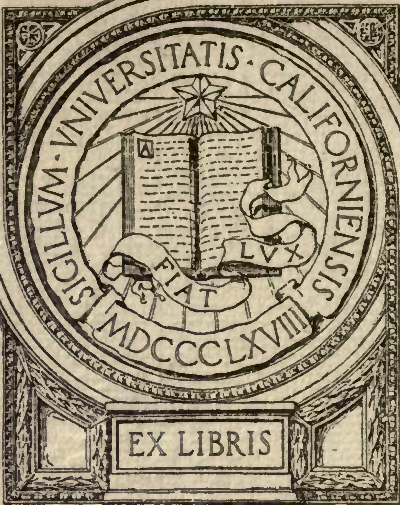
Self-Instruction For Students in Gas Engineering:

Elementary.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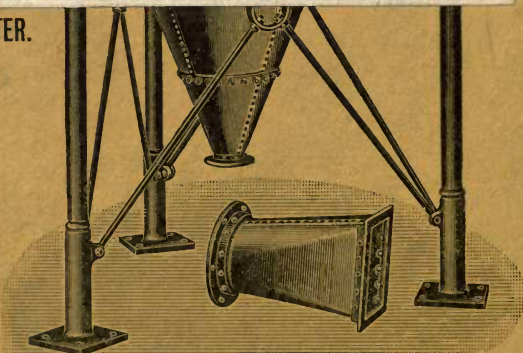

Self-Instruction For Students in Gas Engineering.

BEING

ANSWERS TO QUESTIONS BASED ON THE ORDINARY GRADE SYLLABUS IN GAS ENGINEERING OF THE CITY AND GUILDS OF LONDON INSTITUTE.

By "MENTOR."

FOURTH EDITION.

LONDON:
THE GAS WORLD OFFICES, 8, BOUVERIE STREET, E.C.

Gas Eng.

PREFACE.

SUCH credit as may attach to the publication of this little work is due, in part, to Mr. W. E. Price, Assoc.M.Inst.C.E. In his presidential address to the Southern District Association of Gas Engineers and Managers, Mr. Price suggested for the consideration of the technical journals connected with the gas industry that they might do more than they had yet attempted in the way of assisting students in Gas Engineering in the pursuit of their studies. The Editor of the GAS WORLD, acting on this hint, arranged with a gas engineer and chemist of knowledge and experience to write for that journal a series of articles on "Self-Instruction for Students in Gas Engineering." These have here been brought together in book form. As the title-page indicates, the questions and answers now submitted are based on the Ordinary Grade syllabus of the City and Guilds of London Institute. In a companion volume the same writer deals with the Honours Grade syllabus. Since the publication of the previous editions of the book, the word "Engineering" has been substituted for "Manufacture" in the syllabus, and a new syllabus and examination in "Gas Supply" has been instituted. "Gas Supply" is treated in separate volumes—Elementary and Advanced—also by "Mentor."

It is hoped that the book may prove helpful to students in general, though the subjects treated of in it have been selected with a view to the requirements of those preparing to sit for the examinations held under the auspices of the City and Guilds of London Institute and who may have to rely on their own efforts in acquiring the necessary information. The main object of the work is to guide the student in his reading, and to assist him in forming an idea as to whether he has thoroughly grasped the subject, by giving him a series of questions to answer dealing with every aspect of the various points on which questions may be put. The text-books recommended are :—Newbigging's "Handbook for Gas Engineers and Managers," Hornby's "Gas Manufacture" and "Laboratory Handbook," Hunt's "Gas Lighting," Abady's "Gas Analyst's Manual," and F. W. Stevenson's "Modern Appliances in Gas Manufacture."

It must be distinctly understood that the writer does not desire to assist in anything in the nature of a cramming operation. Before attempting to answer any of the questions put, the student should read up the subject in the standard treatises recommended. Some of the questions should then be attempted, and the student's answers afterwards compared with those given, which, in not a few instances, supply information not contained in the text-books. The student who conscientiously works through the whole of the questions and answers in the manner indicated will be able to assure himself that he has acquired a useful knowledge of the more elementary principles of Gas Engineering, and need have no fear in facing the ordeal of the examination room.

By way of appendix there are included in the present volume answers to the questions set in the Ordinary Grade of Gas Engineering in 1909 and 1910; also a paper read by Mr. W. H. Johns, superintendent of the Saltley Gasworks, Birmingham, before the Midland Junior Gas Engineering Association, on 12th November 1910.

It may be added, for the information of students, that the offices of the Department of Technology of the City and Guilds of London Institute, under whose auspices the examinations in Gas Engineering are conducted, are in Exhibition Road, London, S.W. The Institute takes cognisance of classes only, and not of individual students. Even one student, however, may have facilities given to him to sit for examination. For this purpose he must put himself in communication with the secretary of the Local Committee which superintends the classes and carries out the examinations in his particular district. The regulations for the registration, conduct and inspection of classes, and for the examination of candidates, are contained in the Programme of the Department of Technology, published annually (price 9d. net, post free 1s.) by Mr. John Murray, Albemarle Street, London.

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CHAPTER I.

CARBONIZATION.

(1) Give a general description of the process of obtaining gas from coal.

The process of obtaining gas from coal consists in heating the latter in a closed vessel made of fire-clay, termed a retort, the operation being known as carbonization. The retorts, which are usually D-shaped in cross section, are placed, in a series of from one to nine, in fire-brick arches traversed by a series of flues and heated by a furnace placed underneath them. The retorts are provided with iron doors to render them air-tight. On placing coal in the hot retort and closing the door gas is immediately generated, and passes up a long upright pipe, termed the ascension pipe, to a connecting pipe, known as the saddle or H-pipe, where it joins a vertical pipe dipping into liquid contained in a kind of iron trough, know as the hydraulic main, the vertical pipe being known as the dip pipe. The dip pipe being sealed in the liquid in the hydraulic main, the gas is prevented from returning when the door of the retort is opened for the purpose of drawing and charging. Bubbling through the liquid in the hydraulic main, the gas enters a series of iron pipes, known as the condenser, where it undergoes a certain amount of cooling, the result of which is to throw down the greater part of a thick black viscous liquid, known as tar. Leaving the condenser, the gas passes to the exhauster, a kind of rotary fan used for the purpose of withdrawing the gas from the retorts and enabling it to overcome the resistance offered to its passage through the remainder of the gasmaking apparatus. The next operation is to remove the impurity, ammonia, which is effected by bringing the gas into contact with water in a suitable apparatus. The next stage in the process is to get rid of another impurity, sulphuretted hydrogen, which is brought about by passing the gas through ferric oxide placed on wooden grids in iron vessels, known as purifiers. The purified gas is then measured by a large wet meter, known as the station meter, whence it passes to the gasholder. From the gasholder it goes to the governor, where its pressure is reduced and regulated to the extent necessary to give a proper supply of gas to the district.

(2) What are the considerations to be kept in view in deciding upon the size and shape of a retort? What are the sizes and shapes in general use? Discuss their relative merits.

The primary consideration to be kept in view in deciding upon the size and shape of a retort is that the coal should be capable of being placed in a thin, even layer, so that the heat shall be able to easily penetrate the mass of coal in the interior of the retort, and that there shall not be too much space between the top of the coal and the hot crown of the retort. The shapes of retorts in ordinary use are the round, say 15 to 16 inches in diameter in cross section; the oval, 21 inches by 15 inches; and the ◠-shaped, 18 inches by 15 inches. As regards strength, the round retort is the more durable, and it is easier to draw; but owing to its shape not allowing the coal to lie in a thin layer, it is not so well suited for the production of gas as the oval or ◠-shaped. The oval occupies the next position to the round as regards strength, and the ◠ follows; but the last-mentioned is the most suitable form to employ, owing to its permitting the coal to be placed in a thin, even layer.

(3) State what you know concerning the materials employed in retort settings.

The materials employed in retort settings are retorts and fire-bricks made from fire-clay, which is also used to cement together the various portions of the setting. Fire-clay is the name given to any clay capable of standing a high temperature without melting or becoming soft. Such clays are composed principally of hydrated silicate of alumina. The more alumina there is present in proportion to the silica the more infusible is the clay. The composition of different fire-clays necessarily varies, but, speaking generally, they contain from 2 to 36 per cent. of alumina, 59 to 96 per cent. of silica, 2 to 5 per cent. of oxide of iron, and a very small percentage of lime, magnesia, potash and soda; and the infusibility of the clay depends principally upon the relative proportions of these constituents.

If oxide of iron or the alkalies are present in large amounts they act as a flux and cause the clay to fuse, as in the case of ordinary bricks; the clay from which London bricks are made contains 7·7 per cent. of oxide of iron and 5·1 per cent. of magnesia. On the other hand, a small proportion of lime, potash or soda may improve the clay, by cementing the particles firmly together. Of the fire-clay commonly used in gasworks, mention may be made of the Stourbridge, Newcastle, Dinas, and Lee Moor.

