 2.48 square feet of piping, we have available 1,028 B. T. U.,

$$\frac{1028}{1.29} = 797°,$$

which is an impossible temperature from the piping.

It becomes evident at a glance that the volume of air required to carry out the moisture is not sufficient to carry the heat required in the drying, making full allowance for the heat obtained direct from radiation. It follows that since the incoming air cannot take enough heat from the piping to meet the dryer requirement, there must be circulation within the dryer by which the hot air, after being cooled by the ware and by the evaporation of the water, returns repeatedly to the piping to again become heated, and meanwhile there is escaping from the dryer a quantity of air equivalent to that entering. The purpose of this discussion is to bring up the question of convection relative to the number of changes of air. We have figured the heat values for natural ventilation, and with any increased velocity of the passage of the air over the heating surface the heat loss from the piping due to convection increases and the area of heating surface correspondingly decreases. If we were introducing sufficient air for the heat requirement at a single passage through the piping, then we could determine the velocities for the assumed conditions and for natural ventilation from the formula,

$$\frac{2+\sqrt{V}}{2+\sqrt{v}}$$

and could determine within a practical degree of accuracy the increased heat loss from the piping in consequence.

In the problem in question the quantity of air is such that it attains a maximum temperature before passing all the heating surface, and because of this cannot increase the convected heat.

The circulating air becomes the factor from which we must figure any increased convection, and as this will have a higher temperature than the entering air, we must base any calculations on lower differences of temperature, which means less convected heat per square foot of piping per hour, and in consequence more piping to deliver the requisite amount of heat. We cannot determine the velocity of the circulating air, nor the efficiency of its contact with the piping, nor its temperature upon its return to the piping. It is not possible, therefore, to figure the problem without several uncertain assumptions, and it is best to determine the piping by the method previously set forth from data which can readily be determined, and beyond this to be governed by one's judgment or experience in similar equipment, bearing in mind that as we increase the volume of air or the circulation, we increase convection and decrease piping, and as we decrease difference of temperature between the air and the steam we decrease convection and increase piping.

We have considered only actual steam temperatures in the piping, but there should be some allowance made for loss in transmission from steam to piping, and for conduction through the piping. It is possible to calculate these losses under assumed conditions, but an allowance of 3 to 5 degrees in the temperature difference will usually fully cover such losses.

Figures 41 and 42 show plan and sectional elevations of a steam pipe dryer which, as shown and with various modifications, has found frequent use.

A double row of steam pipes are placed at the floor level under the cars of bricks, and a single row is placed along the walls on each side of each tunnel. The dryer is roofed as shown and down comer flues are inserted in the walls at intervals. The flues are connected with cross horizontal flues at the bottom, forming an inverted T, which extends under the floor piping. The air supply enters through these flues. Alternating with these air inlets are stacks in the roof of the tunnels and extending through and above the protecting roof.

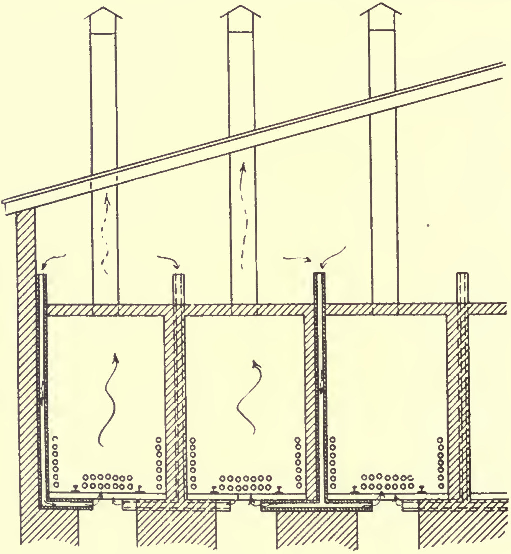


Figure 41.

It will be noted that one feature of this dryer is that the air is taken from the space between the tunnel roof and protecting roof, and it is heated to the extent of any radiation from the tunnel roof.

As much as 3,200 lineal feet of one-inch pipe is used in each tunnel 100 feet long, which is a greater heating surface than that determined by our estimate, but it must be remembered that actual conditions can only determine the amount of piping. We find in use some dryers with less piping than the theoretical amount calculated by us, and some with more, all dependent upon the work to be done and the time.

The dryer shown is properly periodical, but where the clay will stand the severe treatment, the dryer is operated progressively. In the periodical dryer the steam is shut off until the tunnel is filled, and is then turned on and the heat raised as the ware will stand it. If the clay is very tender drying, the air inlets and stacks may be closed until the ware is

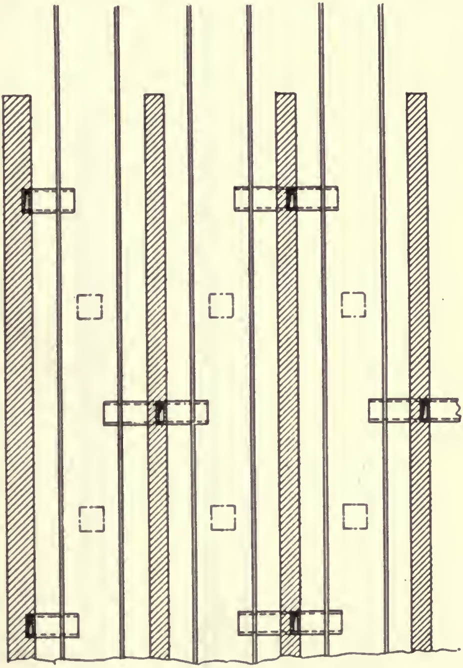


Figure 42.

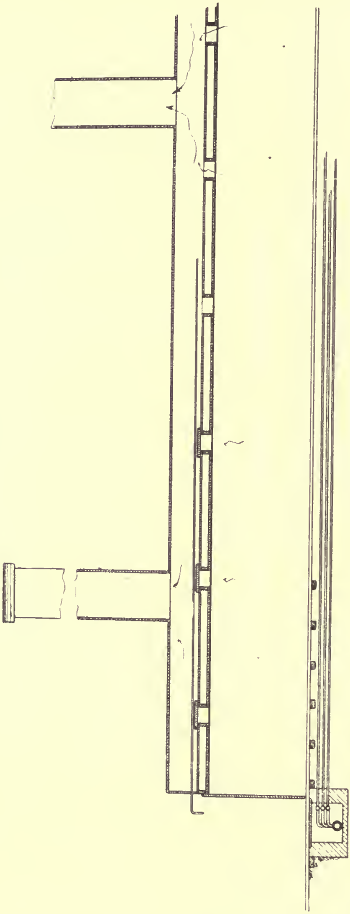


Figure 43.

heated up and in a safe condition to stand the admission of air, and only such amount of air should pass through the dryer as may be needed to carry out the moisture.

In operating the dryer progressively, cars of freshly made ware are put in at the receiving end as fast as cars of dried ware are taken from the delivery end. The steam is on all the time, and the ware from the machine enters at once a drying atmosphere having temperatures of 200 to 250 degrees F., which many clays will not stand. Another objection to the progressive operation is that it would be difficult to adjust the inlets and outlets so that in each part of the tunnels longitudinally there will be the economical relation between air and moisture, and in consequence complete saturation is not attained.

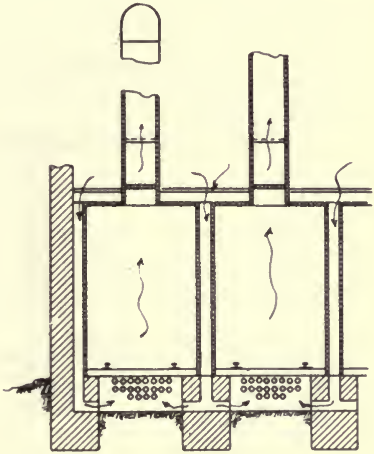


Figure 44.

Figures 43 and 44 show plan and sectional elevations of a periodical steam dryer designed exclusively for tender drying clay. The piping is arranged in three rows and the connections are such that each row is independent. No effort is made to control the individual air inlets except that the roof space from which these inlets draw the air is entirely enclosed, and when desired they can only get such supply as may be derived from leakage. It is not necessary, however, to have any control of the inlets. The outlets are controlled by slide dampers, which can be operated from either end of the dryer.

As soon as a tunnel is filled with ware, the slide dampers to the flue leading to the stacks are closed, and steam is turned into the bottom row of pipes, followed by the second and third row as experience may determine. Thus the ware is heated up in a humid atmosphere, which has proven very effectual as a preliminary treatment in drying tender clays. Following this humidity treatment the slide dampers are drawn, slightly or fully, as the ware may require, and the drying proceeds as in the first described type of steam dryer.

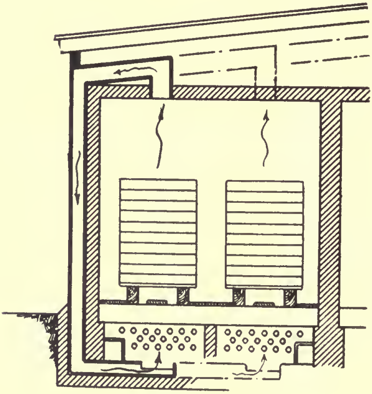


Figure 45.

Figure 45 shows a periodical steam dryer which is used in several plants. The dryer consists of three tunnels holding two rows of bricks in each tunnel. The bricks are handled on lifting trucks in units of about one hundred. Under each row of bricks are three rows of one-inch pipe, making a total of about 2,000 lineal feet of piping for each row of bricks containing approximately 14,000 bricks in the length of the tunnel, or 110 feet. At intervals in the roofs of the tunnels are openings into inclined cross ducts and the latter connect with galvanized iron ducts in the outside walls, which in turn lead under the piping. The moisture ladened air rising from the bricks passes through the openings in the tunnel roof, thence to the flues in the outside walls, where it is presumed to become cooled, the moisture condensed and carried away by a drip at the ground level. It is assumed that the air in this way renews its ability to take up moisture, which is true to whatever extent it becomes heated in passing among the steam piping, but it must be evident to any one that the air thus returned to the dryer is fully saturated all the time while the outside air on an average will not be more than 75 per cent. saturated. No heat is conserved, because the air returned to the dryer has the same temperature as outside air. Possibly the inventor had in mind that the latent heat in the vapor, which is nearly 75 per cent. of all the heat required, would be returned to the air entering, but instead it is given to the outside air.

Under progressive dryers will be described one which actually gives back to the dryer the heat value of the latent heat in the vapor and the additional heat required is that necessary to maintain the dryer losses exclusive of the evaporation of the water.

In the dryer under discussion a small air duct extends along the wall on either side of each tunnel inside the tunnel. These ducts connect with the outside air at the ends of the tunnels and have frequent inlets into the tunnels in their length. The purpose of these is to supply leakage losses, and to restore the air which is carried out by small stacks at the end of the dryers.

So long as clayworkers continue to build dryers which are palpably wrong in principle, it is evident to us that they need instruction in the principles that govern drying.

One point possibly favorable to the above described dryer is that it might have some application as a humidity dryer. If we had absolutely dry air at a temperature which would give it a vapor capacity of "J," let us say, and air containing moisture, but at such a temperature that it also had an additional vapor capacity of "J," will the latter be a safer drying medium than the former? This is affirmatively answered by some, and numerous instances are cited where steam injected into the hot air at the delivery end of the tunnels has overcome considerable loss in the drying. If the temperature is below 212 degrees one can readily see how the steam could be of benefit by reducing the rate of drying through increase in the degree of saturation, but under such conditions lower temperatures should accomplish the same purpose, yet do not. If the temperature is above 212 degrees, the addition of steam theoretically could not affect the rate of drying, since above the boiling point the capacity of the air, if we may so express it, becomes infinite, or, in other words, so long as the steam can escape we cannot lower the drying rate by the introduction of more steam. We do not know whether vapor in itself has any influence on the drying. Undoubtedly numerous instances of the benefits of steam are to be found in high volume air progressive dryers, in which, as will be seen under the discussion of progressive dryers, saturation is not complete at the exhaust end. In such instances the steam introduced at the hot end simply serves to increase the humidity in such parts of the tunnel where humidity is needed to prevent loss through too rapid drying. We have seen steam introduced into the hot air entering the dryer in a number of instances with beneficial results, but we must admit that we cannot see what part it plays in safer drying, unless it corrects a fault in the dryer and adjusts the degree of saturation to a safe degree.

Figures 46 and 47 in plan and section show the general principles of a hot air periodical dryer (Bechtel) which is extensively used in the United States and Canada.

There are a series of parallel tunnels opening on top into the dryer building. A cross duct at one end connects these tunnels with a fan with steam coils attached. The inlets to the floor tunnels are controlled by dampers hinged at the top. On either side of the open floor tunnels are stringers from four to six inches high above the floor level which serve as supports for the pallets containing the bricks. The pallets are loaded at the machine with eighty to one hundred and twenty bricks each and carried to the dry room on lifting trucks and placed on the stringers over the tunnel. As soon as a tunnel is fully covered, burlap is thrown over the bricks, and the hot air is turned into the tunnel duct. The burlap serves as a blanket to prevent rapid escape of the air and permits the latter to become highly saturated with moisture.

Waste heat from cooling kilns may be used in connection with the steam coils, and as the latter may be heated during the day by exhaust steam the drying may be largely done with waste heat.

It is common practice to use eight sections of coils, each section to have four rows of one-inch pipes staggered to insure thorough contact with the incoming air. For brick dryers the pipes are spaced 2¾ inches on centers and the free area so obtained is approximately one and one-half times the area of the fan inlet.

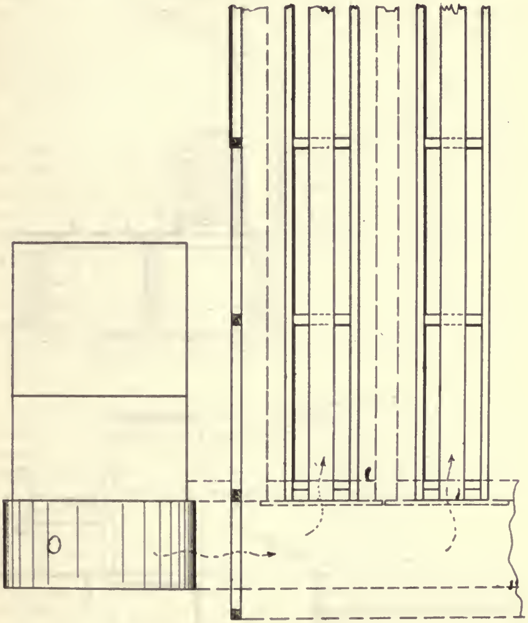


Fig. 46

The fans used are disc, plate, or squirrel cage type, but the latter is the most economical in power consumption and the first mentioned the least economical.

Carpenter has shown that the economic limit of the number of rows of pipes in a heater is between 16 and 24, and in consequence we will get no return from any pipes in series in excess of twenty-four except at air velocities which

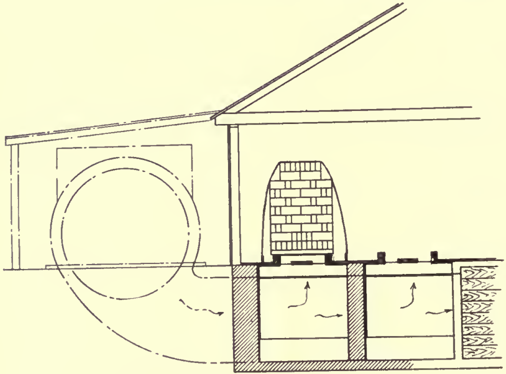
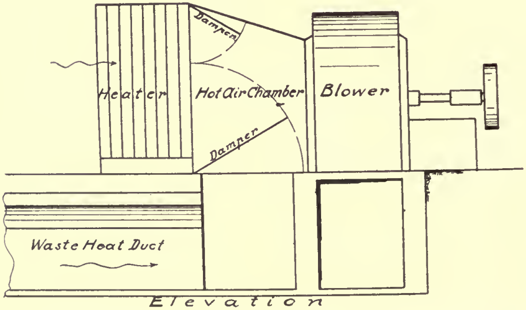


Fig. 47 Cross Section



Elevation
Fig. 48

would not be considered in designing a clay ware dryer. This, of course, applies to a constant pressure.

As stated above, the common practice is to use eight sections containing a total of thirty-two pipes but six sections having a total of twenty-four pipes are arranged for exhaust or low pressure steam, and the final two sections are supplied with high pressure live steam. In this way we get the value of the large amount of latent heat in the exhaust steam and after the air has reached approximately the temperature of boiling water, it is brought in contact with the high temperature live steam pipes and its temperature is raised above 212 degrees F. by the sensible heat of the high pressure.

Figure 48 is a sectional elevation of steam coils, waste heat duct and fan. A damper, or set of dampers, is provided so that any proportion of the necessary volume of air can be obtained from the coils or duct. When there is no waste heat available from the kiln, the duct to the fan is closed and all the air is drawn through the coils involving in many instances the use of live steam to maintain a required air temperature. When the waste heat has an excessive temperature it is tempered with air through the coils and on such occasions nothing but exhaust (waste) would be used in the coils. As the kilns cool the volume of air from them may be increased, and, as needed, live steam is introduced into the coils.

Figure 49 and Figure 50 show in plan and elevation the general principles of a properly connected heater. Both high pressure and exhaust steam are conducted to the coils and controlled by valves and traps so that we may use exhaust or low pressure live steam in six sections, and high pressure steam in two sections, or all the sections may have exhaust steam or high pressure steam as desired, when suitable traps are provided.

The condensation water may be drained back to a receiver and automatically pumped back into the boilers, or tilting traps may be used to deliver the water from the coils to the boilers. Frequently we use a vacuum pump to exhaust the coils and in this way get greater efficiency.

There are many modifications in fitting up the equipment, and a variety of traps, impulse valves, etc., which apply under different conditions, but it is not the purpose of this article to discuss them. Every problem should be worked out by a competent steam engineer and installed under his direction.

One advantage of this type of dryer is that there are no steam pipes under the bricks to be damaged and covered by broken bricks falling from the pallets, and such debris in the tunnels can be easily cleaned out from time to time.

It is very important that the ducts be properly proportioned throughout and the openings from the floor ducts be adjusted to insure a uniform pressure in all parts of the system, otherwise the bricks nearest the cross duct and those over the tunnels nearest the fan will dry first. Since in many installations it is necessary to entirely unload a tunnel before resetting it, and, if the hot air is not properly distributed, the bricks most distant from the fan will be slow drying, and further, since the capacity of the dryer will be determined by these slow drying parts of the system, it is highly important that we get proper distribution of the hot air to all parts of the system.

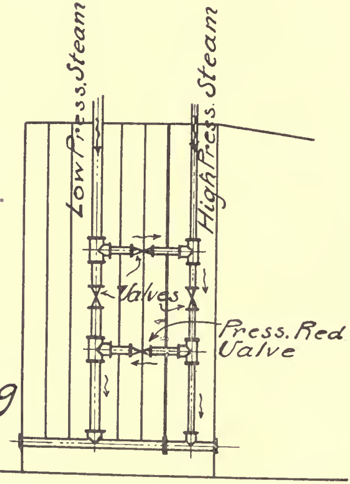
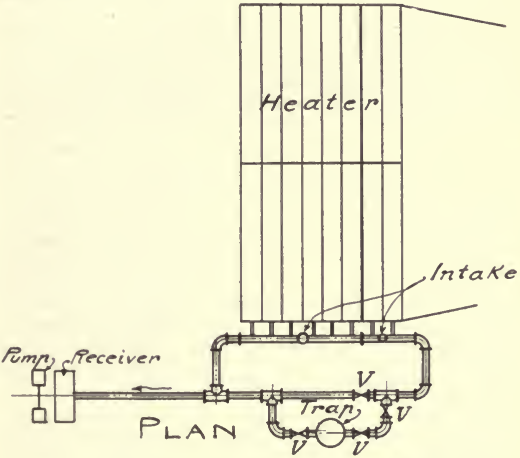


Fig. 49

ELEVATION
SHOWING INTAKE PIPING

Clayworkers who attempt to build this dryer, or any other for that matter, without consulting the designers, usually lose much more in efficiency and thereby in increased cost of operation, than they save in the installation. The distribution of air volumes cannot be accurately pre-determined and the builder of any equipment requiring the uniform distribution of air or gases who has frequent opportunity to practically adjust the equipment to the highest efficiency can work out the problems of a new installation much more effectively than one whose knowledge of the dryer is based on the operation in a neighboring factory, and the efficiency of a properly constructed equipment will be a profitable investment.



PLAN
SHOWING EXHAUST
Fig. 50.

This is the first dryer we have described in which the heating pipes are outside the dryer, but we will find similar heating systems in other types of dryers and a brief discussion of this method of heating will not be out of place here.

In sectional coil heaters used in connection with fan draft, the coils are always placed outside the dryer and the air is sucked through them and forced into the dryer.

One fact which becomes apparent is that we need no longer consider the radiated heat, or, at least only in such degree as the casing and internal construction material other than the piping are heated by radiation and in turn give up the heat by conduction to the air passing through the heater. The radiated heat which we may neglect is not lost, however, except in part that from the outside casing of the coils, since it passes from pipe to pipe and becomes useful in maintaining the temperature of the surface of the pipe, or, in other words, it reduces the condensation which otherwise would occur. In the direct heating system we have radiated and convected heat applied to the purpose of drying and each requires its proportion of steam condensation. In the indirect heating, convection alone carries heat into the dryer but the radiation by maintaining the surface temperature may be said to be given up to the dryer by convection, not to increase the convected heat but to reduce the condensation loss. The convected heat carried into the dryer is constant for any given difference of temperature and fixed air velocity and we get less heat from the indirect method than by the direct and correspondingly less condensation, but we can increase the condensation and thereby the convected heat by increasing the velocity of the air. We would not think of putting the pipes outside the dryer in a natural ventilation system, because, first, as previously pointed out, the volume of air is insufficient to carry the heat required, and second, even though the air volume were sufficient we would have to greatly increase the amount of piping. Increased air velocity, however, completely changes the situation.

There are several formulas to determine the temperatures available for steam coils, but they are not convenient for the clayworkers' use.

The manufacturers of heating and ventilating equipment publish the data in the most convenient form, and the following table is taken from Bulletin No. 273, of the American Blower Company, Detroit, Michigan.

Table No. 1.

To Determine Temperature Rise for Any Steam Pressure or Initial Temperature.

$$R=\frac{T-t}{K}.$$

K=constant as follows.
R=rise.
t=temperature incoming air.
T=temperature steam.

K is as follows for any Pressure and Initial Temperature:

No. of Sections Deep.	300′ Vel.	600′ Vel.	900′ Vel.	1,200′ Vel.	1,500′ Vel.
1	3.9	4.91	5.57	6.2	6.66
2	3.19	2.76	3.13	3.48	3.75
3	1.615	2.04	2.30	2.56	2.75
4	1.333	1.68	1.91	2.12	2.28
5	1.21	1.46	1.66	1.85	1.99
6	1.142	1.32	1.49	1.66	1.785
7	1.11	1.24	1.385	1.54	1.66
8	1.088	1.19	1.310	1.44	1.55
9	1.072	1.152	1.26	1.36	1.46
10	1.06	1.130	1.220	1.305	1.40

If "t" is above Zero add to "R" for Final Temperature.
If "t" is below Zero deduct from "R" for Final Temperature.

Table No. 2.

Properties of Saturated Steam.

Gage Pressure in Lbs.	Temp. F.	B. T. U. in Water	Latent B. T. U. in Steam	Total B. T. U. in Steam
0	212.0	180	970.4	1150.4
1	215.3	183.4	968.1	1151.5
2	218.5	186.6	966.2	1152.8
3	221.4	189.6	964.3	1153.9
4	224.4	192.5	962.4	1154.9
5	227.2	195.3	960.6	1155.9
6	229.8	198.0	958.8	1156.8
7	232.3	200.5	957.2	1157.7
8	234.8	203.0	955.6	1158.6
9	237.1	205.4	954.0	1159.4
10	239.4	207.7	952.5	1160.2
15	249.7	218.2	945.5	1163.7
20	258.8	227.4	939.2	1166.6
25	266.8	235.6	933.6	1169.2
30	274.0	243.0	928.5	1171.5
40	286.7	255.9	919.4	1175.3
50	297.6	267.2	911.3	1178.5
60	307.3	277.1	903.9	1181.0
70	316.0	286.0	897.3	1183.3
80	329.9	294.3	891.0	1185.3
90	331.1	301.8	885.3	1187.1
100	337.8	309.0	879.8	1188.8
125	352.2	324.4	867.8	1192.2
150	366.3	338.0	857.0	1195.0
200	387.8	361.3	837.9	1199.2

To determine the temperature rise we take the difference between the temperature of the steam at any pressure, (table 2) and the temperature of the air and divide by the proper factor from table 1, which gives us the desired temperature.

If we have both low and high pressure steam, we determine the temperature for the low pressure, then with this temperature as the value of "t" we determine the temperature from the high pressure sections.

For example, if we have six sections on exhaust steam at 5 pounds back pressure, and two sections at 60 pounds pressure, with the air at 60 degrees and an initial velocity of 900 feet per minute, we proceed as follows: Low pressure temperature from table 2, 227°.

$$\frac{227-60}{1.49 \text{ (from table 1)}} = 112^\circ \text{ F.} = \text{gain in temperature}$$

$112+60=172^\circ$ = temperature after passing the six low temperature coils.

High pressure temperature from table 2, 307°

$$\frac{307-172}{3.13} = 43^\circ = \text{additional gain in temperature}$$

$172+43=215^\circ$ = final temperature.

It is not claimed that these tables give accurate results, but they are sufficiently close for practical work, and they have the advantage of a ready reckoning which the busy man desires. Greater accuracy can be obtained by calculating the velocity for each section from the formula:

$$\frac{V}{491+(t-32)} = \frac{x}{491+(T-32)}$$

and find the factor for the calculated velocity by interpolation in table 1. For instance, if in the above example we determine the velocity after passing six sections we get a velocity of 1,094 feet per minute and the factor for two sections will be 3.35. This factor gives us an additional temperature of 40 degrees instead of 43 degrees as previously determined. The error is appreciable and would be still more so if we were to calculate the velocities after passing each section, but the difference will be well within the margin of safety allowed by engineers especially in problems of this character for which there is not sufficient experimental data upon which to base an accurate estimate.

The problem of determining the amount of piping required for any given requirement will be worked out in the discussion of progressive dryers and need not be taken up now, except to outline the data.

If the one inch pipes are spaced 2¾ inches the space between will be 1.435 inches and 8.37 spaces one foot long requiring an equal number of pipes will be found in each square foot of free area. This gives us $8.37 \div 3 = 2.79$ square feet heating surface in each row per square foot of free space, or $2.79 \times 32 = 89.28$ square feet of radiating surface in an eight section heater for each square foot of free space. If the velocity is 900 feet per minute we have this many cubic feet of air per minute heated to a temperature of 215 degrees as previously determined, by 89.28 square feet of radiating surface, or reduced to pounds there will be $.074 \times 900 = 66.6$ pounds of air per minute. The mean specific heat of air for volume is

$$[.0188 + .0000009\ (T+t)]\ (T-t)$$

and for weight is

$$[.234 + .000012\ (T+t)]\ (T-t).$$

From this we find that we get 1640 B. T. U. per hour per square foot of radiating surface, which is a decided advance over the return in B. T. U. in natural ventilation. Having determined the B. T. U. per foot of piping we only need to estimate the dryer requirements to ascertain the quantity of piping required.

The Boss Dryer.

Fig. 51 shows a recent dryer development (Boss) in which the lifting car and pallet system is used, but the heating arrangement is quite different from any other type of dryer.

Between the car tunnels are superheating tunnels containing auxiliary steam pipes.

The main heating equipment is a mass of steam pipes in the main air duct in front of the fan. (Not shown in the sketch.) In this dryer, the steam pipes are between the dryer and fan. Exhaust steam exclusively is used in the piping in the main duct. The air entering through the fan is forced among the pipes in the main duct and becomes heated to the full possibility of exhaust steam. Exhaust steam is used in the heating tunnels of the dryer proper and the air in passing these pipes is brought up to the full temperature permissible from exhaust steam. Were it desired, live steam in the auxiliary (tunnel) piping would produce a higher temperature.

Under the steam pipe tunnels are air ducts with inlets into the heating tunnels, which connect at the receiving end of the dryer with a cross duct from a fan.

The pallets have double floors, the bottom being tight and the top perforated, in other words, they are flat boxes with perforated tops. When the pallets are in place they form a part of the hot air distribution system, since they cover ducts from the heating tunnels and have openings through their bottoms to admit the hot air into the pallet and thence the air rises through the mass of bricks and escapes at the top. To prevent lateral escape of the air movable curtains are adjusted to the sides after the tunnels are fully covered with loaded pallets.

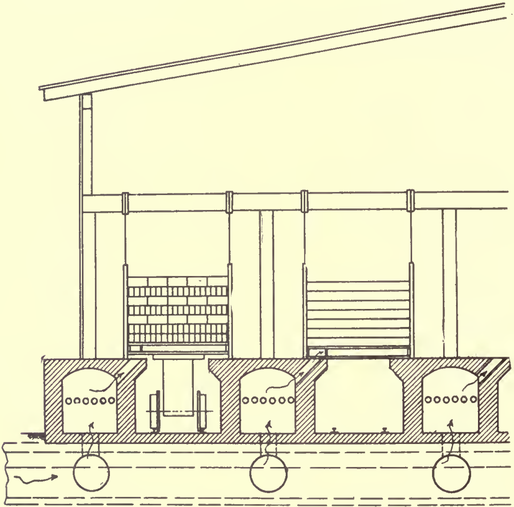


Fig. 51 Cross Section

Waste heat or any heat source is applicable to this system, in conjunction with the steam heating or independent thereof.

The drying principle is exclusively up draft, which has long been held by brick makers to be the best method of drying. The upward passage of the air among the bricks is retarded to any desired practical degree by close setting of the bricks and the top courses may be set to act as dampers, thus preventing too rapid escape of the air.

There are no pipes in the car tunnels and the heating tunnels are covered so that no debris can get into the heating tunnels except such as may fall through the small connection between pallet and heating tunnels when the pallets are removed.

The Pipe Rack Dryer.

The pipe rack dryer shown in Fig. 52 is used in many yards where the clay will stand such severe treatment. It is so well known to the clayworking fraternity that a description is hardly necessary.

The dryer is simply a series of steam pipe racks upon which the flat steel pallets containing the bricks are placed.

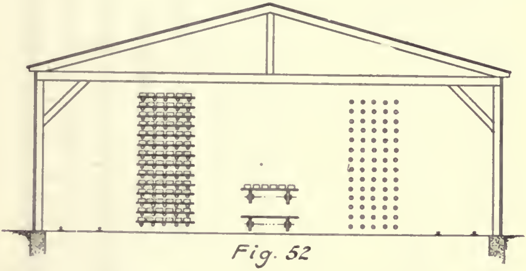


Fig. 52

It is customary to build the racks in four sections each holding 7,500 to 10,000, making the daily capacity of each unit dryer 30,000 to 40,000 bricks.

The pallets loaded with bricks are delivered into the dryer in the passageway between the racks on rope conveyors and the empty pallets are returned on the same conveyor using the under return ropes for the empty pallets.