The difference in the composition of the principal constituents of these clays is shown in the following table:—

	Silica.	Alumina.	Iron.	Lime.
Stourbridge . .	63·30	23·30	1·80	0·73
Newcastle . .	55·50	27·75	2·01	0·67
Dinas . . .	97·62	1·40	0·49	0·29
Lee Moor . .	74·02	21·37	1·94	0·40

(4) Discuss the relative advantages of iron and clay retorts, and state the average life of each description.

The relative advantages of iron and clay retorts may be briefly summarised as follows:—Iron retorts are not capable of withstanding the same amount of heat as clay. They are subject to greater wear and tear, owing to the oxidation of the material composing them; consequently they will not last so long. They are also more expansible; but the expansion is more regular, owing to their being more homogeneous—hence they will stand lighting up and letting down more frequently with less injury than clay, which is an important item in small works. On the other hand, clay retorts are capable of standing a higher temperature and will last longer; their chief disadvantages being their porosity and unequal expansion, which result in their opening and cracking when let down. The first-mentioned objection, however, can be largely overcome by the employment of the exhauster. The average life of an iron retort may be taken as twelve months and that of a clay retort as thirty-six months.

(5) Give a brief description of the method of setting retorts, and show, by a sketch, the method by which the retorts are supported transversely.

The usual method of setting retorts is as follows:—The retorts are placed horizontally in an arch, within a few inches of each other. Placed in the centre, either below the level of the bottom retorts in the case of a setting of eights or nines, or between the retorts if the number is less, is a furnace, in which the fuel which heats the setting is burnt. The furnace is provided at intervals with openings, known as nostrils, which allow the heating gases to pass into the setting. The retorts are supported by transverse firebrick walls, which are formed by building up the brickwork corresponding to the solid portion of the furnace arch, *i.e.*, the spaces between the nostrils, so that there is alternately a solid wall, on which a portion of the retort rests, and a hollow space for the passage of the heating gases. This arrangement extends the full length (10 or 20 feet, as the case may be) of the retort. In this way the gases are allowed to freely circulate around the retorts. The method described is common to all descriptions of retort setting, although various modifications may be introduced in applying the system. For example, in a setting of nines the gases are usually allowed to emerge from the furnace and to spread equally under the lower tier of three retorts; they are then drawn upwards, and, passing over the bridge wall, either enter the regenerator or descend and pass into a chamber in connection with the upright flue, there being in every case a division wall in the centre of the

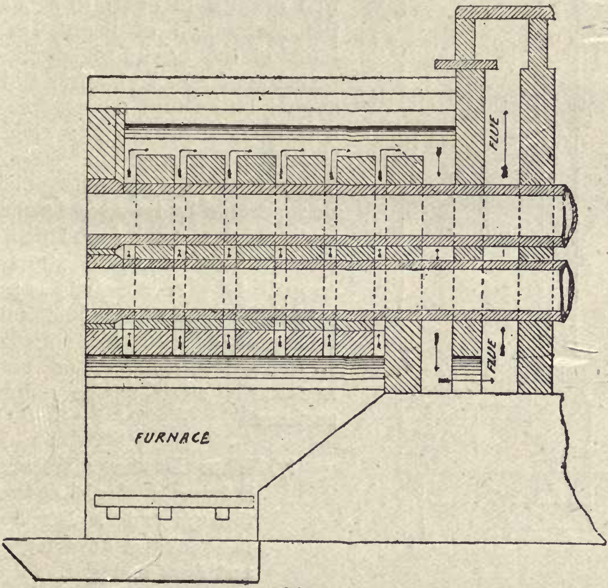

Fig. 1.

setting. In another system of setting retorts the side passages are blocked so that the gases are compelled to pass over the top, where they descend, come to the front, and, as before, either enter the regenerator or are conducted to the main flue. Fig. 1 shows the method of supporting the retorts.

(6) What are the conditions to be kept in view in designing a retort setting?

The consideration to be kept in view in designing a setting of retorts is the necessity of heating the retorts to

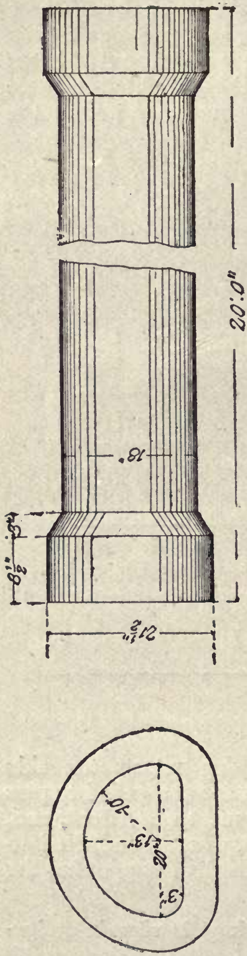

Fig. 2.

the requisite degree with the expenditure of the minimum amount of fuel. The first essential is to ensure a good solid foundation, which should be well drained in order to avoid the abstraction of heat. The joints of the brickwork should be made of fire-clay mortar and should be as thin as possible, and each brick as it is laid should be dipped in water. The retorts in a setting should be supported by transverse walls resting on a solid foundation, the walls being made strong enough to give adequate support during the whole time the setting is at work, without obstructing the draught or unnecessarily covering the retort surfaces.

(7) What is the difference between a single and a through retort? Discuss their relative advantages and disadvantages.

Single retorts are usually made in one piece, and are from 9 to 10 feet in length, while through retorts are made up of three portions, the total length being from 18 to 20 feet. Single retorts have a mouthpiece at one end, the other end being closed, while a through retort has a mouthpiece at each end (Fig. 2). The advantages of a through retort are that, owing to the absence of the closed end, there is less surface for the accumulation of carbon; owing to there being a free passage for the air through the retort when the retort is drawn, the carbon is more easily removed; and, further, there is a gain in heating space in the hottest portion of the setting. The only disadvantage attending the use of through retorts is that they are not suitable for medium-sized or small works, since the setting of "throughs" requires the services of two gangs of men simultaneously, one at each side.

(8) Explain clearly the principles of combustion upon which the heating of gas retorts depends.

The heating of gas retorts is effected by means of the heat generated by the combustion of coke in the furnace or producer. Coke consists principally of the element carbon, and when carbon is burned in air the following reaction occurs, $C + O_2 = CO_2$; and the result is the generation of a considerable amount of heat. The reaction here mentioned can take place in two ways, according to the depth of fuel in the furnace. In the case of a shallow furnace, as met with in an ordinary direct-fired furnace, the reaction occurs as in the equation given, the fuel being burned direct to carbon dioxide (CO_2); but in the case of a generator or regenerative furnace, where we have a deep layer of fuel, the CO_2 first formed is reduced to carbon monoxide by passing through the upper portion of the fuel. Thus $CO_2 + C = 2CO$. This gas is capable of being burned to CO_2 by meeting the necessary amount of air—$CO + O = CO_2$; and this is what occurs in a regenerative setting. The final result is the same in both cases—viz., the combustion of the fuel to CO_2; but in the one case complete combustion takes place in the furnace, in the other case partial combustion only takes place in the furnace, the completion of the process occurring in the most suitable place—viz., in the combustion chamber adjacent to the retorts.

(9) Explain clearly, by the aid of a sketch, the construction of a regenerative furnace, and enumerate some of the advantages attending its use.

The construction of a regenerative furnace is shown in Fig. 3 (p. 8). The producer is filled with coke, which rests upon fire-bars; and it is provided with air-tight doors, so that only the requisite amount of air can enter, through what are known as the primary air openings. The air admitted here is known as the primary or first air supply, and it is usually raised in temperature to about 400° Fahr. by passing through

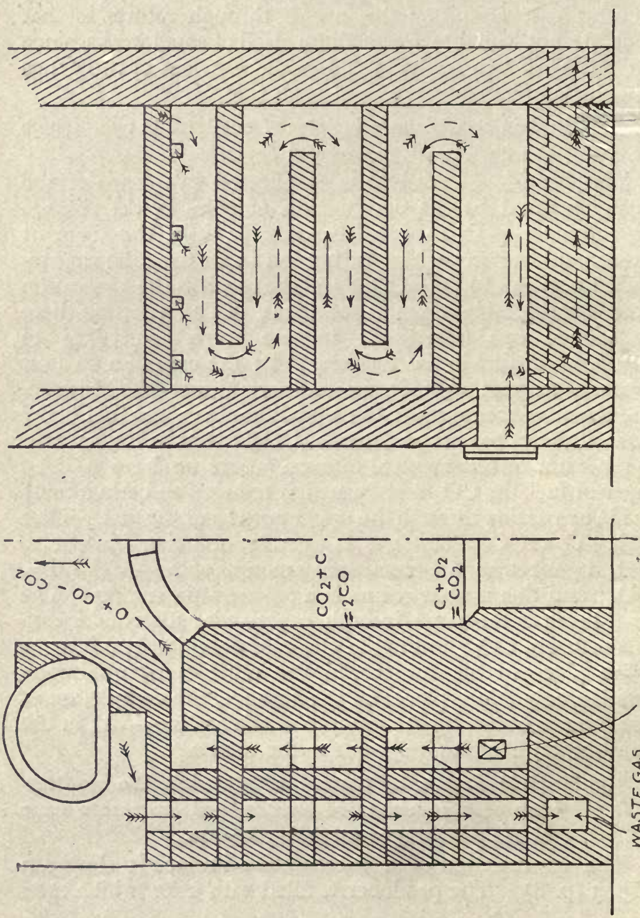

Fig. 3.

a series of heated channels or flues encircling the ash-pit. The combustion of the carbon (in the coke) with the oxygen (of the heated primary air) produces carbonic acid gas (CO_2), and in passing through the remaining portion of the fuel this becomes converted into carbonic oxide gas (CO), which emerges at the nostril holes of the producer, and is termed "producer gas." At this point it meets the "secondary air," which has been raised to a temperature of about 1,800° Fahr. by passing through a brickwork chamber, where it is heated by means of the waste heat from the spent gases, which lose heat to the same extent as the air gains it.

The point where the combustion of the producer gas takes place is known as the combustion chamber; and the resulting products of combustion, after doing their work in heating the retorts, descend into what is known as the regenerator, which consists of a chamber provided with a series of baffling flues, as shown in the sketch (Fig. 3). The waste gases travel downwards, while the secondary air travels upwards, the two portions of the regenerator being separated by a division wall, as shown. By this means the heat of the waste gases is utilised for raising the air to the required temperature for perfect combustion. Some of the advantages of this system of firing are—considerable saving in fuel, amounting, in some cases, to as much as 50 per cent.; increased make of gas per ton of coal carbonized, owing to the good and regular heats obtained; saving in labour, and the longer life of the retorts.

(10) What are the chief points to be attended to in the successful working of regenerative furnaces? How may the working be controlled?

The points to be attended to are to work with as little damper as possible; to regulate the primary air so as to obtain the maximum amount of combustible gas; to keep the generator full of coke; to admit only as much secondary air as will burn the gas produced; to keep the base of the producer cool by attention to the water supply of the drip plates; and to pay strict attention to the cleaning of the fires. The conditions for successful working are indicated by the composition of the producer and flue gases. The producer gas should have the approximate composition of 5·2 CO_2 and 24·8 CO; while the flue gases should show not less than 15 or 16 per cent. of carbonic acid, nor more than 2 per cent. of oxygen. These indications are obtained by an analysis of the gas by means of the Bunte burette.

(11) Mention the essential conditions for obtaining good carbonizing results.

The first essential is, of course, the maintenance of good heats and the spreading of the coal in even layers in the retort, the charge being well backed up off the front of the mouthpiece. The retort lids must be kept tight, and the exhauster must be worked so as to maintain as light a seal as possible, consistent with not drawing in air or furnace gases. The ascension pipes must be kept clear by using the bent auger at every draw, and the charges must be worked off sufficiently well to allow of draws being made at regular times. If the retorts are charged by hand the retorts in any one setting should not all be charged at the one draw, but one or two in each of several settings, as this will help to maintain more regular heats. The fires must be kept free from clinker, the latter being carefully removed from the sides and back of the furnace, so that it is not allowed to climb up. Always clinker before charging. Ash pans or drip plates must be kept supplied with water. The refuse from the ash pans should be carefully picked over, the clinker separated out, and as much combustible matter as possible either returned to the furnace or used under the boilers.

(12) What results follow when a retort is unevenly charged with coal?

In the event of a retort being unevenly charged—that is, in thick and heavy and light and thin portions alternately—the result would be that the gases rich in illuminants would be driven off from the thin portions before the regular time for drawing the charge, with the result that gases having little or no illuminating value would be evolved during the remainder of the time the charge is allowed to remain in the retort. This would probably reduce the illuminating power of the gas obtained from the charge generally; while the thick portion would probably not be properly carbonized in the usual time allowed, and thus cause the make per ton to be less than it ought to be, in addition to producing a soft and spongy coke.

(13) What is clinker, and how is it produced?

Clinker is the fused mass of incombustible material which has to be dealt with in the furnaces, owing to its choking up the air passages between the furnace bars. When the combustible part of the coke with which the furnace is supplied is consumed it leaves behind the incombustible material derived from the ash of the coal, and the constituents forming this material, consisting of silica, alumina, lime, iron, etc., under the influence of the intense heat of the furnace, combine together to form a kind of slag, which is well known by the name of clinker.

(14) What is carbon, or scurf; how is it produced, and how is it usually got rid of?

Carbon is the deposit which forms on the walls of the retort. It is produced by the decomposition of the hydrocarbons in the gas when the gas comes into contact with the hot sides of the retort, more especially if the gas is subjected to an excess of pressure, as when an exhauster is not employed. The usual way of removing the deposit is to arrange for the retorts to stand off for twelve hours, and to allow a current of air to circulate through them, which will have the effect of loosening the deposit so that it can easily be removed by means of chisel bars.

(15) Give the approximate products from one ton of Newcastle coal.

	Lbs.	Per Cent.
Gas (10,000 cubic feet)	380	17·0
Tar (10 gallons)	115	5·1
Virgin ammoniacal liquor	177	7·9
Coke (absolute)	1,568	70·0

CHAPTER II.

EFFECTS OF TEMPERATURE IN MODIFYING QUANTITY AND QUALITY OF GAS PRODUCED.

(16) How would you arrive at (approximately) the temperature of a retort? Give a list of colours corresponding to various temperatures. At what temperatures are iron and clay retorts usually worked?

The temperature of a retort may be approximately judged by means of its colour. The following list gives the colours corresponding to the temperatures named :—

Colour.	Temperature in Degrees Fahr.
Red, just visible . . .	977
Dull red	1,290
Dull cherry red	1,470
Full cherry red	1,650
Clear cherry red	1,830
Deep orange	2,010
Clear orange	2,190
White	2,370

Iron retorts are usually worked at a temperature of from 1,650° Fahr. to 1,830° Fahr., and clay retorts at a temperature of about 2,010° Fahr.

(17) Describe a simple form of pyrometer for high temperatures.

A simple method of arriving at the approximate temperature of, say, a retort consists in placing a small block of wrought-iron in the retort until it has attained the temperature of the latter. This is then immersed in a known weight of water, the temperature of which has previously been noted. The temperature of the retort is obtained from the formula

$$H = t + w\frac{(t - T)}{SW}$$

Where H = temperature of the heated iron.
T = " " water before immersion.
t = " " " after "
S = specific heat of wrought-iron = 0·113.
W = weight of the iron.
w = " " water in which the iron is immersed.

(18) How do varying temperatures affect the quantity and quality of the gas produced from coal?

On gradually heating a sample of coal in a closed vessel, there will be very little alteration until a red heat is reached. At a temperature of 752° Fahr. it is possible to completely carbonize coal. The results of the distillation will, however, principally take a liquid form, and the amount of gas will be small; but what there is given off will be of high illuminating power. On analysing the gas, it will be found that it differs very considerably from the gas produced at ordinary working temperatures. The hydrocarbons present will be found to belong to the marsh gas (methane) and olefiant (ethylene) series; benzene, acetylene and hydrogen being conspicuous by their absence. As the temperature is increased, the gaseous products increase; whilst the liquid products become less, but their density becomes greater. The difference in the character of the products obtained as the temperature is increased is due to the further splitting up of the primary products of the carbonization, which are in themselves low temperature products. Each fresh charge of coal at the outset robs the retort of so much heat in order to effect distillation that the temperature is reduced to the point at which low temperature products only are the first result. But these gaseous bodies having to pass through a considerable mass of incandescent coke, and then along the hot walls of the retort, on their way to the ascension pipe, are decomposed by the heat; splitting up into simple hydrocarbons and free hydrogen, whilst a certain amount of free carbon is deposited on the walls of the retort, in the form known as scurf.

Speaking generally, the effects of temperature are that as the temperature is increased, the yield of gas is also increased; but at the expense of the quality, which is reduced. This is caused by the splitting up of the hydrocarbons given off on distillation into simpler compounds, until at the last stage of the process only free hydrogen is given off. With a very low temperature we obtain a large amount of tar and little gas; the latter, however, of a high illuminating power. As the temperature is increased the liquid hydrocarbons decrease, while the gaseous products increase, so that we obtain more gas and less tar.