A thirty thousand capacity dryer will have four quarters each containing eight sections ten feet long and fourteen rows high. In each row there are five one-inch pipes. The total piping therefore for 30,000 bricks per day is 22,400 lineal feet, not including connections and fittings. Reducing this to square feet of heating surface per thousand bricks we

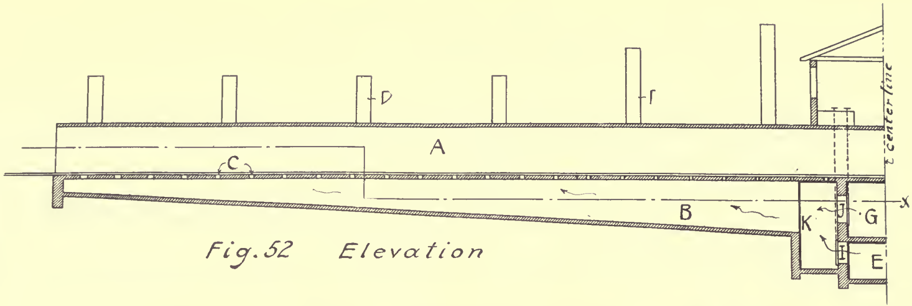


Fig. 52 Elevation

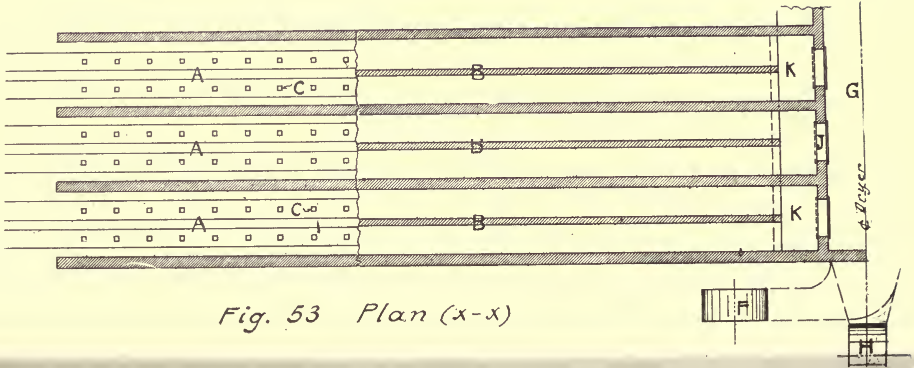


Fig. 53 Plan (x-x)

get 249, which is greatly in excess of the piping requirement as figured for periodical tunnels.

It is likely that the degree of saturation is not high, but the dryer can be depended upon to deliver its full quota of bricks every 24 hours, which is a very important factor in economical operations.

Tender Clay Dryer.

Figs. 52 and 53 show in plan and section one-half of a recently patented periodical dryer, the purpose of which is control of the drying conditions in each tunnel independent of the other tunnels. It has a series of double tracked tunnels, "A," as in some other types of tunnel dryers and under each track is a distributing duct, "B," for the hot air, with graduated inlets, "C," through the tunnel floor, similar to the distributing ducts in waste heat progressive dryers. The moisture ladened air, after leaving the ware, escapes through a series of ventilators, "D," in the roof of the tunnels.

There are two main cross ducts—"G" and "E"—one above the other, to supply the distributing ducts with air. From each cross duct there are damper controlled openings, "I" and 'J," into a series of mixing chambers, "K," directly connected with the distributing ducts.

The lower cross duct, "E," connects with a fan, "F," and the air supply is direct from the outside; namely, cold air.

The upper cross duct, "G," has a separate fan, "H," drawing heated air from any source of heat—kiln, auxiliary furnaces, heating coils, etc.

The illustrations show the cross ducts in the center of the dryer, but this is not essential. It, however, enables the builder to construct a dryer twice as long as one having the heat and air supply at one end, or in a shorter dryer it insures more perfect distribution of the heat and air and in consequence a more equitable temperature from end to end of the dryer, and more uniform drying of the ware.

Cold air alone, or hot air, or a mixture of cold and hot air in any degree and in any volume, may be forced into each, any, or all tunnels, as desired.

After a tunnel is filled with ware, the damper inlet, "I," from the cold air cross duct may be slightly opened, thus permitting a small volume of low temperature air to enter. As the ware will stand more rapid circulation, the cold damper can be opened to greater extent. Following this the temperature of the air can be increased by opening the inlet, "J," from the hot air cross duct and can be carried higher and higher by further increase of the latter opening, at the same time reducing the cold air inlet.

No. 1 tunnel may be filling and the air inlets will be closed, thus disconnecting this tunnel from the cross air ducts. No. 2 tunnel may be unloading and its dampers also will be closed. The drying in No. 3 may be so far advanced that the full hot air temperature may be used and it may get its supply of air entirely from the hot air duct, while No. 4 tunnel may require a mixture of hot and cold, in which case both hot and cold air inlets will have their dampers partially opened, and No. 5 tunnel, just starting, may, perhaps, safely use only cold air. It may be that a factory is making two kinds of ware, one of which requires a slow careful drying, while the other will stand rapid treatment. It is claimed that all of these conditions are practicable in this dryer.

At first glance one would say that a progressive regulation would be difficult to control, but regular progression probably is not the intention of the inventor, nor is it necessary. The operation would likely be in stages—two or at most three—and experiment must determine the temperature and duration of each stage for the different wares. Each tunnel is provided with a recording thermometer, and when a tunnel is first connected, the dampers may be adjusted to the desired temperature for the first stage. At the expiration of the first period the dampers may be adjusted to bring the temperature to that required during the second period, and again for the third period, should a third period be required. Intermediate adjustments would be required to correct variations in the temperature of the air from the sources of supply.

The dryer is essentially for tender drying clays, such as require careful treatment in the start but which may be finished rapidly. The ordinary waste heat dryer has to be adjusted for the careful treatment all through in order to protect the tunnels freshly filled and in consequence the full drying period is excessive, often times impractically so. For such clays a dryer which enables the operator to advance the rate of drying in each tunnel independently, has a decided advantage. For clays which will stand abuse in drying, the temperature can be maintained at a maximum all the time and a single control through the hot air fan would be simpler than any multiple control. This single control is equally applicable to the above described dryer in which event the cold air fan and duct become superfluous.

A feature of the dryer, especially for hollow ware, is that the movement of the air is directly upward through the ware and the drying is more uniform and there is less damage in in consequence. There are several dryers, both periodic and progressive, in use, having this updraft feature, and the promoters of the horizontal draft types justly claim that one cannot get full value from the heat by a single short passage of the air through the ware—in other words, that the saturation will not be complete and there will be a waste of heat. This is true, but of no moment, if only waste heat is used in the drying. If heat is generated for the drying, naturally the less degree of saturation will require more fuel, but this may be offset by quicker and safer drying.

A standardization of sixty-eight Ohio clays showed 15 per cent that could be safely dried in commercial operations in twenty-four hours; 51 per cent required from twenty-four to seventy-two hours; 19 per cent were only safe between seventy-two hours and seven days, while the remainder required in excess of seven days. Ohio is a favored state in its clay-working materials, yet the percentage of clays that rank first class in drying behavior is low. There are few states that can make as good a showing as Ohio, and there are some states in which good drying clays are so rare that 2 per cent will probably include all that are first class in drying qualities. There is, therefore, a large field for a tender clay dryer.

CHAPTER X.

Pottery Drying.

UNDER THE HEAD of pottery we include all ware which is the work of the potter—white and yellow ware, porcelain, electrical ware, sanitary products, stoneware, etc.

The drying of these wares requires different conditions, depending upon the size and shape of the ware, upon the mixture and upon the process of manufacture.

In view of the varying treatment required in the several wares, there is no general type of dryer applicable to all, and it is beyond the province of this article to describe the drying methods in any detail.

Pottery is largely the product of hand labor and each piece as it leaves the potter's hands, or at most several pieces on a pallet, is taken to the dry room by hand.

Since hand work enters so largely into the manufacture of pottery, it is essential that the work rooms have abundance of light and air, and in general we find the potters' benches, jollys, jigs, etc., along the outer walls of the factory building.

Since the ware is moved by hand another essential feature is that the distance from the benches to the dry rooms shall be a minimum.

In consequence of these two factors we frequently find the dry rooms in the center of the manufacturing room. The distance to the dry room is thus very short, and, of course, equally short from the dryer to the finisher or back to the potter, to whom the molds must be returned.

A modern arrangement for some lines of ware is the continuous operation plan, now applied to so many industries, in which the raw materials enter at one end and in each stage of the manufacture advance toward the warehouse for finished ware, which places the dry room adjacent to the manufacturing room and opening into it. The succeeding rooms depend upon the character of the ware and the process of manufacture.

The dry rooms for small ware consist of a series of compartments four or more feet wide, depending upon the size of the ware, and ten or more feet long, depending upon the width of the building and the space required for the potters. On either side of each compartment are shelves spaced to suit the ware in question and extending to the ceiling of the room. The passageway between the shelves is simply wide enough for the workmen who fill and empty the shelves, and is made as narrow as possible in order to get a maximum drying capacity within the allotted space. In some lines of ware the compartments or dry rooms are provided with doors which close the room when not being filled or emptied, but in other lines the rooms are merely racks, with passageways for the workmen distributing the ware.

The heating is by steam pipes, usually three one-inch pipes along the floor under each set of shelves, or six pipes to each room. As the ventilation is natural, usually very crude and slow, the air within the room is practically heated by radiation, or, more properly should we say, that the fixtures, walls, shelves, molds, etc., are heated by radiation, and the air is heated by contact with the pipes, and with the fixtures, etc. In some lines of ware which will stand more rapid treatment, the pipes are distributed under each shelf, or each alternate shelf, which brings the heating surface in closer touch with the ware.

As in other clay industries, insufficient drying room is one of the handicaps of the pottery industry, and potters are constantly studying the problem of how to increase the drying operation within the space available, without damage to the ware and without increased cost.

Instead of the rooms with passageways the dryer becomes more compact—in fact, the space occupied is more than doubled in capacity—by having the shelves hung on trolleys and overhead tracking, which permit pulling them out for filling and emptying. Thus, each shelf is brought nearer the potter and the distance traveled per day by the off-bearers is lessened. Every foot increase in the distance the ware has to be moved adds to the cost—otherwise there would be no question in regard to dryer capacity. At first glance, the movable shelf plan seems the most advantageous, but it must be remembered that there must be a wide space between the potters' benches and the shelves to provide room for the shelves when pulled out, besides working room around them.

It is a question whether the movable shelves with their greater initial cost and greater cost of upkeep have any advantage over the fixed racks with passageways.

Mr. Herford Hope, in a paper before the sixteenth annual meeting of the American Ceramic Society, and later in a lecture before the potters of Ohio in the Ohio State University, presented a new type of pottery dryer adapted to small ware.

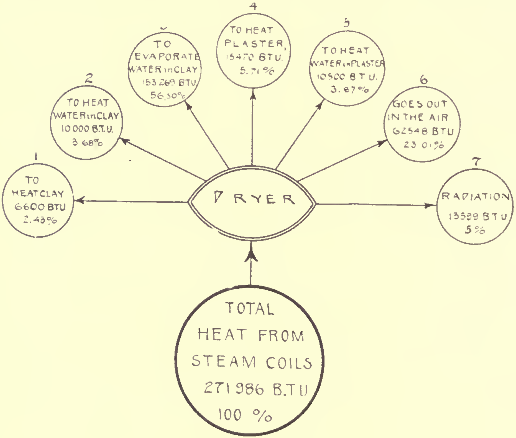


Fig. 54

Instead of rectangular rooms with shelves on either side, or rectangular racks which can be moved in and out on trolleys, he suggests a hexagonal closet. In the center of each closet there is a vertical shaft to which the shelves are attached radially, and the whole shelf contrivance can readily be swung around a circle, similar to a revolving clothes horse. The door to this closet is opposite the potter's bench, and the passage into it between any two sets of shelves, is "V" shaped. As the shelves of each section or "V" of the shelves are filled, the apparatus is moved one section. Mr. Hope shows that no greater floor space is occupied and that the off-bearers travel less distance per day. If no greater floor space is occupied, and the distance traveled by the off-bearers is reduced, the hexagonal closet is an advance over the rectangular, provided the first cost and the subsequent upkeep are not excessive.

A vertical shaft properly installed offers no mechanical difficulties, and the upkeep will be practically nothing. The initial cost will be greater than the fixed shelves, but not as great as the shelves attached to trolleys. It seems, therefore, that Mr. Hope offers to the pottery industry a decided advance in the type and arrangement of the dry rooms.

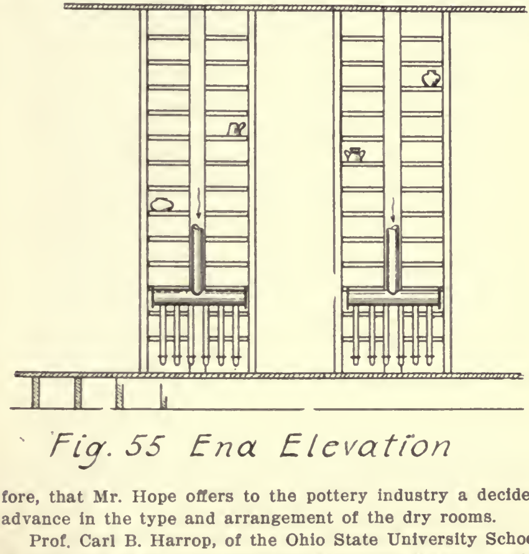


Fig. 55 End Elevation

Prof. Carl B. Harrop, of the Ohio State University School of Ceramics, in a lecture before the potters of Ohio, on the subject of "Pottery Closet Dryer Calculations," assumes the radiation and convection from the steam piping to be 3.25 B. T. U. per hour per square foot of radiating surface per 1 degree difference in temperature. In a note he explains: "In a case of this kind, it is exceedingly difficult to determine just how much of the heat is radiated from the pipes and how much is carried away from the pipes by convection (by the incoming air). Experiments and calculations show that the radiation will be approximately 1.25 B. T. U. The difference, 2 B. T. U. (3.25—1.25), cannot be carried in by the amount of air at 120 degrees, which was calculated as sufficient to carry out the moisture.

"The explanation of this is that there is an internal circulation of the air going on continuously inside the dryer, i. e., some of the air which goes into the dryer, becomes heated, rises, gives some heat to the ware, takes up some moisture from the air and escapes. Other portions of the entering air does not escape immediately but cools sufficiently to drop to the bottom of the dryer and again passes around the pipes, is reheated and rises again to perform more work."

This accords fully with our view of the action of a natural

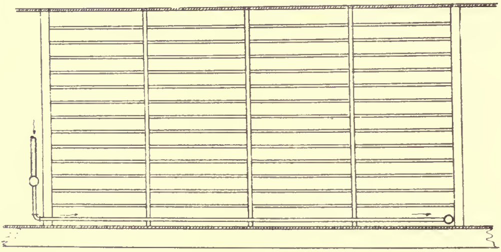


Fig. 56 Side Elevation

draft steam pipe dryer as expressed in a previous article of this series.

Prof. Harrop's data is based upon 5 pounds steam pressure and 60 degrees temperature of incoming air, and his calculations develop the preceding diagram—Fig. 54—as the heat balance for a white ware pottery dryer.

The calculations lead to the conclusion that a closet 4 feet 3 inches wide (containing shelves on either side and passageway in the center), 8 feet high and 10 feet long, will require six 1-inch pipes, 10 feet long, which is common pottery practice.

Figs. 55 and 56 show end and side elevation of the general construction of fixed pottery shelves for small white ware, stoneware, and other ware not too large to be placed in shelves, and which will not permit piping under each shelf.

CHAPTER XI.

Terra Cotta and Other Special Dryers.

IT IS A QUESTION whether we are justified in describing a dryer as typical of terra cotta. We have seen terra cotta modeled in a single piece over 40 feet long and 10 feet high. After the modeling the piece in question was cut into sections to be dried and burned, but each section was so complicated that the drying had to be watched and controlled. For such ware, and there is a great deal of it, a dryer of any type is obviously out of the question.

Monumental pieces of terra cotta can only be dried on the modeling floor, and the drying process involves the use of wet cloths here and there on each piece to insure uniform drying without damage.

This is equally true of other delicate wares, such as glass pots, flattening stones and retorts, some of which exceed a ton in weight, and the manufacture of which from start to finish requires several months.

Smaller terra cotta products, such as moldings, etc., which can be cut into small pieces of uniform size, can be dried more quickly, and such pieces may be and usually are removed from the modeling floor to some type of dryer.

One prominent terra cotta plant has the modeling floor (press room) underlaid by flues from the kilns, and all the heat from the burning kilns passes under this floor. At night, arrangement is made to force into the press room hot air from cooling kilns. This method is economical, but lacks sufficient control.

In two, perhaps more, installations the press room is underlaid by steam pipes in sections, each section being controlled by valves.

In several instances special dryers are provided for ware which will stand more rapid treatment than that of the press room.