The following table shows the effect of varying temperatures on four samples of the same coal:—

Temperature.	Cubic Feet of Gas Yielded. Per Ton.	Illuminating Power (Candles).
(1) Dull red . . .	8,250	20·5
(2) Hotter	9,693	17·8
(3) Hotter	10,821	16·7
(4) Bright orange . .	12,006	15·6

(19) Upon what basis are coals usually compared for gas-making purposes? A certain coal yields 10,350 cubic feet per ton of 14½ candles, how would you compare its value with another coal which yields 10,000 cubic feet per ton of 16 candles?

Coals are usually compared on the basis of the pounds of sperm they are capable of yielding per ton. In speaking of the quality or illuminating power of gas it is assumed that the candle-power represents the number of candles burning 120 grains of sperm per hour, with the gas burning at the rate of 5 cubic feet per hour; and in order to arrive at the pounds of sperm per ton the rule is to multiply 120 by the candle-power and divide by 5. This will give the value of the gas in grains of sperm for each cubic foot, and on multiplying this by the total number of feet per ton and dividing by 7,000 (the number of grains in a pound) we obtain the pounds of sperm to the ton. This rule may be contracted by multiplying the yield of gas by the candle-power, multiplying by 24 ($120 \div 5$) striking off three figures and dividing by 7. Thus, in the example given:—

```
   10350
    14·5
  ------
   51750
  41400                     10000
 10350                         16
 -------                   ------
 1500750                   160000
       4                        4
 -------                   ------
 6003000                   640000
       6                        6
----------                 --------
7)36018000                7)3840000
----------                ---------
 514·54                    548·5
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showing that the coal yielding 10,000 cubic feet of 16 candle gas is the better coal.

CHAPTER III.

APPARATUS EMPLOYED FOR CONVEYANCE OF THE GAS IMMEDIATELY ON ITS LEAVING THE RETORTS.

(20) Describe, with sketch, the apparatus through which the gas has to pass immediately upon leaving the retort.

The apparatus through which the gas has to pass immediately on leaving the retort is shown in Fig. 4 (p. 17). It comprises the iron mouthpiece, A, the ascension pipe, B, the arch, H, or saddle pipe, C, the dip pipe, D, and the hydraulic main, E, the last mentioned communicating either with a back main running parallel to the hydraulic or with a main at the end, known as the foul main, which conveys the gas to the condensers. Ascension pipes are usually 6 inches in diameter at the mouthpiece, tapering to 5 inches at the junction with the saddle pipe, the latter and the dip pipe being 5 inches in diameter. There are various descriptions of saddle pipes; but in every form of pipe provision should be made for clearing them in case of stoppages.

(21) What is the function of the hydraulic main and dip pipe?

The hydraulic main and dip pipe together fulfil the functions of an automatic valve, which enables the gas to pass freely forward while gasmaking is in progress, but prevents it from returning when the retorts are opened for the purpose of drawing and charging. The hydraulic main further serves to collect the volatile products from a large number of retorts into a common stream, and also as a cooler to liquefy some of these products. The gas as it enters the hydraulic main is laden with tarry matter which gives it the appearance of a brown vapour, but the greater

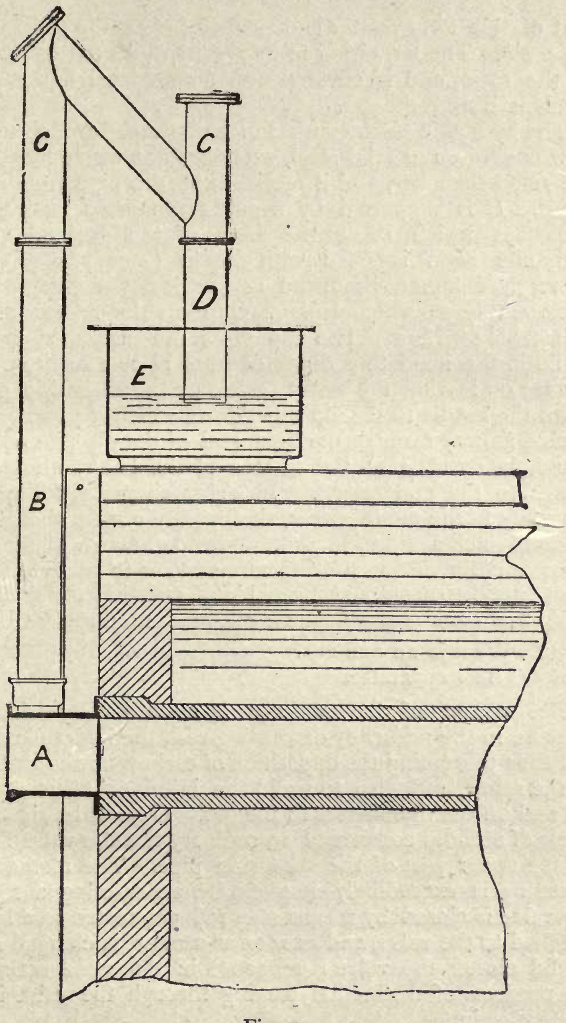

Fig. 4.

part of this tarry matter is deposited before the gas leaves the main. The tar, owing to its gravity, sinks to the bottom of the main, and is covered with ammoniacal liquor, also condensed from the gas.

The hydraulic main consists of a U-shaped trough made of wrought-iron or mild steel, extending the whole length of the retort benches, and it receives the dip pipe from each retort. It is supported by wrought-iron joists resting on buckstays which brace the front of the setting. The hydraulic main is filled with liquid (usually a mixture of tar and liquor, produced as previously described) to a certain level, which is kept constant by means of an adjustable overflow. The dip pipes are immersed in the liquid in the main to a depth of from 1½ to 2 inches; and the gas on leaving the retort travels up the ascension pipe, down the saddle to the dip pipe, down which it passes, and, forcing its way through the light seal of the dip pipe in the liquid, it emerges at the surface of the latter, whence it passes to the condensers. In order to prevent the gas returning to the mouthpieces, the hydraulic main should be made of such a width, in proportion to the area of the dip pipes and their several distances apart, as to provide sufficient liquid to form a seal capable of resisting the greatest amount of back pressure which can be exerted against it.

(22) What is an anti-dip? Describe some simple form of this apparatus.

The object of the anti-dip is to do away with all pressure in the retort, by dispensing with the hydraulic seal, and thus preventing the deposition of carbon on the interior of the retort, and also to avoid the injurious effect of the tar seal on the illuminants in the gas. One of the simplest forms of anti-dip consists of an ordinary throttle valve fixed on the upper part of the ascension pipe. The method of operating is exceedingly simple. Before opening a retort the valve is closed by means of a rod connected to a lever attached to the valve, and as soon as a retort is charged and the lid closed the valve is reopened in the same manner, the products of distillation passing through the valve into the foul main.

(23) Discuss the importance of keeping the hydraulic main level and the dip pipes of equal length. What results follow when these precautions are not observed?

The importance of observing the conditions referred to in the question arises from the fact that it is necessary that each dip pipe shall have an equal amount of seal. The results which follow from the non-observance of these conditions are that some pipes have an excess while others have a deficiency of seal; and this would cause pressure, in the one case, with a corresponding risk of leakage, together with deposition of carbon on the retorts, while in the other case air and furnace gases would be drawn in, reducing the quality of the gas and increasing the sulphur compounds.

(24) Discuss the position of and method of supporting the hydraulic main.

The position of the hydraulic main, which is usually on the top of the retort bench, should be such as to allow it to be sufficiently removed from the heat of the settings to prevent pitching of its contents, and it should be supported in such a manner as will enable it to be always maintained perfectly level throughout its length. It was at one time the practice to support the main on brick piers resting upon the brickwork of the bench, but there is a great disadvantage in this method of support, on account of the unequal expansion of the heated brickwork throwing the main out of level, which tends to the unsealing of the dip pipes; and when the bench needs re-building it is an obstacle to the progress of the work. The main should be supported independently of the setting by carrying it on joists spanning the bench and attached to the front wall buckstays which tie in the setting.

(25) What are the points to be kept in view in deciding upon the size of a hydraulic main? A hydraulic main is 20 feet long and 2 feet wide inside, at the level of the liquid contained therein; dipping into it are ten dip pipes, 6 inches in diameter and 30 inches long to the underside of arch pipes, or where the liquid would overflow in case of an excess of back pressure.

Show how to arrive at the amount of seal required to prevent the unsealing of the dip pipes in the event of the exhauster stopping, the maximum amount of back pressure being 30 inches.

As stated in the answer to question No. 21, the hydraulic main should be made of such a width in proportion to the area of the dip pipes as to provide sufficient liquor to form a seal capable of resisting the greatest amount of back pressure which can be exerted against it.

The first operation is to arrive at the area of the dip pipes by squaring their diameter and multiplying by 0·7854.

$$6^2 = 36 \times \cdot 7854 = 28\cdot 27'' \times 10 = 282\cdot 7''.$$

$282\cdot 7 \times 30 = 8{,}481$ cubic inches as the total cubical capacity of the dip pipes; and this divided by the area of the hydraulic main in inches $= 240 \times 24 = 5{,}760 = 1\frac{1}{2}''$, nearly, as the amount of seal required.

(26) Describe some form of self-sealing retort lid.

There are various descriptions of self-sealing lids. One in common use is that invented by Mr. Robert Morton, provided with Holman's eccentric fastener. This form of lid is made of cast-iron moulded to the shape of the mouthpiece, and is faced and planed, the corresponding surface on the mouthpiece, where the two surfaces come into contact, being also faced and planed. The lid is fixed to a lug projecting from the mouthpiece, and is so arranged as to be capable of swinging round on a swivel hinge. On the opposite side there is a catch which engages with a cross-bar, and this secures the lid when the latter is shut, the lid being tightened up by the eccentric lever.

(27) Discuss the method of supporting retort mouthpieces.

The iron mouthpieces were at one time simply attached to the retorts by means of a number of bolts and nuts, but it frequently happened that these burnt through, leaving the mouthpiece unsupported; so latterly a system of bracing has been adopted, consisting either of an old rail or bulb-iron, which bears on the two adjacent flanges of the mouthpiece and is tied in to the buckstays. This provides for the burning away of the bolts, and also takes the weight of the mouthpiece.