Fig. 57 shows a dryer used in the manufacture of terra

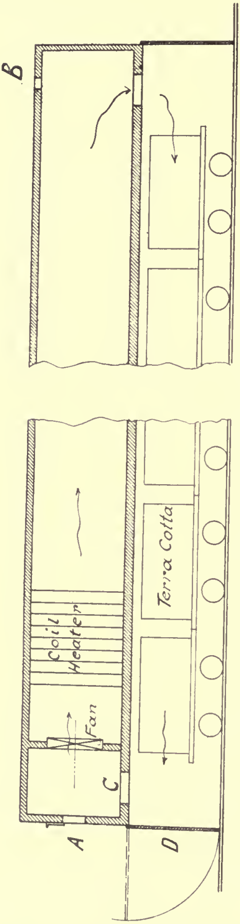


Fig. 57 Longitudinal Section

cotta. It is of the tunnel type and two-storied. The lower tunnel receives the terra cotta on cars. In the upper tunnel is a fan and set of steam coils.

The fan forces the air through the heating coils, thence the length of the upper tunnel, from which it passes into the lower tunnel and returns to the fan. With no outlet for the air there will be no incoming air, and the fan merely creates circulation. When the air becomes fully saturated no drying can take place.

In one instance the practice was first to continue this circulation until the ware became fully heated up, then to open a door, "A," in the end of the upper tunnel leading to the fan, also open the exit door, "D," of the lower tunnel, and close the opening, "C," between the upper and lower tunnels at the fan end. With these changes the fan would draw air from the outside, force it through the coils and to the end of the upper tunnel, then down into the lower tunnel and returning to exhaust at the delivery end of the latter.

In two other installations a small relief or escape hole, "B," is placed at the end of the upper tunnel opposite to the fan. Part of the air, forced through the coils by the fan, escapes through this relief hole, while the remainder passes through the ware and returns to the fan.

The quantity of air which escapes through the relief hole must be replaced by outside air through "A." The lower tunnel doors are kept closed all the time except in filling and emptying, and after the inlet and vents are adjusted to the ware no changes are necessary.

In this dryer we have the most satisfactory conditions for drying difficult ware—a rapid circulation of hot, nearly saturated air.

In two factories which have come under our observation all ware that has reached the stage of rapid drying and can be removed from the press rooms (which have steam-heated floors) is taken to drying rooms which have slotted floors and through which air is forced by a plate fan. The air is drawn from the outside through heating coils, or from cooling kilns. It is also provided that hot air, after passing through the dryers, may be forced into the press room to maintain the temperature of the latter and provide a nearly saturated air, which is desired for the initial drying stages of freshly molded wares, and also during the modeling.

Typical waste heat progressive dryers are also used in some factories.

The Scott System.

The Scott system is a method of drying, rather than a dryer, since the purpose of the system is to eliminate the dryer. It is applicable to stiff-mud bricks. Dryer cars, trucks, etc., are replaced by conveyor belts.

The take-off belt from the cutter is extended along the fronts or ends of the kilns. Opposite the entrance of each kiln a cross-conveyor takes the bricks from the main conveyor into and through the kiln, and from this belt they are taken off by the setters.

The bricks are set six to eight courses high, or to whatever height they will carry the weight. The floor of the kiln is completely covered to this height, and it is the aim of the system to have the kilns of such size that they will hold one day's run of machine.

The kilns have a system of under-floor flues, and after the kiln floor is fully covered with the first setting of bricks, hot air by means of a fan is forced through these distributing flues and up through a perforated kiln floor, among the bricks, and escapes from the top of the setting.

If the clay will stand rapid drying, the bricks so set can be dried during the night sufficiently to carry the weight of a second setting on top of the first lot.

In this case the cross-conveyor is raised to the proper height for a second setting, and the total height at the end of the second day is twelve or more courses. At night the heat is again turned in, perhaps completing the drying of the first setting, and hardening the second setting sufficiently to carry the weight of a third setting. The operation is repeated until the kiln is filled to the proper height, and the burning begins with the advantage that, except the last setting, the bricks are dry, or nearly so, and heated up.

If the clays will not stand such rapid work, two kilns are used alternately, thus giving thirty-six hours for drying each setting.

The take-offs, dryer transfer men and tossers in the kiln are eliminated, except one man is required to remove the waste cut from the belt where cutters making a waste cut are used, and one man is required to transfer the bricks from the main belt to the cross-conveyor.

Before introducing the hot-air system of drying, it was attempted simply to set the bricks in the kiln as high as they would stand and dry them during the night by means of light fires in the furnaces, but this method of drying failed because it was impossible to properly distribute the heat, and the system only became practical with the introduction of hot-air drying as worked out by Mr. Scott.

In one instance, where natural gas was available, gas pipes with a series of jet flames were placed through the arches, and at night these were kept burning to provide heat for drying. We do not know how successful this gas firing method proved to be, but it has not been duplicated so far as we know.

The gas-pipe method of drying is very simple, but it is only applicable to up-draft kilns, while the Scott system in its entirety is equally applicable to up-draft, rectangular down-draft, and chambered continuous kilns, and is in operation in yards equipped with these several types of kilns.

The Underwood system of burning up-draft kilns with producer gas would give a wider use of the Scott system of conveying and drying, provided it is practical to dry the bricks in kilns with a direct flame, as in the natural gas flame method mentioned above.

Among brickmakers, especially those using continuous kilns, there has been some discussion in regard to the possibility of drying the bricks regularly set in the kiln, thus eliminating the dryer.

The practicability of this is doubtful. In the first place, few clays will in the green state support the weight of regular setting.

Next arises the difficulty of regulating the rate of burning to that of drying, and this has been found a difficult problem, and an unsolved one in this country, by those who are trying to introduce car tunnel kilns for drying and burning, in which the bricks are set on cars at the machine and the loaded cars travel successively through the several stages of drying, burning and cooling in a tunnel kiln. The discussion of this operation belongs under the head of progressive dryers and will there be considered.

However, if drying in the continuous kiln becomes practicable, it will lead to a decided change in the construction of our kilns, and in this event a kiln along the lines of the German zigzag kiln, with its low crowns and convenience for mechanical setting, would likely be developed.

Among the economies suggested by those discussing the problem is that of fuel, the claim being made that the drying could be done entirely with waste heat. This is a mistake. The only waste heat in a continuous kiln is that which escapes through the stack or draft fan, which is very little, and that lost by radiation, which is not recoverable.

If we succeed in utilizing the continuous kiln for drying we must increase the present burning fuel consumption from 50 per cent. to 100 per cent., which in itself is a problem in many continuous kilns at present operated. In our present knowledge, and with the present continuous kiln development, drying stiff-mud products in the kiln is not feasible, except possibly in some type of car tunnel kiln, of which there are now one or two promising prospects being worked out.

Car Tunnel Kilns.

A car tunnel kiln may combine the processes of drying and burning in one operation.

The car tunnel kiln dates back more than one hundred and sixty years. The first patent is seventy-five years old, while the more or less successful modern kiln was patented more than forty years ago.

Several attempts have been made to introduce the kiln in this country with very meagre results in drying.

The principle of the operation is that the green ware on cars from the machine enters the tunnel at one end and passes successively through drying, watersmoking, heating up, burning and cooling zones, and arrives at the exit end finished and ready for shipment.

It has been found impractical in general to adjust the operation of the kiln to suitable drying conditions, and the general opinion in countries where the kiln has reached its highest development is that the drying must be carried on in a separate compartment. Undoubtedly, some shales and clays in this country will stand the severe drying condition necessarily developed in the tunnel kiln in order to keep pace with the rapid burning, but for general application the combined operation in a unit tunnel is not practical in the present commercial development of the kiln.

The practicability of the single tunnel may be questioned for any clay, or at least except in rare instances, aside from the ability of the clay to stand severe drying treatment.

There are many clays that will stand any kind of abuse in drying, but there is the question of heat and moisture to be considered. Clays contain combined water up to 14 per cent.

of their weight, and in the tunnel kiln we have the vapor of this combined water to contend with as well as the moisture vapor which is removed in a dryer.

In the car tunnel kiln then we must provide heat and air to carry the heat, not only to remove the moisture from the ware, but to carry the additional burden of combined water. Even with air dried ware entering the kiln it was found impractical to maintain sufficient temperature to prevent condensation before the combustion gases and hot air reached the end of the drying tunnel. Otto Bock, a German engineer, overcame the condensation difficulty by widening the tunnel at the cold end, and introducing iron partitions between the kiln walls and cars of ware. In other words, he built iron ducts in the sides of the tunnel into which the saturated gases were drawn and the ware within the tunnel was heated by radiation from the ducts.

It will readily be seen that the development of the car tunnel kiln has many difficulties to overcome.

The use of separate drying tunnels of any type in which to dry the ware and to serve as a storage room to keep the kiln in operation when the machines are not in operation is the method in successful commercial use.

The heat from a tunnel kiln, because of the burden of water vapor which it carries, is not valuable for direct drying, but in indirect drying we not only realize the sensible heat in the gases but may also realize the latent heat from any condensed vapor.

The combination of a tunnel kiln with a radiated heat dryer of the Moeller and Pfeifer type, or perhaps any type, will result in a maximum economy and this is the present commercial development of the car tunnel kiln.

It is not the province of this discussion to consider recent patents, but we will digress to mention two which give promise to overcome the drying difficulties of the car tunnel kiln.

The Drayton kiln introduces diaphragms on short cars at regular intervals, which partition the tunnel into separate compartments, or, in other words, in a measure convert the tunnel into a chambered kiln. The firing is down draft, either producer gas, or direct coal fired, but with this we are not here concerned. The movement of the combustion gases is down through the burning compartment, up through the heating up and watersmoking compartment, down through the dehydration compartment, and thus up and down until the gases are drawn off by a fan. We do not wish our readers to accept the above statement literally. One compartment is exclusively for the burning, but ahead of that the compartments are not reserved exclusively for any particular stage of the process—heating up, watersmoking and drying. As in a chambered kiln the gases are drawn ahead through several compartments until the temperature and water vapor burden have reached a minimum and maximum respectively—in a word, until the dew point is reached—when they are removed from the kiln.

A preheating flue extends from the cooling compartments behind the fires to the drying compartments ahead of the dew point compartment and the initial drying is done with air of any desired temperature and uncontaminated with combustion gas and also free from water vapor, except that originally in the entering air.

Another kiln now in the experimental stage covers each car with a muffle and when the cars are connected in the tunnel the muffles form a series of compartment kilns. The firing is done inside the muffles and the air and combustion gases pass from muffle to muffle as the cars advance through the tunnel. The tunnel is a casing for the moving compartment kilns on cars, and a drying tunnel. Each muffle-covered car is loaded mechanically inside the muffle with dried bricks and on top of the muffle is placed a load of green bricks. After the car has passed the firing zone and entered the cooling zone, an aperture in the top of each or any muffle may be opened, thus permitting the hot air from the cooling bricks to rise into the drying tunnel and by suction pass longitudinally to the end of the tunnel similar to a progressive waste heat dryer.

The muffles in conjunction form the kiln proper, in which the burning is done. The muffle roofs are the floor of practically a waste heat progressive dryer. The movement of the muffles carries the drying bricks forward and thus the muffle roofs combine the dryer floor and brick carriers. The tunnel enclosing the muffled cars has sufficient head room to include the drying bricks and is at the same time the drying and kiln tunnel.

As each car leaves the tunnel the burned bricks are removed from the inside of the muffle, and the dried bricks on top of the muffle are placed inside, after which the car is run back to the tunnel receiving entrance and again started on its course through the tunnel after receiving a new load of green bricks on its roof.

The kiln is still in the experimental stage but the experiments have advanced to the extent of trying out the burning features commercially, and, it is reported, successfully. The drying features remain to be proven but it is believed that, with the elimination of the combustion gases and the water vapor which the combustion gases carry, there will be no greater difficulty in the drying than there would be in any waste heat progressive dryer. The bricks will enter a warm moist atmosphere and as they advance the temperature will increase, while the degree of saturation will decrease. Finally they will be subjected to the radiation and convection from a hot radiating floor which should remove the hygroscopic water.

Since the above was written a commercial kiln, complete in every feature, has been put in operation and the problems connected with successful operation are now being worked out.

CHAPTER XII.

Conservation of Heat in German Factories.

IN A PREVIOUS article we described some German methods of constructing dryers above continuous kilns to make use of the radiated heat from the kilns. This is seldom done in this country, partly because of the great amount of labor required and partly because of cheaper fuel.

The Germans build expensive plants where necessary to get the full benefit of the fuel consumed, while we are very careless in this regard—often ridiculously careless.

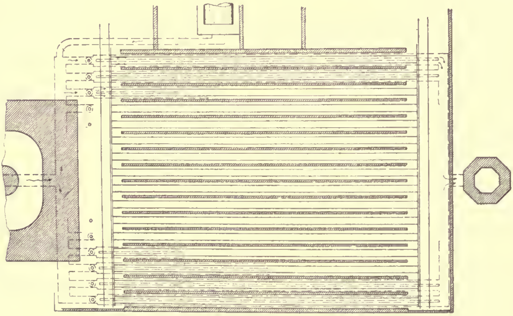


Fig. 58 Plan

Figs. 58, 59 and 60 show plan and section of a German dryer equipment, making extensive use of waste heat.

The main draft flue of a continuous kiln is connected with the stack through a series of flues, covered with corrugated iron plates, under the dryer tunnels, and the steam boiler's

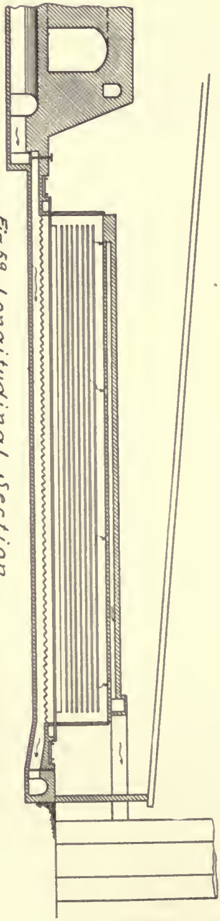
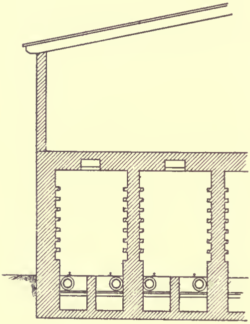


Fig. 59 Longitudinal Section

draft flue is similarly connected. Thus they get the waste heat of all combustion, either in the kiln or the boiler furnaces, and all the heat of cooling kilns.

The exhaust steam from the engines is carried through the tunnels in large ribbed pipes (see Fig. 60), which are much better radiators than the ordinary steam piping so largely used in this country.

The exhaust from the drying tunnels is taken up through the roof of the tunnel into ducts leading to the stack, as shown in Fig. 59, and any condensation of moisture in these ducts gives up the latent heat of vapor to maintain the roof temperature and the drying tunnels are not robbed of heat to supply the radiation loss.



Cross Section
Fig. 60

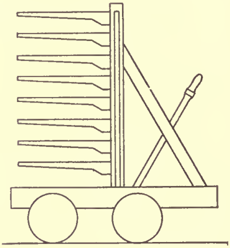


Fig. 61

The dryer is for the pallet system, and periodic in operation, and the projections in the tunnel walls are supports for the pallets. The pallets are handled by a lifting rack car or truck, Fig. 61, holding the number of pallets required in the height of the tunnel.

We do not present this German dryer as one worthy of adoption in this country, but merely to illustrate the degree to which the Germans carry conservation of heat and as a hint to clayworkers of this country that they are allowing comfortable profits to go to waste.

Moeller and Pfeifer Dryer.

In the development of progressive dryers the Germans first advanced the principle that the air should enter with the ware and that the temperature should advance as moisture was taken up. It is evident that the exhaust air leaving the dryer at the hot end would carry a large weight of moisture—pound for pound, or even more—and in consequence a much smaller volume of air would be required than in our progressive dryers.

A number of German dryers, using this principle, have been developed, the most interesting of which is that of Moeller and Pfeifer. It also illustrates the recuperation of heat values characteristic of German industrial operations.

Figs. 62, 63 and 64 show this dryer in plan, longitudinal section and cross-section.

In the plan, I is the direct coal-fired furnace at the hot end of the dryer G. The dryer is only partially waste heat, since German operators largely use continuous kilns, in which heat from cooling ware is not available for drying.