(28) State what you know concerning stoppages in ascension pipes.

The two factors tending to cause stopped pipes are high heats and a heavy seal. The method of preventing such stoppages is to keep the pipes cool and to provide as light a seal as possible, and this to be of liquor. In order to keep the ascension pipes cool they should project about 8 inches from the front of the setting, and in order to prevent excessive radiation from the front walls of the retort setting the walls should be made of a thickness of 14 inches. A device which has often proved effective in preventing the pipes from stopping "high up" consists in allowing a fine stream of water to drip into a funnel fitted to the top of a goose-necked syphon so that the water can flow down the ascension pipe. The most essential precaution, and one which must never be omitted, is to insert a bent auger into the outlet from the mouthpiece to the ascension pipe every time the retort is drawn.

(29) In what condition does the crude gas leave the retort, and what bearing has this on the subsequent manufacturing processes?

The crude gas as it issues from the retort consists of a mixture of permanent gases, while carried in suspension are a number of hydrocarbon and other vapours of varying density; and as the illuminating and calorific power of the gas is largely dependent on the hydrocarbons contained in it, it is of great importance to be able to retain as many of the hydrocarbons in a permanently gaseous state as possible. These hydrocarbons differ in their characteristics. Those of the greatest density are reduced to the liquid form by a simple reduction of temperature, and constitute what is known as tar, large quantities of which are deposited in the hydraulic main, although the temperature at that point is only about 130° Fahr. It is, therefore, almost hopeless to expect to be able to retain this class of hydrocarbon in the gas; but there are other and lighter hydrocarbons which can be retained by suitable means, since they are not so susceptible to the effects of temperature. These are, however, very much affected by the solvent action of the heavier hydrocarbons deposited in the hydraulic main and elsewhere, more especially if the temperature is below, say, 100° Fahr. But this prejudicial effect can be prevented by separating the gas as quickly as possible from contact with the heavy hydrocarbons, by arranging for the dip pipes to be sealed in liquor and by not allowing the heavy tar from the hydraulic main to flow along with the gas, but allowing the latter to flow into a separate main from the tar, which is taken off direct and led into the tar well. The lighter tars, which condense afterwards, do not injure the quality of the gas, provided the temperature is above 100° Fahr. From the foregoing it will be seen that the treatment the gas receives prior to entering the condenser has an important bearing on its quality.

(30) What is, approximately, the temperature of the gas in the retort and at the outlet of the hydraulic main, respectively? What reason can you assign for the difference?

The temperature at which the gas is generated may be taken as being that of the retort, viz., about 2,010° Fahr., and at the outlet of the hydraulic main the gas has a temperature of from 130° to 150° Fahr. The principal reason for this great difference is the rapid absorption of heat by the volatile constituents of the coal in assuming the gaseous form. This heat is latent in the gas in a similar manner to the latent heat in the production of steam.

CHAPTER IV.

CONDENSATION.

(31) What is the object of condensation, and to what extent is it carried out in the various portions of the manufacturing plant?

The object of condensation is twofold, viz., to cool the gas, and thus render it fit for the subsequent purifying processes, and also to eliminate from it certain substances which, if not taken out at an early stage of the manufacturing process, would block up the purifying and other plant. The substances which it is necessary to get rid of are the hydrocarbons known as tar, and the vapour of water. But as some hydrocarbons are extremely useful as light-giving agents, and by suitable treatment can be retained in the gas, great care must be taken not to cause these to be deposited with the other hydrocarbons which cannot be retained. A considerable amount of condensation takes place between the retort and the hydraulic main, and a further amount of work is done in the condenser, where the temperature will be reduced to the requisite point; but after leaving the condenser there still remains suspended in the gas a number of vesicles enclosing small globules of tar, which can only be eliminated by friction, by subjecting the gas to treatment in a tar extractor, or in the condenser of Pelouze and Audouin.

(32) What are the results attending condensation?

The results attending perfect condensation are the cooling of the gas to the requisite degree, say from 130° Fahr. to 60° Fahr.; the elimination of the whole of the tar, amounting to from 10 to 12 gallons per ton of coal carbonized, together with considerable quantities of ammoniacal liquor, consisting of the liquefied aqueous vapour in combination with ammonia; and the removal of a portion of the impurities, sulphuretted hydrogen and carbonic acid. The quantity of the condensed aqueous vapour amounts to from 13 to 20 gallons per ton.

(33) State the principles upon which the usual methods of condensation depend.

The usual form of condenser consists of a series of pipes exposed to the cooling action of the air, and its action depends upon transmitting the heat from the hot gas and vapours in the interior to the external air in contact with the outer surfaces of the pipes, which air, becoming rarefied, ascends by reason of its lower density, and is constantly being replaced by fresh air of a lower temperature and higher density.

(34) What are the factors which determine the size of the condensing plant, and what amount of condensing surface should be allowed?

The amount of condensing surface required depends upon the amount of condensable products deposited by the gas, and this varies with the character of the coal. Newcastle coals do not condense so much water as, say, coals from the Derbyshire district. A condensing surface of 5 superficial feet per thousand cubic feet of gas made per day would prove sufficient in the former case, whereas the latter would require double the surface, or 10 superficial feet. Mr. Newbigging, in his "Handbook," gives 10 superficial feet as the area in every case.

(35) Describe the classification of the different descriptions of condensers in general use.

The condensers in ordinary use may be divided into two classes, viz., air condensers and water condensers, the former class embracing the vertical, horizontal, annular, and battery, and the latter class the Livesey and the Morris and Cutler.

(36) Give brief descriptions of the vertical, horizontal, annular and battery condensers, giving sketch of the horizontal.

The ordinary vertical condenser consists of a series of pipes, usually two 9 feet lengths, placed vertically, through which the gas passes up and down alternately. This is brought about by attaching the pipes at the bottom to a cast-iron box provided with a series of mid-feathers which dip to a certain depth in the liquids deposited from the condenser, so as to form a seal. The pipes are connected by semi-circular bends at the top. The condenser products flow away from the collecting cistern through a seal pot to the tar well.

The horizontal condenser, shown in Fig. 5, consists of a series of pipes arranged side by side in pairs, the end of each length being joined to that of the next. The pipes are supported on a framework so arranged that from the

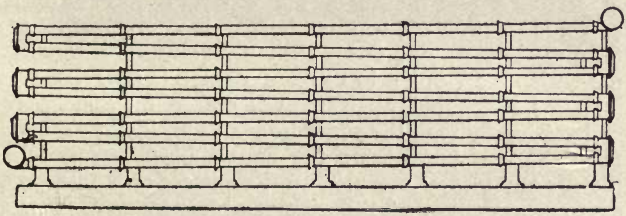

Fig. 5

inlet at the top, through the entire run of the apparatus to the outlet at the bottom, there is a gradual inclination, which enables the products of condensation to flow away to the outlet (which is provided with a pipe dipping in a seal pot) and thence to the tar well. Blank flanges are bolted on the end of each length of pipe for convenience in cleaning out.

The annular condenser consists of a series of large pipes placed vertically, each of which encloses a smaller pipe, thus forming an annular space through which the gas travels. In addition, there are other pipes, placed diagonally, which connect alternately the top and bottom of the larger pipes. This arrangement has the effect of causing the gas to always travel through the annular space in the downward direction; and the current of heated air moves upward through the inner air pipe. Provision is made for regulating the air draught according to the atmospheric temperature prevailing, either by means of moveable covers or by butterfly valves fixed at the bottom. A small pipe is connected to the bottom of each condensing column for the purpose of carrying away the products of condensation into a main running alongside the condenser and leading into the tar well.

The battery condenser consists of an oblong cast-iron vessel, 12 to 24 inches wide, 12 to 18 feet high, and of length varying according to the requirements of the works. It is divided internally by plates or mid-feathers extending to within a few inches of the top and bottom of the apparatus alternately, so that the gas is compelled to pass from the inlet up and down each division until it arrives at the outlet. In order to increase its condensing power 2-inch or 3-inch tubes, open at each end to the atmosphere, and passing through the vessel from side to side, are securely fixed. These tubes serve the double purpose of cooling the gas and also of breaking up the current of flow, so as to cause a separation of the condensable vapours. Suitable syphons are fixed at each division for carrying off the condensed products.