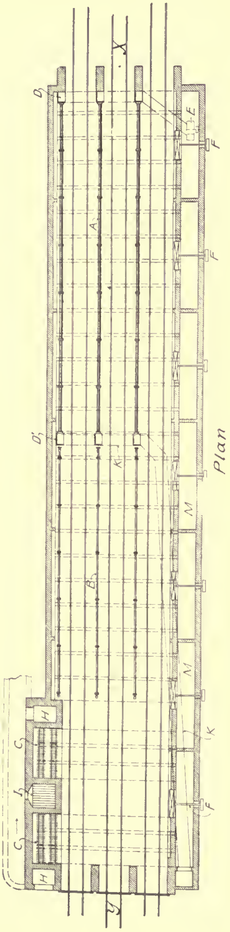
The combustion gases from the furnace pass horizontally through ribbed radiating tubes or flues C, thence into flues H connecting with stack or fan.

Opposite the furnace is a circulating fan F, in fact, there are a number of these circulating fans, as seen in the plan.

The fan F draws the air through the ware, forces it back under the dryer floor through the ducts N, up around the radiating pipes C, and thence through the ware, a continuous rapid transverse circulation of the air through the ware, with no tendency to a forward movement by the circulating fans.

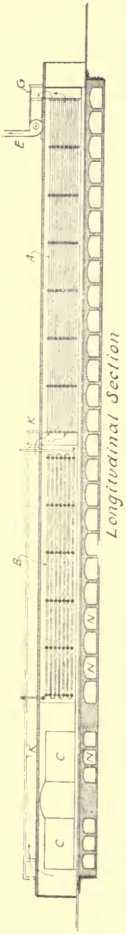
In the plan and longitudinal section we have on the dryer roof at the cold end (X) of the dryer a fan E connecting with a cross duct G, and in turn with down comer ducts D. The ducts D connect with heating pipes A, which parallel the cars of ware from near the longitudinal center of the dryer to the cold end. The ends of these pipes at the center of the dryer enter vertical ducts D, which connect with a cross and longitudinal duct K to the hot end over the dryer roof. The duct K enters the vertical duct O at the hot end and this duct O at the bottom opens into the end chamber M into which the under ducts N discharge. Thus the circuit with the drying chamber is complete.

There are no doors at the cold end X and the air here enters freely. It is immediately taken up by the first fan F and



Plan

Figure 62.



Longitudinal Section

Figure 63.

the rotary circulation through the heating pipes and ware started. The suction of the fan E acting through the hot end of the dryer slowly advances the air from fan F to fan F until the hot end is reached, and the saturated (or nearly) air is drawn into the duct O and started back toward E.

The movement of the air in the dryer is that of a spiral with a rapid lateral motion and a slow forward movement. The air, as it advances through the drying room, is being used to take up moisture and thus dry the ware. When it reaches the hot end Y its usefulness as a drying medium is finished, and upon its return through the ducts and pipes its heat is given up to the incoming air.

Not only is the sensible heat of the air and vapor given up but in cooling there must be a large condensation of water vapor from the highly saturated hot air which returns to the dryer the latent heat required in the evaporation.

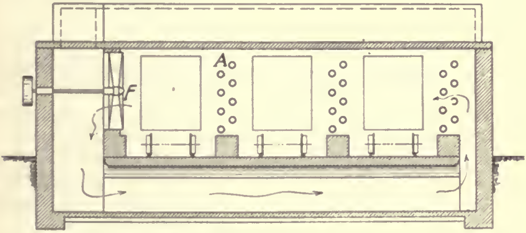


Fig. 64. Cross Section.

The dryer losses are the heat taken out by the cars and the ware; the heat in the low temperature saturated exhaust air the volume of which is very small; the radiation losses. These losses are supplied by furnace I.

If there is available exhaust steam from the factory engine it is utilized in radiation pipes B between the furnace I and the exhaust air heating pipes A.

In connection with a car tunnel kiln the furnace may be dispensed with. The process in the kiln will be extended to the extent of heating up and watersmoking, and the waste gases from the kiln will have a temperature of 500 degrees to 800 degrees F. These gases will be drawn through the radiators at the hot end of the dryer, and will supply the heat normally supplied by the auxiliary furnace.

CHAPTER XIII.

Progressive Dryers.

THE periodic tunnel dryer, as its name indicates, is intermittent in its operation. A tunnel is filled with ware, then the heat and air are turned in and continued until the ware is dry when they are shut off and the ware removed.

A progressive dryer is one in which the air volume is constant and the temperature remains unchanged in so far as it is practical to maintain a constant temperture. In the type used in this country, the heated air enters at one end, passes through the tunnels and escapes at the other end. The ware, usually on cars, enters at the air exit end of the tunnels commonly termed the receiving end, travels through the tunnels to the delivery end where it is removed from the dryer and taken to the kilns.

The entering air, hot and with great capacity for moisture, first comes in contact with the hot dry ware leaving the dryer. As the air passes through the tunnels it successively comes in contact with cooler, wetter ware, until at the receiving end it passes among the cold, damp ware just from the machine. In its passage through the tunnel it becomes cooled thereby lessening its capacity for moisture and at the same time it is taking moisture from the ware. The dew point is presumed to be reached as the air leaves the tunnel at the receiving end.

The drying condition is theoretically ideal. The entering hot air comes in contact with ware in condition to stand a high temperature and which needs such high temperature to drive off the hygroscopic water in the pore spaces of the clay mass.

The air leaving the dryer comes in contact with green ware which frequently must be carefully heated up without any drying in order to open up the pore spaces, so that when the ware reaches that portion of the tunnel where drying begins the water will be drawn to the surface of the ware by capillarity as rapidly as it is removed by evaporation. The humidity drying treatment, so necessary in safely drying many clay wares, is automatically carried out in the progressive dryer.

We fail oftentimes in the adjustment of the dryer and in its operation.

The normal condition of a progressive dryer is to be full of ware all the time and this is not maintained in any plants, or at least in very few.

Also the escaping air should be saturated, or nearly so, otherwise there is a loss of heat. If we assume that a dryer has been properly adjusted to a ware and that the inlet temperature is 200 degrees F., while the escaping air has a temperature of 100 degrees F., and the temperature midway of the dryer is, let us say, 150 degrees F., we have the condition illustrated in diagram No. 1, Fig. 65. During the night the heat advances until in the morning we have the condition illustrated in No. 2 diagram. After a shut down, Monday morning, for instance, the heat has progressed until the condition represented in diagram No. 3 is attained.

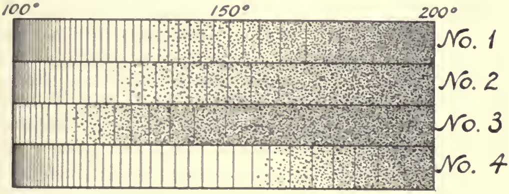


Figure 65.

The setters in starting work in the morning may draw several cars from each tunnel, enough oftentimes to keep them occupied until noon. The first bricks from the machine come in contact with a temperature and drying condition not intended, and if they stand it the dryer could be changed to more rapid drying conditions with fewer tunnels in operation. If the bricks do not stand this more severe treatment the fault is not with the dryer but with its operation. A progressive dryer should have receiving and delivery tracks for storage outside the dryer and at intervals during the night cars of dried ware should be drawn and cars of green ware entered. It is not practical to store cars equal to a day's output, but it is common practice to construct the storage tracks to hold three cars on each track. A tunnel holds fourteen to fifteen cars and on the basis of a twenty-four hour period, three cars per tunnel are equivalent to one-fifth of a day's output. If the dryer has a forty-eight or seventy-two hour period, the three cars are equivalent to two-fifths or three-fifths of a day's run. These storage cars aid materially in maintaining the normal condition of the dryer.

Operators often find that the output of the dryer is insufficient to keep up the desired capacity. The first step is usually to increase the temperature which changes the conditions to that shown in diagram No. 2 or No. 3, Fig. 65. If the ware cracks, as often is the case, the difficulty may, perhaps, be overcome by reducing the air volume which retards the advance of the heat without necessarily lowering the temperature at the delivery end. With the higher temperature thus maintained at the delivery end we are enabled to drive off the moisture remaining in the partially dried bricks without damage to the bricks behind, since the latter do not get into the high temperature zone until in a condition to stand the higher temperature. Diagram No. 4 illustrates this condition except that the temperature shading should be deeper to show a higher degree of heat.

There are a number of ways in which the conditions in the dryer can be changed without altering the construction of the dryer, but when these fail it becomes necessary to make such changes in the construction as will give desired results. These changes will be considered under the discussion of the several types of progressive dryers.

CHAPTER XIV.

Radiated Heat Dryers.

THE RADIATED HEAT DRYER is a development from the direct coal-fired hot floor. The first step in the development was to cover the hot floor with tunnels. The next step introduced air around the furnaces and into the tunnels, and improvements have been made from time to time in the air circulation and heat radiation. While the name "radiated heat dryer" is appropriate, yet the dryer really makes use of convection as well as radiation. The entering air circulates around the hot furnace walls and becomes heated by contact with them. It then passes into the tunnels and gives up the heat to the ware and to the work of evaporation. The smoke flues extend the full length of the tunnel under the tunnel floor, and the heat from its walls is radiated to the ware. The improvements in the dryer are toward better air circulation and contact with the hot furnace walls, and toward smoke flue construction, which will give a maximum radiating surface with minimum wall resistance to the passage of the heat by conduction from the inner to the outer surface of the flue walls.

The furnaces are at the delivery end of the dryer, in a pit below the dryer tracks, and usually and preferably are built into the dryer, in order that any radiation from the furnaces, ordinarily reckoned as a loss, is available in the tunnels for drying purposes. The furnaces are simple box grates and are coal-fired.

We have worked out the following table from an article, entitled "A Contribution to the Technology of Drying," by R. H. Minton, in Vol. VI, Trans. Am. Cer. Soc. Mr. Minton's calculations are based on nine-pound bricks, containing in round numbers two pounds of water each. The air is assumed

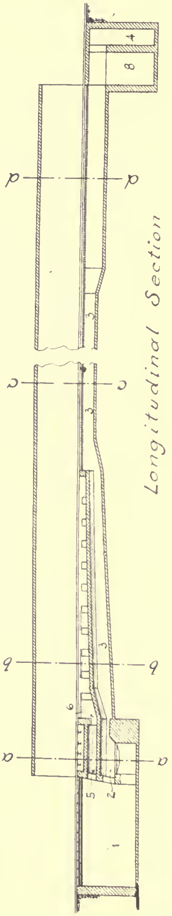


Figure 66.

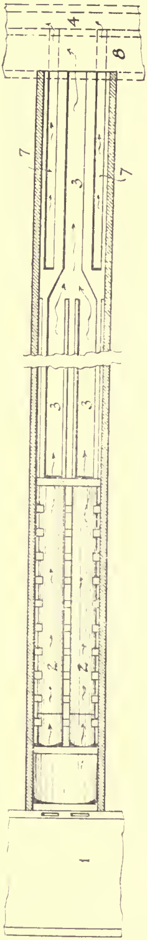


Figure 67. Plan.

to have an initial temperature of 50° F., and to be 75 per cent. saturated.

—Fuel and Air Requirement Per Thousand Bricks Daily—

No.	Temp. F.° Hot End.	Temp. F.° Exhaust.	Coal in Pounds.	Cu. Ft. Air Per Hour.
1	82	59	271	246,965
2	109	68	283	144,309
3	176	86	281	71,888
4	314	104	264	38,087

A waste heat dryer in temperatures and air volume will operate somewhere between No. 3 and No. 4, inclusive, while a radiated heat dryer will fall below No. 4. In a waste heat dryer the heat source is outside, and there is no opportunity to recuperate the heat in the dryer. In consequence there is a greater fall in temperature from the entering end to the exit, and, other conditions being the same, the volume of vapor which can be carried out is less.

In the radiated heat dryer the smoke flue (radiating flue) is constantly giving up heat to replace that used in the drying operation, and because of this heat we can remove more moisture with a smaller volume of air. As has been previously stated, there is no relation between air volume and moisture volume; the air has nothing to do with it, except, as in the case of a waste heat dryer, the volume of heat is determined by the volume of air.

Radiated heat dryers can work with a relatively small volume of air. In one instance we found 28,000 cubic feet of air per hour per thousand bricks, but this is greater than an ordinary radiated heat dryer, because of fan draft in this particular instance, where usually only natural draft is used.

The quantity of fuel per thousand bricks used in a radiated heat dryer depends upon the volume of water to be evaporated, upon the weight of clay and iron to be heated up, upon the dryer losses, and upon the efficiency of the operation.

The quantities given by Mr. Minton are fairly representative, taking into consideration the volume of water assumed to be removed. Our records show variations from 200 pounds to 380 pounds per thousand bricks, the latter consumption being due to improper construction and inefficient operations.

Fig. 66 is a longitudinal vertical section through a tunnel of a double track radiated dryer, and Fig. 67 is a plan view below the tracks, and Figs. 68, 69, 70 and 71 are vertical cross-sections of the same. The numerals marked on the several drawings indicate the following features of the dryer: No. 1 is the firing pit below the track level; 2 is the furnace, one for each track in the dryer; 3 is the combustion or smoke flue, which extends the full length of the dryer and connects with the main draft duct, 4.

The dryer under description differs from the usual radiated heat dryer in that the air and moisture at the exit are drawn down through the ware and out through the floor of the dryer. To accomplish this, double-track tunnels are used, and the two smoke flues (3) are brought into one flue in the center

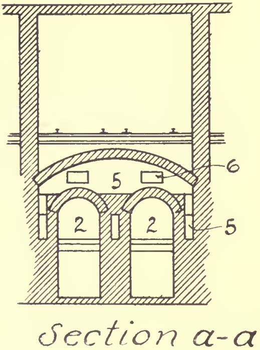


Figure 68.

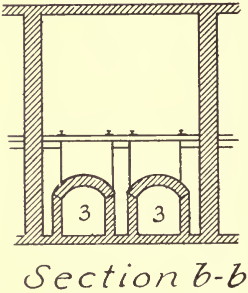


Figure 69.

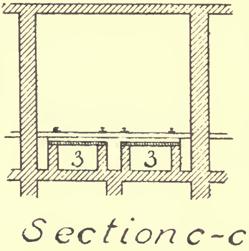


Figure 70.

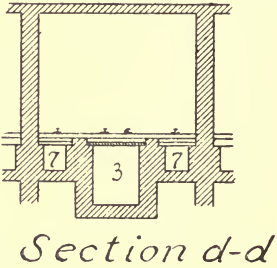
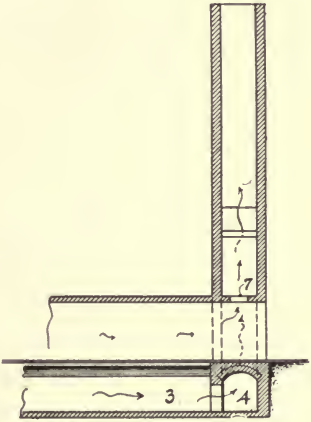


Figure 71.

of the tunnel near the exhaust end. The air enters through openings in the furnace fronts—such openings being on either side and above the furnaces—circulates around the furnaces, collects in the hot air chambers, 5, enters the tunnel proper through openings 6, thence rises through the ware and is drawn the length of the tunnel. The entering hot air, instead of rising immediately through the ware, may, by means of sheet-iron plates, with graduated openings under the tracks, be distributed under several cars as in waste heat and other hot-air duct dryers. On either side of the single smoke flue, near the exhaust end, are air and moisture ducts 7, with perforated floor (not shown), which connect with air and moisture duct 8. The smoke (4) and moisture (8) main ducts lead to stack or fan at one side of the dryer, and the air and furnace drafts are controlled by dampers.

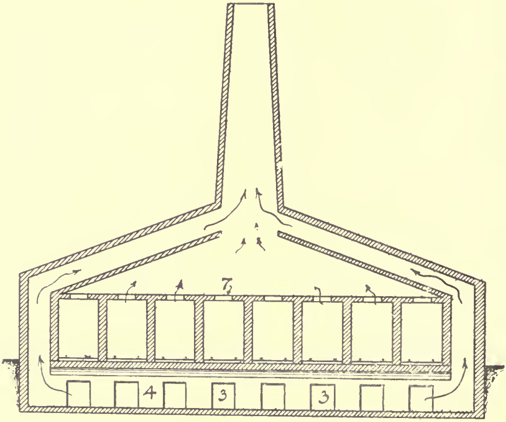


Long'l Section

Figure 72.

The smoke flues (3) are brick for a distance of 30 to 40 feet from the furnaces, on account of the intense heat, and beyond they have brick walls covered with cast-iron plates.

The idea is to build these flues of materials having the least conductivity resistance and the largest possible radiating surface. The flues must be of bricks near the furnaces, but the walls are only 4 inches thick, and the sides, as well as the crowns, are exposed except buck walls at intervals to support the crowns and to carry the tracks. Beyond the brick flue cylindrical iron pipes have been used to the exhaust end, but the more common construction is that of 4-inch brick side walls covered with iron plates. Sheet-iron plates have been used and sealed with sand; flat, overlapping cast-iron plates make a simple covering, but greater radiating surface is had from curved and corrugated plates.



Cross Section

Figure 73.

A more usual form of radiated heat dryer exhausts the air and moisture through the tunnel roof at the end. Figs. 72 and 73 are sections through the exhaust stack of such type. As will be seen, the smoke flues (3) connect with an underground cross-duct (4), which leads to either side of the dryer, thence up the back over the dryer to a center stack. The moisture outlets (7) are in the tunnel roof and the exhaust air and moisture are directed into the smoke stack.

The hot radiating flue under the cars of ware induces a circulation, as indicated in Fig. 74, which we do not get in the typical waste heat progressive dryer, and with this circulation there is slow progression of the air toward the exhaust end.

The value of this circulation is too often overlooked in the setting of the ware on the cars. The bottoms of the cars become heated by direct radiation, thus giving an upward impulse to the returning air flowing under the cars. We frequently find the ware set in such a way as to prevent the passage of the air; particularly is this true in paving brick manufacture where standard cars are used. Standard cars have slats proportioned and spaced for standard bricks, and paving blocks on such cars overlap the spaces and close them to the passage of the air.

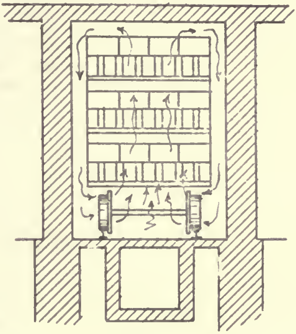


Figure 74.

A brief discussion of the merits and efficiency of a radiated heat dryer may not be out of place. We are often confronted with the inquiry in regard to the proper dryer. Naturally, this cannot be answered without full information in each individual case, but some general principles may be discussed.

There are many plants with scove, updraft or continuous kilns from which little waste heat is recoverable. (Note: We may be criticised for including the continuous kiln in this category, since in a number of installations heat for the dryer is taken from a continuous kiln. We hold, however, that it is not waste heat, since it must largely be replaced for the kiln operation, but concede that such a kiln may be an economical place in which to generate heat. However, as a general rule, the greatest economy results when the heat is generated where it is to be used. The absurdity of the continuous kiln waste heat claim becomes apparent when one realizes that in a number of plants less fuel is consumed in the kiln than would be required in the dryer. We cannot rob the kiln of all its fuel value, and more, and have left the necessary requirement for heating up, watersmoking and burning the bricks.) If, also, the steam power is low, as is often the case, or the plant is electrically equipped, a direct coal-fired radiated heat dryer is essential. If the steam power is high, then a steam pipe progressive dryer, which is quite as truly a radiated heat dryer, should receive consideration.

A steam-driven plant, with down-draft kilns, is no place for a radiated heat dryer, especially the coal-fired dryer, but if the plant is electrically driven and near the coal fields, where fuel is cheap, it may be economy to lose the kiln waste heat in order to save the cost of power required to drive the fans necessary to recover the waste heat.

The selection of the type of dryer, then, is dependent upon the kind of kilns, the character of the power, the cost of fuel, and also necessarily upon the product to be dried.

The radiated heat dryer may justly claim efficiency when in its proper place and properly installed.

The heat carried away in the combustion gases is essential to create draft, both for the furnaces and the tunnels.

The relative high temperature at the air exhaust end causes loss only in case the saturation is correspondingly low, but in view of the small volume of air, of its slow movement through the tunnels, and of the circulatory tendency, as illustrated in Fig. 74, there is no reason why the saturation should not be practically complete, in which case the high exhaust temperature becomes an efficiency factor.

The circulation of the air gives in some degree a vertical movement through the ware which is more satisfactory than horizontal draft, and the slow forward movement in connection with the rotary circulation relieves us of the necessity of fitting the dryer closely to the mass of ware.

The horizontal movement of large volumes of air through a tunnel dryer requires that there be little free space in order that the air may be forced among the ware, otherwise there is little drying and excessive loss. It is difficult to adapt such a dryer to several kinds of ware on the same yard—tile on double or triple-deck cars, brick on single or double-deck cars, pallet rack cars—and in such installations the radiated heat dryers are more efficient.

CHAPTER XV.

Steam Progressive Dryers.

THE ARRANGEMENT of a steam progressive dryer differs from that of a steam periodical dryer in that: The steam piping is massed at the delivery (hot) end of the dryer, the air enters at the delivery end, moves horizontally through the dryer, and, with the vapor, is drawn off through a suitable stack at the receiving (cold) end of the dryer.

The steam dryer may be a series of tunnels, each equipped with the proper amount of piping and under individual control, or more often it is a single large room.

The piping is arranged in coils, four to six pipes deep at the delivery end, two to four pipes deep in the next section and two pipes in the section most distant from the delivery end. It may extend the full length of the dryer, or only one-half or two-thirds, depending upon the character of the clay, or as the designer deems best.

Either exhaust or live steam is used for heating.

The air volume required is relatively low, since the heat is not dependent upon the volume of air. As the heat is used up by evaporation of the moisture, it is replaced by direct radiation from the pipes under the ware and by circulation of the air around the ware, among the pipes, and up through the ware.

Fig. 75 is a longitudinal vertical section and Fig. 76 a transverse vertical section of a steam pipe tunnel progressive dryer. The air enters from the outside at the delivery end and is distributed under the piping by a floor with graduated openings. The piping is under the tracks and fully exposed within the tunnel. At the receiving end there is no piping shown and this section of the dryer is used for heating up the ware in a humid atmosphere. If the clay will stand severe treatment the piping may be extended fully to the re-

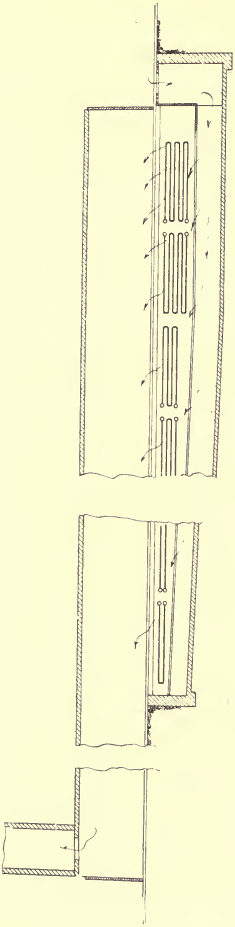


Figure 75.

ceiving end and drying begins very quickly after the ware enters.

The drawing does not attempt to go into any details of construction and is merely a sketch to illustrate the principle.

Calculations of heat requirement and amount of piping were made for periodic steam pipe dryers and need not be repeated here. Both rely upon natural draft and use a small air volume. The draft in the progressive type may be somewhat stronger, thus increasing the heat taken from the piping by convection, but the difference is not material and is easily within the conditional variations of the problem.

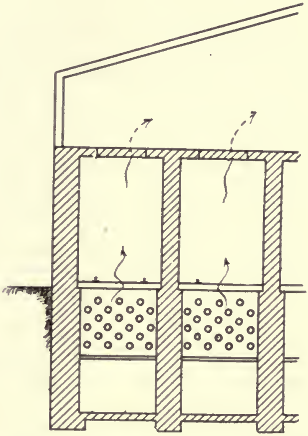


Figure 76.

The steam pipe progressive dryer for very tender clays is sometimes built in two compartments in series.

The first or receiving compartment is short and without any provision for the admission or removal of air—in other words, the first compartment, in which a constant temperature is maintained, is merely a heating-up room. The air in this room is necessarily nearly saturated with moisture since no air escapes except by leakage and wall and roof absorption.

The room also serves as a storage room and it is immaterial whether it is kept full or not, provided the ware remains in the room sufficiently long to become thoroughly heated up and put in condition for the drying process. As ware is removed from the delivery end of the dryer proper, and the cars of ware moved forward, the space thus provided at the receiving end is filled from the heating-up room. The dryer proper is truly progressive, and since the ware is previously put in condition to withstand the first stages in drying, the piping may extend from end to end.

A heating-up section is common in other types of dryers, but in none of them do we go to the extent of a separate closed room.

In one or two instances in the operation of radiated heat dryers it was found beneficial to enclose the receiving tracks and at the same time remove the original tunnel doors at the receiving end. The smoke and exhaust air and moisture ducts were not extended to the end of the receiving tracks (converted into a receiving room). The ware on the receiving tracks became heated in some measure by circulating air from the tunnels, but it was removed from direct heat radiation from the smoke ducts and also from the draft current of air. The ware in this warm dead air space went through a sweating stage which has been proven of value in preparing tender drying materials for the drying treatment.

In the single progressive dryer this heating-up space results from not extending the piping to the receiving end, but the ware is subjected to the current of nearly saturated air, although not necessarily so.

So, too, in progressive waste heat dryers do we provide dead air heating-up space where the ware requires it. The difficulty often is that the need of the ware is not previously determined. A dryer is designed and guaranteed for rapid work and afterward its adaptation to the ware requires material changes.

CHAPTER XVI.

Waste Heat Progressive Dryer.

THE PROGRESSIVE waste heat dryer has found wide use in this country. As the name implies, it is progressive and uses only waste heat where there is sufficient waste heat for the work and on this score the margin is sufficiently small to make suitable equipment and proper operation important.

In round numbers under the conditions assumed in a problem to be discussed later, about 1,632,000 heat units are required to dry 1,000 bricks. If the bricks are burned at a temperature of 1850° F. (Cone 07) and in cooling the heat is recoverable down to 500° F., we have an available temperature of 1850—500=1350° F. The bricks weigh 6,000 pounds and the specific heat is .2. Thus we get from the cooling brick 1350×6000×12=1,620,000 heat units. There will be approximately 1,000 brick in the kiln construction for each 1,000 brick burned and the average temperature of these brick will be about 1000° F., half of which, perhaps, is recoverable, or 500×6000×.2=600,000 heat units. This makes a total of 2,220,000 heat units, not counting radiation losses, which may be 30 per cent to 50 per cent. If the radiation losses in cooling are proportional to those in burning, we have under the above assumption insufficient heat in the cooling kilns to dry the product. Higher temperatures in burning will increase the heat supply and the balance may be better or worse than our figure, depending upon the dryness or wetness of the green bricks. We do not give the above figures as data, but simply as an illustration.

Besides the waste heat of cooling kilns, there is the waste heat in the exhaust steam. If the factory is using 150 h. p., we have in the exhaust $\dfrac{34.5\times150\times970\times10}{50}=1{,}003{,}950$ heat units per thousand brick.

34.5 = Pounds of water per h. p. hour.
150 = Total h. p.
970 = Heat units per pound exhaust steam.
10 = Hours daily operation.
50 = Capacity per day in thousands.

A waste heat dryer necessarily involves the use of a fan, and the most modern installations use two fans. In considering the steam supply, we only reckoned ten hours operation, but the fan operation will be twenty-four hours per day and every day.

Probably 30 h. p. will be required to drive the dryer fan engines and from these we will recover $34.5\times30\times970\times24=$

engines and from these we will recover $\dfrac{34.5\times30\times970\times24}{50}=$

481,896 heat units per thousand brick. This is not in addition to the factory waste steam, but materially increases the total as previously estimated on a ten-hour basis.

The losses between the engine and the dryer is much less than those between the kilns and the dryer and the value of the steam is a material one in reckoning the available waste heat supply. With the exhaust steam it is evident that there should be sufficient waste heat to do the drying with a safety margin of 100 per cent, yet through improper design, faulty construction and inefficient operation, the waste heat supply oftentimes falls short and has to be supplemented with additional fuel in some way. Small and complicated hot air ducts between the kilns and fan and restricted kiln connections are frequently the cause of excessive loss in collecting the heat, and failure to approximate the dew point in the dryer exhaust results in great loss in the application of the heat. A manufacturer would not load his cars with useless dead weight, but complacently moves a dead load of useless and expensive air through his dryer. That he may be getting his ware dry is no evidence that the work is being economically done.

The use of the fans brings up a factor of cost which must be considered. On the basis of five pounds of coal per h. p. hour, the fan engines will require 3,600 pounds of coal per day, which, at \$2.00 per ton, is \$3.60, or \$0.07½ per thousand brick. Maintenance brings this cost above \$0.10. In fact, we find many fan installations where the operation cost exceeds \$0.15 per thousand brick.

The progressive waste heat dryer is undoubtedly the most economical mechanical dryer, but one must not jump to a conclusion that it will be most economical in every situation.

We may be burning a low temperature product and not have sufficient heat from the kiln; public service electric power may be available at a less cost than steam; licensed engineers command higher pay. When the waste heat supply is short, we supply the deficiency by direct fired auxiliary furnaces. This introduces fuel cost besides power, and often scumming difficulties.

Difference in size of kilns and in character of product are frequently annoying factors—indeed, they enter into the cost in proportion as they affect the capacity. When a large kiln is cooling there is an excess of heat, but a small kiln may not have enough to carry the drying over until a large kiln is ready to turn in. In changing from hollow ware to brick, the hollow ware does not contain heat enough to dry the heavier ware and the operation of the factory is delayed until kilns of cooling brick are available for drying.

The use of combustion gases from kilns has not been considered and it would materially change the situation. The combustion waste gases and the heat of cooling kilns would give sufficient heat without considering the engine exhaust. The direct application of combustion gases rapidly deteriorates the dryer cars, and frequently causes scumming and in consequence the continued use of combustion gases should be through an economizer in which the heat of the gases serves to heat air for drying and in this way we get the benefit of the heat without the loss and damage by direct use of the gases. An economizer involves the use of fan draft for the kils, which in itself often would be an advantage over natural draft.

In the selection of the dryer there are many questions to be considered, and one should canvass the whole situation before reaching a decision.

Auxiliary furnaces to supply deficiencies in waste heat supply are frequently imperative, although, as previously mentioned, their use is objectionable. Where wood is abundant its use in the furnace removes the objections since wood contains no sulphur and its products of combustion will not injure the cars nor cause scumming. Either oil or natural gas may be used, since they are very low in sulphur, but coal or coke give a combustion gas seriously objectionable in clay ware dryers.

Figs. 77 and 78 show a wood-burning furnace adapted to clay ware drying, or it may be equipped with grate bars for coal burning. The bridge wall is made broad and filled with brick checker work. This checker work assists in maintaining a uniform temperature, acting as a regenerator and at the same time brings the gases into intimate contact, thus giving better combustion. A chamber is provided back of the bridge wall to serve as a dust collector and spark arrester.

Figs. 79, 80 and 81 are plan and sections illustrating the relation of steam coils, kiln ducts and auxiliary furnace and duct. All the air, whether from coils, kilns or auxiliary furnace comes into a mixing chamber adjacent to the fan, and each source of hot air supply is controlled by damper. We can, therefore, use all kiln heat, all auxiliary furnace heat, all steam coil heat, or any proportion of each. The kiln ducts are usually placed underground and preferably so, but it is important that the ducts be perfectly underdrained and that they be built moisture proof, as far as possible.

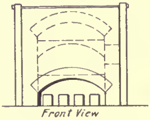


Figure 77.

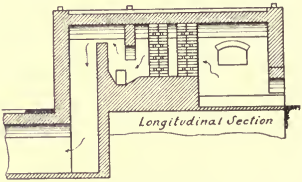


Figure 78.

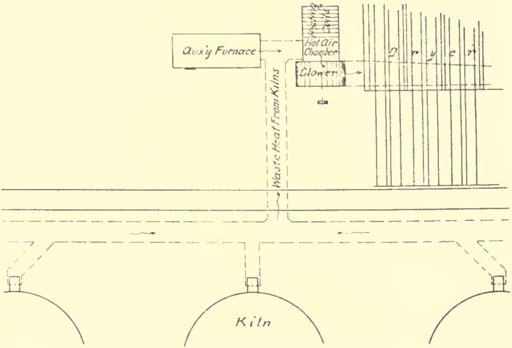


Figure 79.