(37) How do the Livesey and Morris and Cutler condensers differ from those mentioned in the preceding question? Briefly describe them, and state their advantages.

The Livesey and Morris and Cutler condensers differ from the condensers described in the preceding answer in the cooling medium employed, viz., water in place of air. The Livesey water condenser consists of a series of large-sized cast-iron pipes laid in a shallow open brick tank, or trough, the pipes being laid in parallel lines. Between each line a brick partition is built, a water-way being left through the division at alternate ends. At the end at which the gas leaves the condenser cold water is admitted to the trough, and it flows in the opposite direction to that of the gas, thus ensuring that the cooling process is gradual and even, and avoiding the gas being subjected to a sudden chill.

The condenser of Morris and Cutler consists of a cast-iron rectangular box having vertical divisions, which form a series of compartments 8 inches or 9 inches wide, the divisions being stopped short at alternate ends so as to leave room for the passage of the gas, causing it to travel to and fro several times the length of the apparatus before leaving the outlet. Within the compartments a number of wrought-iron tubes are placed at a distance of about 6 inches apart, the tubes being $\frac{3}{4}$ inch or 1 inch diameter. In each compartment two or three vertical baffle plates are inserted, with the object of preventing the warm gas from rising to the top and stratifying in layers of different temperatures. Cold water is admitted into the tubes at the end of the compartment at which the gas leaves, and flowing through them in the opposite direction to the flow of gas, absorbs heat from the latter, and so gets gradually warmer, finally leaving the apparatus at the end at which the gas enters it.

The advantages obtained by the employment of the condensers just described are that the action of the apparatus is more under control, and the greater efficiency of water as compared with air as a cooling medium. This is strikingly shown in the following experiments by Peclet:—

Excess of Temperature in the Gas.	Quantity of Heat Lost by a Square Unit of Exterior Pipe Surface.	
	When Radiating in Open Air.	When Plunged into Water.
For an excess of 10° Fahr.	8	88
,, ,, 20° ,,	18	266
,, ,, 30° ,,	29	5,353
,, ,, 40° ,,	40	8,944
,, ,, 50° ,,	53	13,437

It will be seen from the figures given in the above table that when the difference in the temperature of the gas and the water employed for cooling is only 10°, the effect of the water is considerably greater than that of air when the difference of temperature is five times as great.

(38) What is the object of the condenser of Pelouze and Audouin? Briefly describe the apparatus.

The object of the condenser of Pelouze and Audouin is the breaking up of the suspended tarry particles in the gas, which are not acted on by the skin contact in the ordinary type of pipe condenser. The apparatus consists of an outer cylindrical cast-iron chamber having a gas inlet and outlet pipe and an outlet for the condensed liquids. Inside the cylinder is another cylinder of perforated sheet-iron, which constitutes the condenser. The sides of the condensing chamber are two thin sheets of iron having a concentric space between. The inner sheet is perforated with holes one-twentieth of an inch in diameter, and the outer with a series of large-sized slots. The outer sheet is so arranged as to offer a blank surface opposite the small holes in the inner sheet. The gas and condensable vapours pass through the perforations, with the result that the vapours are what may be termed wire-drawn, and striking against the blank space opposite are deposited thereon, whence they flow to the receptacle below and thence to the tar well, while the gas passes on through the slots in the outer cylinder to the outlet pipe. The condensing cylinder is so balanced as to be capable of acting as its own regulator. This is effected by causing it to move in a hydraulic seal, so that as the make of gas increases or decreases the cylinder rises or falls, with the result that a larger or smaller number of openings are uncovered for the passage of the gas.

(39) Describe, with sketch, the usual method of automatically getting rid of the products of condensation without loss of gas. What points have to be studied in arranging the apparatus?

The universal method for getting rid of liquid products either from the condensing or scrubbing plant is by the agency of the dip pipe and seal pot, shown in Fig. 6. The seal pot is a cylindrical cast-iron vessel of about 24 inches diameter, having an overflow at the side at a predetermined level, which regulates the amount of seal. The pot is filled with liquid, into which a pipe, coming from, say, a condenser, dips. The liquid products pass by way of this pipe into the pot whence they overflow, while the gas is prevented from escaping by reason of the seal of the contained liquid. In large works these pots are frequently grouped together in a concentric brickwork receptacle known as the seal well, which is capable of containing considerable quantities of liquid. The contents of the several seal pots overflow into this common well, whence they either flow away by gravitation or are pumped

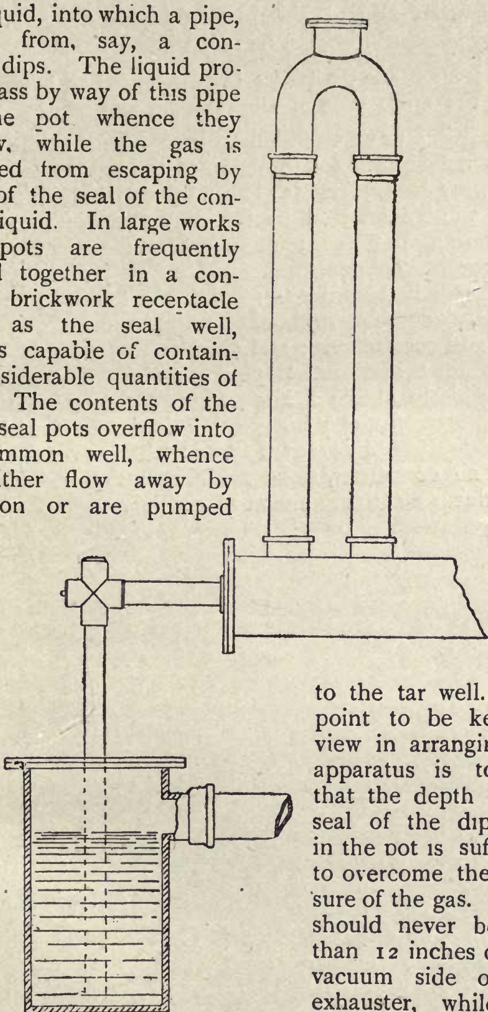

Fig. 6.

to the tar well. The point to be kept in view in arranging the apparatus is to see that the depth of the seal of the dip pipe in the pot is sufficient to overcome the pressure of the gas. Seals should never be less than 12 inches on the vacuum side of the exhauster, while on the pressure side of the exhauster all seals should be 6 inches deeper than the greatest pressure likely to be met with.

(40) What are the points to be attended to in conducting the operation of condensation, and why?

The points to be attended to in condensing the gas are not to reduce the temperature of the gas to too great a degree, say lower than 45° Fahr., otherwise the illuminating power will be affected by the deposition of some of the hydrocarbons in the gas; and to perform the operation slowly, since sudden condensation also acts prejudicially, for the same reason. In order to regulate the temperature in cold weather, all condensers should be fitted with suitable by-pass valves and connections; and thermometers should be fitted in the inlet and outlet pipes, so as to enable those responsible to obtain a knowledge of the temperatures at these points. In very hot weather it will be found advantageous to have a stream of water trickling over the surface of the air condenser, since the evaporation resulting from this induces a certain amount of cooling.

CHAPTER V.

THE USE OF THE EXHAUSTER.

(41) State the cause which led to the introduction of the exhauster and the object of its employment.

The necessity for the employment of the exhauster originated with the introduction of clay retorts, owing to their greater porosity and the higher temperatures at which they were worked as compared with iron retorts. The objects of the exhauster are to overcome the resistance offered to the passage of the gas through the different portions of the manufacturing plant and to effect the withdrawal of the gas, as quickly as it is generated, from contact with the hot walls of the retort. In the case of iron retorts, owing to the more homogeneous character of the material composing them, there was not the same necessity for the use of the apparatus, since these are much tighter than those made of clay, and also, through their not being worked at such high temperatures, there was not so much risk of the decomposition of the hydrocarbons in the gas. In the case of clay retorts, where an exhauster is not employed the back pressure causes the gas to leak through the porous walls of the retort and to be burnt in the furnace, in place of going forward to the gasholder; and subjecting the gas to pressure when in contact with the hot walls of the retort causes the hydrocarbons to be decomposed, with the formation of scurf, which takes up retort space and robs the retort of heat.

(42) Into what classes may exhausters be divided? Mention some of the leading types of each.

Exhausters are usually either rotary or reciprocating. Rotary exhausters embrace those of Jones, Laidlaw, and Beale, and reciprocating exhausters those of Methven, Anderson, and Dempster.

(43) Describe briefly, the Beale exhausters manufactured by Gwynne, Donkin, and Waller, respectively, and state the principal point to be attended to in the construction of this type of exhauster.

The Beale exhauster as manufactured by Gwynnes Limited consists of a cylindrical cast-iron case provided with inlet and outlet branches. Within this case a cast-iron drum of much smaller diameter revolves on shafts fixed at each end, which project through stuffing-boxes on the end plates of the outer case, and is carried in suitable gun-metal bearings. One end of the projecting shaft is sometimes provided with a pulley or, as is generally the case, it is coupled direct to the crank shaft of a steam engine. The drum is fixed parallel to the length of the outer case, but eccentrically to its diameter, touching but not resting upon the bottom of the outer case. Passing through the drum at opposite sides are two blades or diaphragms, which are guided at the ends by steel-cased pins working in sliding segments, which travel in grooves fixed in the end plates of the outer case. This causes the slides to be drawn in and out as the drum revolves eccentrically to the outer case, the speed at which the exhauster works being so arranged as to produce a continuous sweeping of the walls of the outer case, resulting in the gas being sucked in on the inlet side, carried round above the drum and discharged on the outlet side of the outer case. Slips and springs are fitted to the edges of the blades to ensure close contact with the case. Each revolution of the drum and slides draws in and discharges double the contents of the case, minus the contents of the drum and slides.