The proper kiln connection has been a fruitful cause of study and experiment.

A common method is to connect the dryer duct with a stack duct, each under damper control. With the stack damper open and the dryer damper closed, the kiln is under natural draft and the products of combustion pass into the air. After the kiln is burned, a change in the dampers shuts off the stack and turns the hot air into the dryer. There are three objections to this method:

1. It is difficult to keep dampers tight and in consequence combustion gases find their way into the dryer to vitiate the air, scum the bricks and blacken them with soot, and destroy the car equipment.

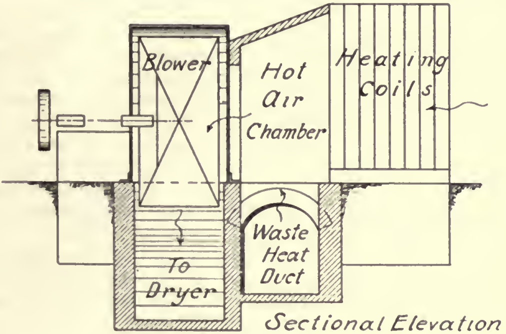


Figure 80.

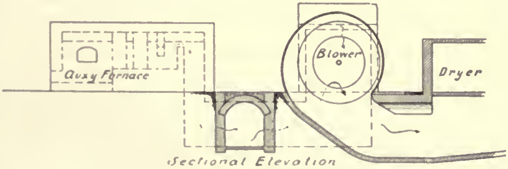


Fig. 81.

2. Less heat is obtained by down draft through the kiln floor.
3. Some wares are damaged by forced draft among them during the cooling stages.

Regarding the dampers we have found any single damper unsatisfactory and we have tried double dampers without success. Some yards close the dryer duct with a brick wall, which is replaced before each burn. After a kiln is burned and ready to connect with the dryer fan, the stack is dampered off and a hole is punched in the dryer duct wall. This hole is enlarged as the kiln cools down, to keep up the heat supply by a larger volume of air. Obviously this method has no merit. It is not tight, nor is it a satisfactory control.

In one instance, the dryer duct was below the draft duct and the two were connected by a vertical flue from the bottom of the draft duct. The top of the vertical flue was recessed and in the recess was bedded a heavy fire clay slab, thus closing the connection. The sulphur gases which leaked by these dampers destroyed the reinforcement in the dryer roof and the roof fell in. This damper looked good on paper, but it failed in practice. A fairly tight sand sealed damper might be constructed in this way, but the deep dryer ducts would be expensive in first cost and difficult to drain.

The simplest and at the same time fully effective damper is a stub duct connected to the dryer duct by a gooseneck. When the gooseneck is removed, the connection between the kiln and dryer is completely broken and there can be no combustion gases leaking into the dryer.

Clayworkers are familiar with the fact that the bottom of the kiln cools first, even though we may be drawing air down through the ware. This, we think, is sufficient proof that we cannot get all the heat out of the kiln through the floor.

One argument in favor of the bottom draft is that at any time combustion gases can be turned into the dryer to supply any deficiency. We hold that there should be no occasion to use combustion gases from kilns or coal-fired furnaces. If the steam equipment is proper, the deficiency can be made up in live steam, but if the deficiency is excessive and continuous, either the kilns and dryers should be connected by an economizer or the waste heat dryer should be replaced by some other type.

In one plant the distributing ducts are the full length of the tunnels, as in Fig. 85. Suspended in these ducts, which are very large, are cylindrical smoke pipes connected with the kiln draft flues at one end and with an exhaust fan at the other end. All the combustion gases from the kilns are drawn through these pipes and the heat therefrom is available for drying. The heat from cooling kilns is made use of by means of a separate fan in the usual waste heat progressive dryer manner. Thus we have an economizing system as part of the dryer construction.

This manner of using the products of combustion would be equally applicable to a radiated heat dryer, except both combustion gases and heat from cooling kilns would be handled through the smoke flues by the single smoke flue fan.

The most convenient place to connect the dryer duct with the kiln is through the wicket, and a goose neck connection is simple and effective. In the majority of kiln setting there is some space next to the wicket and there is always space over the wickets and in the crown. The suction of the fan draws the air from around the wares rather than through them, and we not only get more heat in this way but the wares are not damaged by direct draft through them.

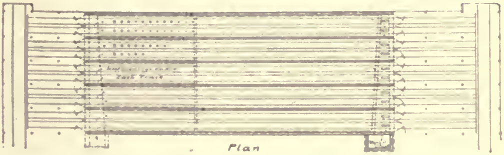


Fig. 82.

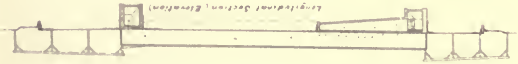


Fig. 83.

The most efficient place to connect the dryer and kilns is on top of the kiln crown where we fully recover the heat so far as recovery is possible. The wares under such conditions cool entirely by radiation. It is not convenient to make connections through the crown, and we usually compromise on the wicket, or in some instances a furnace connection.

Figs. 82, 83 and 84 show a plan and sections of a typical waste heat progressive dryer.

The hot air cross inlet duct from the fan is tapered on bottom and one side to correspond with the air volume reduction as each distributing duct receives its proportion. The taper is on the distributing duct side so that the end walls of the distributing ducts are in echelon and thereby each duct mechanically cuts off a proportion of air for its supply. The distributing ducts have graduated openings under each track for a distance of several car lengths.

The number of cars subjected to the direct upward blast of hot air through the graduated openings depends upon the ware.

If the ware will stand severe treatment we extend the distributing ducts a greater distance, even the full length of the dryer, as shown in Fig. 85, but extension to this degree is not good practice because any approach to complete saturation is impossible under such conditions, and economy of operation is coincident with complete saturation.

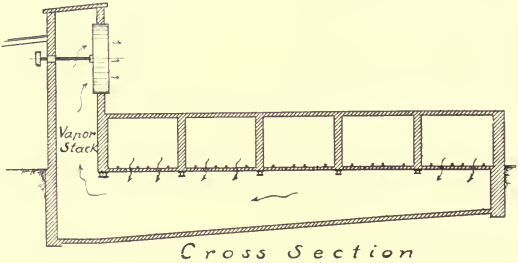


Fig. 84.

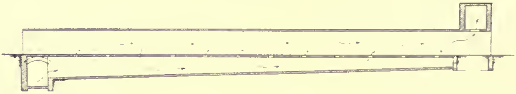


Fig. 85. Elevation.

A common practice is to extend the ducts four car lengths so that one car will be over the inlet cross duct and three cars over the graduated opening subjected to the direct blast of hot air. Five to eight car lengths subjected to the direct air blast are not uncommon. Other things being equal, the longer the distributing ducts and corresponding greater number of graduated openings, the more quickly the drying will proceed.

Besides the changes in the distributing ducts there are a number of modifications in the exhaust duct.

Fig. 86. Elevation.

In one installation the exhaust ducts return under the dryer floor to the distributing ducts and there connect with an exhaust cross duct. We get two advantages from this construction: It brings the fans close together and both can be housed in a single room and driven from the same shaft. The returning air keeps the floor of the dryer warm. Not only the sensible heat of the air and vapor becomes useful, but also the latent heat of any condensation. If the air is saturated to the dew point at the exhaust end of the dryer, there must be some condensation in the return ducts to the exhaust fan, and the heat from this condensation is given back to the dryer through the dryer floor.

A vertical air movement is much better than a horizontal one, especially for hollow ware. In any progressive dryer we have an upward movement of the air from the distributing ducts but beyond that the movement is horizontal to the exhaust and if the ware is not close to the roof of the tunnel which the hot air invariably tries to follow, there will be poor contact between the air and ware. The exhaust cross duct is generally placed underground in order to pull the air down, but it is not very effective and except at the end of the tunnel over the exhaust duct is without any influence on the horizontal movement of the air.

To get a vertical movement, dryers are sometimes constructed with exhaust ducts having graduated openings similar to the distributing ducts, as illustrated in Fig. 86. The movement then is up through the distributing ducts' openings, over an intervening space which may be much or little as required, and down through the openings in the exhaust ducts. The exhaust cross duct may be at the end of the tunnels or any predetermined distance from the end in order to provide dead air heating up space, and moreover the exhaust ducts' openings nearest the exhaust cross duct may be closed to increase the dead air heating up space, but one which will have its floor heated by the escaping air and vapor. Similarly where the exhaust cross duct is on top as in Fig. 85, it may be placed at any distance from the end of the tunnel and thus provide a heating up space removed from the direct air current.

Air Volume and Heat Requirement for Waste Heat Dryers.

Assume for 1,000 bricks the following:

1,000 pounds metal in cars.
6,000 pounds clay in bricks.
1,000 pounds water in bricks.

The conditions of the problem are:

Outside air 80° F., 90% saturated.
Exhaust from dryer 100° F., 100% saturated.

The temperature assumed represents average maximum summer conditions, which will require the greatest quantity of air. A dryer equipped and adapted for these conditions will have excess capacity at lower temperatures or less degree of saturation.

Data used—specific heat:

Air—.234+.000012 (t-32).
Vapor—.42+.0001 (t-32).
Clay—.2.
Iron—.12.
Water—1.00.

The problem is first to find the volume of air required, and, second, the temperature to which it must be heated to do the work.

From the "Vapor Capacity of Air" table (page 19), we find that air at 80° F. and 90% saturation carries .145 pound of moisture per 100 cubic feet, while at 100° F. and 100% saturation the burden will be .291 pound of moisture. One hundred cubic feet of air, when raised from 80° to 100° expands to 103.7 cubic feet, from the law that the volume of a gas is directly proportional to its absolute temperature

$$\left(\frac{100}{491+80-32}=\frac{X}{491+100-32},\ X=1.037\right).$$

After raising the temperature of the original air to 100°, a volume of 100 cubic feet at this temperature will contain $\frac{.145}{1.037}=.140$ pound of moisture, provided no additional moisture is taken up, and the vapor pressure will be $\frac{.140}{.291}=48\%$ of 1.918=.920. As moisture is taken up, the volume increases directly as the pressure. The pressure increases 1.918—.920=.998, and each unit volume at 100° becomes $\frac{29}{29-.998}=1.036$.

The volume increases to 1.037 because of advance in temperature, and each unit volume of this increases to 1.036 in consequence of increased pressure, due to additional moisture taken up; therefore, the total volume of each unit of original air is 1.037×1.036=1.074. Since each unit volume at 100° and complete saturation contains .291 pound of water vapor, each unit volume at 80° and 90% saturation when saturated at 100° will contain 1.074×.291=.3125 pound.

Each 100 cubic feet of incoming air under the changed conditions has capacity for .3125—.145=.1675 pound of moisture.

We have 1,000 pounds of moisture to be removed, and therefore will require $\frac{1,000}{.1675}\times 100 = 597,014$ cubic feet of air.

A common drying period is twenty-four hours, which determines an air volume of 411 cubic feet per minute per thousand bricks.

The weight of a cubic foot of dry air at 80° F. is determined from the formula: $\frac{1.325271\times M}{459.2+t}$ (page 584, Kent), in which M equals barometric pressure and t equals temperature. From this, we find the weight of a cubic foot of dry air at 80° F. and 29″ barometric pressure to be .071 pounds.

Air expands as moisture is taken up, and in one cubic foot of the 90% saturated air at 80° there will be less than .071 pound, since the vapor is lighter than air and displaces it.

From the formula: $\frac{29}{29-(1.025\times .90)}$ we get a value of 1.0328 cubic feet. This formula is based on Boyles law, that the volume is inversely proportional to the pressure. In the formula, 29 equals barometric pressure, 1.024 equals vapor pressure at 80° F. (From vapor capacity table.)

The actual weight of air in one cubic foot will be $\frac{.071}{1.0328} =$ .06876 pound. To this must be added the weight of vapor from the vapor capacity table, .00145, giving a total of .07021, which is the weight of one cubic foot of 90% saturated air at 80° F.

We required 597,014 cubic feet, which is 41,916 pounds (597,014×.07021) of air, including the moisture naturally contained in it.

The problem now before us is to determine the temperature of the air which will be necessary in order to bring sufficient heat into the dryer to do the work.

This problem can only be solved by a series of approximations.

The heat units required are as follows:

1. 1,000×.12×temperature is the heat taken out by cars.
2. 6,000×.2×temperature is the heat taken out by the bricks.

3. $1{,}000 \times 20$ is the heat absorbed by the water in the bricks.

4. $1{,}000 \times 1{,}035.6$ is the latent heat of vapor at 100° F.

5. $41{,}051(100-80)[.234+.000012(100-32+80-32)]$ is heat taken out by dry air.

6. $866(100-80)[.42+.0001(100-32+80-32)]$ is heat taken out by vapor originally in the air.

7. Dryer radiation loss estimated at 10%.

Under items 1 and 2, the temperature is indeterminate. In items 3 and 4, we assume that all the evaporation takes place at the exit at a temperature of 100° F., but in reality it is occurring at all temperatures between the maximum and 100° F. However, saturation is not complete until the end is reached. If the evaporation took place at 150°, the latent heat would be less and the sensible heat required for the water would be greater. The resulting vapor would have a temperature of 150°, but as it approached the exit it would cool down and give back to the dryer requirement its excess temperature. The heat taken from the dryer, therefore, will only be that required to heat the water to the exit temperature and to evaporate it at that temperature. This also explains why item 4 is not made a part of item 6, the latter item being only the moisture originally in the air, which leaves the dryer at a temperature 20° F. higher than its initial temperature.

In order to solve the problem, we must assume a temperature to which the air must be heated, in order to get values for the heat taken out by the cars and bricks.

Let us assume a temperature of 300°, an advance of 220° F. We have then the several items:

1	26,400 heat units
2	264,000 heat units
3	20,000 heat units
4	1,035,600 heat units
5	193,260 heat units
6	7,460 heat units
	1,546,720 heat units
7. Radiation loss, 10%	171,858 heat units
Tot. heat requirement,	1,718,578 heat units

The entering air per degree advance in temperature requires:

$$\begin{array}{r} 41{,}050\ [.234+.000012\ (300+80-64)]=9{,}761 \\ 866\ [\ .42+\ .0001\ (300+80-64)]=\ 391 \\ \hline 10{,}152 \end{array}$$

$\frac{1,718,578}{10,152}$=169° advance in temperature, or a thermometer temperature of 169+80=249° F.

Evidently our assumption of 300° F. was too high. Had we assumed 240°, the resultant determination would have been 241°, and a third assumption of 241° (1,632,044 heat units) gives 241°, fractional degrees not considered.

Suppose we have the inlet and exit temperatures, which can easily be determined in any dryer, and wish to determine the volume in order to adjust the fan to economic condition.

We will take the temperatures in the previous problem in order to check results.

A cubic foot of the initial air contains .00145 pound of moisture, and, as previously determined, weighs .07021 pound. A pound of the mixture will contain $\frac{.00145}{.07021}$=.02065 pound of moisture and .97935 pound of dry air.

The heat, in excess of the initial heat, brought into the dryer per pound of initial air is as follows:

Air (241—80) [.234+.000012 (241—32+80—32)] .97935=37.3823
Moisture (241—80) [.42+.0001 (241—32+80—32)]
....02065= 1.4818

38.8641
Radiation loss, 10%=...................... 3.8864

Available heat units per pound of air=..... 34.9777

Each pound of air, including the initial moisture, removes from the dryer:

Air (100—80) [.234+.000012 (68+48)] .97935=.........4.6106
Moisture (100—80) [.42+.0001 (68+48)] .02065=........1783

Total heat unit loss per pound of air=..............4.7889

Available heat for the dryer:
34.9777—4.7889=30.1889 heat units.

The fixed heat requirement is:
1. 1,000×.12×161= 19,320
2. 6,000×.2×161= 193,200
3. 1,000×20= 20,000
4. 1,000×1,035.6= 1,035,600

1,268,120 heat units

The number of pounds of air required will be: $\frac{1,268,120}{30.1889}$= 42,006 pounds of air.