The Beale exhauster as manufactured by the Bryan Donkin Company, Limited, consists of an outer case of an elliptical shape, the width being greater than the height. As in the Gwynne exhauster, there is an inner drum fitted with blades which in this case are joined by a cast-iron guide sliding on a rotating block fixed in the centre of the exhauster, where the velocity is lowest, and consequently a considerable reduction in friction is effected. The outside bearing on the drum shaft follows the usual lines at the end where the exhauster is driven, but at the other end the drum forms the bearing, by reason of its being made longer and running in a recess formed in the end plate. Messrs. Donkin, in their latest form of exhauster, adopt an arrangement for utilising the capacity of the internal drum. They achieve this result by flattening two sides of the exterior of the drum and attaching projecting pieces to the sliding guide, which runs the whole length of the drum, so as to convert the guide into a piston which works to and fro in the drum, somewhat after the manner of the piston of a steam engine. The end covers are provided with ports, which enables the gas to be drawn into the drum at one end at the same time as it is being discharged at the other.

The rotary exhauster of Messrs. Geo. Waller and Son consists of the usual cylindrical cast iron outer case with a smaller internal drum. The inlet and outlet ports of the outer case are made larger than is customary. The inner drum is prolonged at the ends, and is carried in recesses provided in the end plates. It has a shaft attached to it at one end, which projects through a stuffing-box in the end plate. Passing through the centre of the outer case is a fixed spindle, to which are hinged four blades radiating from the spindle and passing through four small rollers fitted into holes in the periphery of the inner drum, these holes being bored perfectly true. The rollers have an oscillating motion, in order to give the necessary movement to the blades as they open and close in their travel. The outer end of the inner drum is fitted with a ring which is bored out at the proper distances apart in order to take the projecting ends of the small rollers. In this type of exhauster the centre spindle ensures that the blades are kept in contact with the periphery of the outer case, and so dispenses with the segment guides used in the exhauster of Gwynnes Limited, thus considerably reducing the friction. It is claimed for this exhauster that while the capacity between the blades is less than in the ordinary two-blade exhauster, each revolution makes four deliveries instead of two, giving an increased delivery of somewhere about 50 per cent.

The principal point to be attended to in the construction of rotary exhausters is good workmanship, in order to prevent as much as possible what is known as "slip," a certain amount of which, however, is unavoidable, since it is necessary for there to be contact between the ends of the blades and the outer case, and also between the drum and the outer case, without very much friction. As showing the importance of paying attention to this point, it has been stated that with a clearance of only 0·031 of an inch, and with the exhauster working against a back pressure of 20 inches, slip occurs of the whole of the gas.

(44) Describe some form of reciprocating exhauster.

An example of a reciprocating exhauster is that manufactured by Messrs. R. and J. Dempster, Limited. It consists of two double-acting pumps fixed horizontally, with a steam engine placed between them, all secured to one heavy bedplate. The pistons of the three cylinders are worked by their respective connecting rods direct from the crank-shaft. The pumps are arranged to work at quarter centres to each other, so that the discharge of gas is always uniform, thus ensuring a steady gauge. Provision is made in the crank for an adjustable screw, by means of which the stroke of the piston in the gas cylinder can be adjusted to pass any quantity of gas, and so ensure a steady gauge with any make of gas.

(45) What are the points to be attended to in the working of an exhauster, and how is the working controlled?

The points to be attended to in the working of an exhauster are to have a steady gauge and to avoid both excessive and insufficient vacuum. An excessive vacuum results in the drawing in with the gas of air and furnace gases, which causes a loss of illuminating power, while a deficiency of vacuum causes leakage and the formation of scurf in the retort. Owing to various causes, the production of gas is usually not very regular, and the steam pressure also varies considerably, but these conditions must not be allowed to interfere with the vacuum, which must be steady, and evenly maintained. This result is effected by means of various devices. In the early days of gas lighting, and at the present time in small works, the speed of the exhauster is controlled by means of a small gasholder which is connected to a throttle valve placed in a small main connecting the inlet and outlet of the exhauster, and which allows a portion of the gas to return from the outlet to the inlet of the exhauster. There is a pipe leading from the hydraulic main to the gasholder, so that the inlet vacuum is capable of exerting its influence under the crown of the holder; and, consequently, if the exhauster is giving too much vacuum, by running at too great a speed, this vacuum acts upon the holder, causing it to fall. By this falling of the holder the throttle valve is opened wider, thus allowing more gas to return from the outlet to the inlet of the exhauster, and thus, by giving the latter more work to do, the vacuum is restored to the original amount. Should the vacuum be reduced, then the operations above described are reversed; the holder in this case rising and closing the throttle valve, causing less gas to be returned to the inlet of the exhauster.

This method of controlling the vacuum is very wasteful, however, as it throws additional work upon the exhauster, by causing it to churn a portion of the gas over and over again. A great improvement was subsequently effected by transferring the throttle valve to the engine driving the exhauster, retaining the small gasholder, which is worked in the same manner as in the original method; but as it communicates direct with the throttle valve of the engine the speed of the latter is varied inversely as the vacuum varies. This method has been elaborated and improved upon by various makers of gasworks apparatus, so that it is now possible to ensure a perfectly steady gauge under considerable variations of steam and gas pressure.

(46) What apparatus does an exhauster attendant require in order to efficiently control the exhauster under his charge?

The exhauster house should be provided with three gauges, one on the inlet main to the exhauster, another in direct communication with the hydraulic main, and another on the outlet of the exhauster. The first-mentioned gauge will show whether the mains from the retort house (including the condenser) are clear or not; the second one will show the pressure on the retorts, after making allowance for the depth of seal on the dip pipes; whilst the last-mentioned gauge will indicate the total amount of back pressure exerted against the exhauster; so that, with a knowledge of the limiting seals of the different portions of the plant, there will be ample warning in case of any obstruction which would cause a blow. The exhauster should be provided with a governor, which either works a by-pass valve fixed on a main connecting the inlet and outlet, or is connected direct to the steam throttle valve of the engine actuating the exhauster. In either case it should be in direct communication with the hydraulic main. There should also be an automatically acting flap valve which would open in the event of the exhauster breaking down. There should also be a jet photometer, with an oxide purifier, connected to the outlet of the exhauster, the indications of which would show if there was anything wrong in the retort house, such as air being drawn in, etc. There should, further, be a recording exhaust register under lock and key, by which a continuous record of the vacuum can be seen.

(47) What are the essential features of a good exhauster?

The essential features of a good exhauster are that it should be simple in its construction and work with a minimum of friction and power, that it should give a steady gauge, and that the internal parts should be as gas-tight as possible, seeing that as much as 9,000 cubic feet per hour will pass back or slip through an opening one square inch in area when subjected to a back pressure of only 14 inches of water. As some exhausters have to contend against as much as 50 inches, the necessity for tightness is obvious.

(48) State the principal advantages attending the use of the exhauster.