In our original calculation we found 41,916 pounds required, a discrepancy of 90 pounds, due to the use of whole numbers in temperatures. The difference is about one-half of one per cent and is negligible.

Another Method of Determining Air Volume.

Another, and perhaps simpler, method of determining the air volume is by use of a formula developed by H. M. Prevost Murphy and published in the Engineering News in 1908.

The water vapor which a pound of dry air can carry is found by the formula: $W = \frac{KH}{2.036P - H}$, in which W=pounds of water vapor per pound of air at temperature t, and pressure P in pounds per square inch. P for 29" barometric pressure=29×.4912=14.24.

The values of H and K are given in the following table:

t	K	H	t	K	H	t	K	H	t	K	H
0	.6113	.0439	78	.6206	.9585	156	.6320	8.744	234	.6463	45.61
2	.6115	.0481	80	.6209	1.024	158	.6323	9.177	236	.6467	47.32
4	.6117	.0526	82	.6211	1.092	160	.6326	9.628	238	.6471	49.08
6	.6120	.0576	84	.6214	1.165	162	.6330	10.10	240	.6475	50.89
8	.6122	.0630	86	.6217	1.242	164	.6333	10.59	242	.6479	52.77
10	.6124	.0690	88	.6219	1.324	166	.6336	11.10	244	.6484	54.69
12	.6126	.0754	90	.6222	1.410	168	.6340	11.63	246	.6488	56.67
14	.6128	.0824	92	.6225	1.501	170	.6343	12.18	248	.6492	58.71
16	.6131	.0900	94	.6227	1.597	172	.6346	12.75	250	.6496	60.81
18	.6133	.0983	96	.6230	1.698	174	.6350	13.34	252	.6501	62.97
20	.6135	.1074	98	.6233	1.805	176	.6353	13.96	254	.6505	65.21
22	.6137	.1172	100	.6236	1.918	178	.6357	14.60	256	.6510	67.49
24	.6140	.1279	102	.6238	2.036	180	.6360	15.27	258	.6514	69.89
26	.6142	.1396	104	.6241	2.161	182	.6364	15.97	260	.6518	72.26
28	.6144	.1523	106	.6244	2.294	184	.6367	16.68	262	.6523	74.75
30	.6147	.1661	108	.6247	2.432	186	.6371	17.43	264	.6528	77.30
32	.6149	.1811	110	.6250	2.578	188	.6374	18.20	266	.6532	79.93
34	.6151	.1960	112	.6253	2.731	190	.6377	19.00	268	.6537	82.62
36	.6154	.2120	114	.6256	2.892	192	.6381	19.83	270	.6541	85.39
38	.6156	.2292	116	.6258	3.061	194	.6385	20.69	272	.6546	88.26
40	.6158	.2476	118	.6261	3.239	196	.6389	21.58	274	.6551	91.18
42	.6161	.2673	120	.6264	3.425	198	.6393	22.50	276	.6555	94.18
44	.6163	.2883	122	.6267	3.621	200	.6396	23.46	278	.6560	97.26
46	.6166	.3109	124	.6270	3.826	202	.6400	24.44	280	.6565	100.40
48	.6168	.3350	126	.6273	4.042	204	.6404	25.47	282	.6570	103.70
50	.6170	.3608	128	.6276	4.267	206	.6407	26.53	284	.6575	107.00
52	.6173	.3883	130	.6279	4.503	208	.6411	27.62	286	.6580	110.40
54	.6175	.4176	132	.6282	4.750	210	.6415	28.75	288	.6584	113.90
56	.6178	.4490	134	.6285	5.008	212	.6419	29.92	290	.6590	117.50
58	.6180	.4824	136	.6288	5.280	214	.6423	31.14	292	.6594	121.20
60	.6183	.5180	138	.6291	5.536	216	.6426	32.38	294	.6600	125.00
62	.6185	.5559	140	.6294	5.859	218	.6430	33.67	296	.6604	128.80
64	.6188	.5962	142	.6298	6.167	220	.6434	35.01	298	.6610	132.80
66	.6190	.6393	144	.6301	6.490	222	.6438	36.38	300	.6615	136.80
68	.6193	.6848	146	.6304	6.827	224	.6442	37.80	302	.6620	141.00
70	.6196	.7332	148	.6307	7.178	226	.6446	39.27	304	.6625	145.30
72	.6198	.7846	150	.6310	7.545	228	.6451	40.78	306	.6631	149.60
74	.6202	.8391	152	.6313	7.929	230	.6455	42.34	308	.6636	154.10
76	.6203	.8969	154	.6317	8.328	232	.6458	43.95	310	.6641	158.70

We determine from the above formula that a pound of incoming dry air at 80° F. and 90% saturation carries .02046 pound of water vapor $\left(\frac{.6209 \times 1.024 \times .90}{2.036 \times 14.24 - 1.024} = .02046\right)$.

The weight of a pound of air with water vapor will be 1.02046 pounds. A pound of the mixture will have $\frac{.02046}{1.02046} =$ .02 pound of water vapor and .98 pound of air.

This weight of dry air at 100° F. and 100% saturation will carry $\frac{.6236 \times 1.918 \times .98}{2.036 \times 14.24 - 1.918} = .0432$ pound of water vapor.

Each pound of the incoming air mixture has capacity to remove from the dryer $.0432 - .02 = .0232$ pound of moisture.

Since there are 1,000 pounds of moisture to be removed per thousand bricks, there will be required $\frac{1{,}000}{.0232} = 43{,}100$ pounds of initial air mixture.

This method of figuring gives us a result of 2.8% higher than the method previously used.

The weight of a cubic foot of dry air at 80° F. is determined from the formula $\frac{1.325271\ M}{459.2 + t}$ (page 584, Kent), in which M is barometric pressure in inches of mercury and t equals temperature.

From this we determine the weight of a cubic foot of dry air at 80° F. and 29″ barometric pressure to be .07128 pound.

Air expands as moisture is taken up, and in one cubic foot of 90% saturated air at 80° F. there will be less than .071 pound, since vapor is lighter than air.

From the formula $\frac{29}{29 - (1.024 + .90)}$ we determine that one cubic foot of dry air, in taking up moisture to the degree of 90% saturation, expands to 1.0328 cubic feet. This formula is based on Boyles law, that the volume is inversely proportional to the pressure. In the formula, 29=barometric pressure, 1.024=elastic force of vapor at 80°. (H in above table.)

The actual weight of air in one cubic foot of the mixture will be $\frac{.07128}{1.0328} = .069$ pound.

A pound of mixed air and vapor, as previously determined, contains .98 pound dry air and .02 pound water vapor. The weight of water vapor in a cubic foot of air at 80° and 90% saturation is found from the proportion: $\frac{.98}{.02}=\frac{.069}{X}$, in which $X=.00141$. By Seger's formula, used in our capacity table, this value is .00145.

The weight of a cubic foot of the air mixture is $.069+.00141=.07041$ pound.

The volume of air required will be $\frac{43,100}{.07041}=612,129$ cubic feet per thousand bricks. Under the other method of determination, the volume was 597,014, a difference of about 10 cubic feet of air per minute per thousand bricks.

Either method gives results sufficiently accurate for any practical purpose.

Calculations along this line should be of great value in adjusting a waste heat dryer to the highest efficiency. We can determine the temperature by thermometers, the degree of saturation by wet and dry bulb thermometers or the more convenient diagramatic modifications of the same, and the air volume by anemometers or Pitot tubes. With such data we should be able to properly adjust the operation of the dryer.

In the waste heat dryer, the highest efficiency will come from an initial high temperature. The advantage comes in several ways:

1. The high temperature means materially less volume.
2. Less volume means slower progress through the tunnels, with consequent proportionately greater reduction in temperatures.
3. Less volume and lower exit temperature assure more complete saturation.
4. Less volume takes correspondingly less heat out through the exhaust.
5. More complete saturation means less trying conditions on the ware entering the dryer.
6. Less volume means less power to drive the fans.

The size of the fan is always a perplexing question, and one that usually has to be decided before the exact data in regard to moisture and perhaps temperature can be determined. Fortunately, a fan has a wide range; and, provided we install one of sufficient size, it can be adjusted to any desired volume.

The capacities of fans, as given by the manufacturers of such equipment, do not apply to our conditions, nor would any capacity table be of general application. We draw the air through a simple to complex checker work and flue system, and force it into and through the dryer against a resistance much greater than an ordinary heating system.

It has been our practice to determine the actual air requirement under adverse conditions, and then select a fan of double this capacity at three-fourths ounce pressure.

The piping required for a waste steam heat application will depend upon the weight of exhaust steam.

Under the discussion of periodic dryers, we presented a formula ($R = \frac{T\text{-}t}{k}$) to determine temperatures possible from coil heaters. R=rise in temperature, T=temperature of the steam, t=temperature of the air, k=factor from table accompanying the table. If the steam pressure is 4.3 pounds, which would approximate 5 pounds back pressure on the engine, its temperature will be 225°. The temperature obtainable from a six-section heater with air velocity of 900 feet per minute, air temperature of 80° will be $T = (R+80)\frac{225-80}{1.49}+80 = 177°$ F. We ordinarily install eight sections, but the last two are arranged for high pressure steam, to enable us to supplement with live steam when there is a shortage of kiln waste heat.

Each pound of steam condensed at atmospheric pressure delivers 970.4 heat units.

Each pound of air requires:

Air $(177-80)\ [.234+.000012\ (193)]\ .97935 = \ldots 22.45$ heat units
Moisture $(177-80)\ [.42+.0001\ (193)]\ .20265 = \ .88$ heat unit

23.23 heat units

Each pound of steam, therefore, will heat $\frac{970.4}{23.23} = 41.6$ pounds of air.

If there are 100 horsepower available, we will have $100 \times 34.5 = 3{,}450$ pounds of steam per hour, and this will heat $3{,}450 \times 41.61 = 143{,}520$ pounds of air per hour, or 2,392 pounds per minute.

In the discussion of periodic dryers, we determined 2.79 square feet of heating surface in each row of pipes per square foot of free area. This gives $2.79 \times 24 = 66.96$ square feet in six sections, and this radiating surface heats 900 cubic feet, or $.07021 \times 900 = 63.19$ pounds of air per minute. $\frac{2,392}{63.19} \times 66.96 = 2,534$ square feet of radiating surface, or 7,602 lineal feet of one-inch pipe to condense the steam from 100 horsepower.

This result is only approximately correct, since it does not take into consideration any radiation loss from the coils, and in consequence some of the steam will be required to maintain this loss; but, as this would reduce the amount of piping required, the result obtained gives us a desired factor of safety, and no correction should be made.

The addition of two sections using live steam will decrease the radiating surface required.

From the formula $\frac{T\text{-}t}{k} = R$, we determine that live steam at 60 pounds in two sections of heater coils will advance the temperature from 177° to 218°. This advance of temperature will require a heat consumption of 9.937 heat units per pound of air.

We have previously determined that a pound of air from 80° to 177° requires 23.33 heat units, making a total of 33.267 heat units to heat a pound of air from 80° to 218°.

We found that a pound of exhaust steam heats 41.61 pounds of air to 177°, and similarly determine $\left(\frac{904}{9.937}\right)$ that a pound of live steam will heat 90.96 pounds of air from 177° to 218°.

The relative steam consumption is proportional to the weight of air heated, and may be determined from the equations $\frac{1}{132.57} = \frac{1-x}{41.61}$ and $\frac{1}{132.57} = \frac{1-x'}{90.96}$, in which x equals .686 for exhaust steam and x' equals .314 for live steam.

The live steam radiating surface per square foot of free area is $2.79 \times 8 = 22.32$ square feet.

One hundred horsepower in live steam will heat $3,450 \times 90.96 = 313,812$ pounds of air per hour, or 5,262 pounds per minute. $\frac{5,262}{63.19} \times 22.32 = 1,859$ square feet of radiating surface to condense 100 equivalent horsepower in live steam.

We found that 2,534 square feet would be required for exhaust steam.

If both are used at the same time, the surface of each will be:

1,859×.314= 584 square feet of live steam pipe surface.
2,534×.686=1,738 square feet of exhaust steam pipe surface.

2,322 total surface required, or 6,966 lineal feet of piping.

Making due allowance for uneconomical dryer operation, this amount of piping will suffice for 30,000 bricks per day, each brick containing one pound of water.

It will be noted that the result bears no relation to the dryer capacity, being simply dependent upon its volume of steam available.

If we wished to determine the piping required to supply heat to dry 1,000 bricks under the conditions of the original problem, we must first determine the temperature obtainable from exhaust steam, which in the above problem we found to be 177°. We will assume that two sections are to be used for live steam. In the formula $R=\frac{T-t}{k}$ and the table of the factor k included in the discussion of periodical dryers, we know, or can easily determine, the value of R=64, t=177, k=3.13; and from these, by substitution in the formula ($64=\frac{T-177}{3.13}$), we determine that the live steam must have a temperature of 377°, which is a boiler pressure of 175 pounds.

This steam temperature is higher than we would have in practical operation, but it can be reduced by the use of a greater number of sections of live steam coils.

The number of sections required is easily determined. The temperature of the air entering the live steam sections is 177°, and it must be advanced to 241°, an increase of 64°.

Substituting in the formula $R=\frac{T-t}{k}$, we have $64=\frac{T-177}{2.30}$ for three sections and $64=\frac{T-177}{1.91}$ for four sections. The first equation gives 324° for T, which corresponds to a steam pressure of approximately 80 pounds, and the second equation gives 299°, which is slightly in excess of 50 pounds pressure. Either of these pressures are commonly used in brick plants, and for our problem we will use four sections of live steam piping.

Since the air velocity through the heater is assumed to be 900 feet per minute, each square foot of free area passes $900 \times .07021 = 63.2$ pounds of air per minute.

As already shown, the exhaust steam in six sections heats the air to 177° F, and there must be heat developed in the live steam sections to advance the temperature to 241° F.

The total heat development will be:

1. $63.2\ (177-80)\ [.234+.000012\ (193)]\ .97935 = 1{,}418.2$
   $63.2\ (177-80)\ [.42+.0001\ (193)]\ .02065 = \ldots\ 55.6 - 1{,}473.8$
2. $63.2\ (241-177)\ [.234+.000012\ (354)]\ .97935 = 943.8$
   $63.2\ (241-177)\ [.42+.0001\ (354)]\ .02065 = \ldots\ 38.0 - 981.8$

Total heat units per sq. ft. of free area=.... 2,455.6

The total heat units required for 1,000 bricks is 1,632,044, which, on the basis of a twenty-four-hour drying period, would be $\frac{1,632,044}{1,440} = 1{,}133.4$ heat units per minute.

The free area per thousand bricks will be: $\frac{1,133.4}{2,455.6} = .46$ square foot.

The piping included within this area will be $2.79 \times 6 \times 4 \times .46 = 30.80$ square feet for exhaust steam and $2.79 \times 4 \times 4 \times .46 = 20.53$ square feet for live steam, making a total of 51.33 square feet, or 154 lineal feet of one-inch pipe for 1,000 bricks.

Note—Since the weight of air required for 1,000 bricks is a factor in determining the total heat requirement, we can determine the free area required direct from the weight of air, $\frac{41,916}{1,440} = 29.1$ pounds of air per minute, and $\frac{29.1}{63.2} = .46$ square foot of free area.

The amount of piping, as above determined, is that required for perfect operation of the dryers; but dryers are seldom operated economically, and to whatever extent they vary from the theoretical operation, in the same proportion will the heat requirement increase, and correspondingly must the steam heating system be enlarged.

In many installations, double the theoretical amount of piping is installed, which is an admission that practical operations may be only 50% perfect; but in no instance need the piping be more than 50% in excess of the theoretical requirement.

However, excess piping does not necessarily involve loss of heat, because the steam is condensed only in proportion as the heat is removed from the piping by the air. The greatest loss in waste heat dryers is in using an excess of air, which must be heated up.

About 12% of the total dryer heat requirement is used in heating the air, and if the air is only 50% saturated, as it leaves the dryer the requirement for the air becomes 24%.

The boiler horsepower required per thousand bricks can easily be approximately determined, since we only need to divide the heat requirement per hour by the heat value of a pound of steam, $\frac{1,632,044}{24 \times 970.4} = 70$ pounds of steam, or about 2 H. P. A safety margin of 50% would increase this to 3 H. P.

Finis.

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