The advantages attending the use of an exhauster are an increase in the amount of gas made per ton; an improvement in the quality of the gas; an increase in retort space available for carbonizing, due to the absence of scurf; a longer duration in the lives of the retorts, by the avoidance of the use of chisel bars in the removal of scurf, although, of course, it is impossible to prevent the accumulation of some carbon ; and a decrease in the amount of fuel used, due to the absence of the non-conducting scurf.

CHAPTER VI.

THE REMOVAL OF IMPURITIES.

(49) Mention the chief impurities found in crude gas. Briefly describe their properties and the necessity for their removal.

The chief impurities in crude coal gas are ammonia (NH_3), carbon dioxide, commonly spoken of as carbonic acid (CO_2), sulphuretted hydrogen (SH_2), bisulphide of carbon (CS_2), and other compounds of sulphur, principally of an organic nature.

The first mentioned impurity, ammonia, is a compound of 1 volume of nitrogen with 3 volumes of hydrogen, and is, therefore, represented by the chemical formula, NH_3. By weight it contains 82·35 per cent. of nitrogen and 17·65 per cent. of hydrogen. Its molecular weight, being the sum of the atomic weights forming the molecule, is 17. Ammonia is a colourless gas possessing a very characteristic pungent smell. It is much lighter than air; its specific gravity, taking air as 1, is 0·586, while 1 cubic foot at 60° Fahr. and 30″ Bar. weighs 315·77 grains. When strongly cooled or subjected to great pressure it condenses to a liquid. Ammonia is extremely soluble in water, the resulting solution possessing the characteristic odour of the gas, and colouring reddened litmus paper blue and turmeric paper brown, which shows that it possesses all the characteristic properties of an alkali. Under ordinary conditions it is incombustible, but if mixed with oxygen it burns with a pale yellow flame. Ammonia is especially distinguished by its property of uniting with acids to form salts, which property is made use of in the manufacture of sulphate of ammonia, and in the process of washing and scrubbing, in which the ammonia combines with the carbonic and hydro-sulphuric acids in the gas. It is necessary to remove ammonia from the gas on account of its destructive action on the brass and copper work of the index wheels of meters and gasfittings with which it may come into contact, besides giving off various oxides of nitrogen when burned; in addition to which, being a valuable commodity in the form of sulphate of ammonia, its removal is commercially important.

Carbonic acid (CO_2) is a colourless, odourless gas which will neither burn nor support combustion. Under ordinary conditions water will dissolve its own volume of the gas, but its solubility is greatly increased by changes in temperature and pressure. The reasons for its removal are its detrimental action on the illuminating power of the gas and the fact that the "sulphur compounds" cannot be taken out by means of lime unless CO_2 is absent.

Sulphuretted hydrogen (SH_2) is a colourless gas having a characteristic nauseating odour. It is freely soluble in water, and burns in air, producing sulphurous acid (SO_2) or sulphur (S_2), according to the conditions prevailing as to an excess or a deficiency of air; this property being utilised in the Claus kiln. The necessity for the removal of sulphuretted hydrogen is due, first of all, to its poisonous and offensive odour, and also to the fact that it tarnishes bright metal work by forming a sulphide of the metal.

Carbon bisulphide (CS_2) is a heavy, colourless liquid which is extremely volatile. It is only slightly soluble in water. It boils at 117° Fahr., and its vapour ignites at 300° Fahr. The necessity for the removal of carbon bisulphide is due to the fact that when it burns SO_2 is formed, and under certain conditions this is oxidised to SO_3 (sulphuric anhydride).

(50) Explain how the impurities above mentioned are produced and the approximate amounts of each usually met with.

Ammonia is obtained in the destructive distillation of coal by the union of the nitrogen with the hydrogen, $N+H_3=NH_3$. Carbonic acid (CO_2) is formed by the union of the carbon with the oxygen, $C+O_2=CO_2$. Sulphuretted hydrogen (SH_2) is the result of the union of the hydrogen with the sulphur disengaged from the iron pyrites (FeS_2) in the coal. Carbon bisulphide (CS_2) is produced by the union of sulphur from the same source with the carbon in the coal. The two compounds last named are formed as follows :—When a retort is charged with coal the outside portions in contact with the hot walls of the retort are rapidly raised in temperature, and the sulphur which is liberated by the breaking up of the iron pyrites vaporises and combines with free hydrogen to form sulphuretted hydrogen. But this portion of the charge will become "coked" sooner than the mass in the centre, so that when the latter is hot enough to give off the vapour of sulphur, this, having to pass over the hot carbon, will combine with the latter to form CS_2. Thus, $C+S_2=CS_2$.

The amounts of the various impurities may be approximately taken as being about 1·5 per cent. by volume of ammonia, or 476 grains per 100 cubic feet, in the gas leaving the retort. The carbonic acid and sulphuretted hydrogen from various kinds of coal are given in the following table by Mr. Lewis T. Wright :—

IMPURITIES IN CONDENSED BUT UNWASHED GAS.

Class of Coal.	CO_2 Grains per Cubic Foot.	CO_2 Per Cent. by Volume.	SH_2 Grains per Cubic Foot.	SH_2 Per Cent. by Volume.	
Newcastle	12	1·5	9	1·4	Carbon bisulphide from 35 to 50 grains per 100 cubic feet.
Yorkshire Silkstone	12	1·5	8	1·3	
Derbyshire "	12 to 19	1·5 to 2·3	6 to 12	1 to 2·0	
Cannels	30	3·7	3 to 6	0·5 to 1·0	

(51) Which is the first impurity to be removed, and why?

The first impurity to be removed from the gas is ammonia, which, if not taken out at the usual point, viz., immediately after the exhausters, would be lost, by going forward to the lime and oxide purifiers ; in addition to which, it would lock up some of the last-mentioned agent and render a certain portion of it useless as a purifying material, besides forming a most objectionable compound with the lime.

(52) What are the conditions for effectively freeing gas from ammonia?

The conditions for effective ammonia purification are that the gas should be cooled down to a temperature of not higher than 60° Fahr., and that it should be quite free from tarry matters. The absorption of ammonia by water is most effective at low temperatures, and the absence of tarry matters conduces to a longer life and more efficient duty from the scrubbers, by preventing the material with which they are usually filled becoming clogged, and thus rendering them inefficient. For this reason it is customary to pass the gas through some form of tar extractor before entering the scrubber, in order to get rid of the suspended tarry globules.

(53) State the principles upon which the removal of ammonia depends.

The removal of ammonia from gas depends upon the solubility of ammonia in water, which at ordinary temperatures is capable of absorbing 700 times its volume of ammonia gas, the amount of absorption increasing as the temperature of the water is lowered and *vice versa*. It is necessary to note, however, that the circumstances under which water absorbs ammonia are not such as occur in ordinary gasworks practice. The quantity of ammonia that water can absorb depends in a great measure on the pressure of the ammonia gas, so that when we say that water will absorb 700 times its volume of ammonia gas it is assumed that the pressure of the ammonia gas is equal to that of ordinary atmospheric pressure; and since the quantity of ammonia in the crude gas is only 1·5 per cent. by volume, it follows that the maximum pressure it is capable of exerting can only be 1·5 per cent. of the total pressure of the gas, which is practically atmospheric pressure. Further, in the same manner as the strength of a solution of ammonia in water is dependent upon the pressure of the ammonia gas with which it is in contact, so is the strength of gas liquor dependent upon the pressure exerted by the ammonia in the crude coal gas with which the liquor is in contact, and, conversely, the proportion of ammonia in the crude coal gas is dependent upon the strength of the gas liquor with which it is in contact.

Gas liquor of varying strengths and temperatures have definite pressures which cause them to give up ammonia to the gas if the ammonia pressure of the latter is less than that of the liquor, while if the ammonia pressure in the gas is greater than the pressure of the liquor, the latter will gain in strength by abstracting ammonia from the gas until the ammonia pressure remaining in the gas balances that exerted by the liquor.

The tension or pressure of ammonia that will balance that of any gas liquor varies with the strength of the liquor and the temperature, the tension increasing with the temperature. The reason why it is necessary to finally use clean water in the washing process is that the compounds of ammonia with carbonic acid and sulphuretted hydrogen are dissociable at ordinary temperatures, and in consequence of this dissociation their solutions exert an appreciable ammonia tension, so that the liquor deposited in the condensers, e c., cannot remove all the ammonia from the gas, but must leave an amount equal to the ammonia pressure of such liquor to be dealt with by clean water. Liquor of so low a strength as 1 ounce saturation test exerts at 60° Fahr. an ammonia pressure that is considerably over that allowed by the London Gas Referees, or 4 grains per 100 cubic feet, and this is increased as the temperature rises; hence the necessity for using so much more water in summer than in winter.

(54) Give a brief general description of the method by which ammonia is removed from gas.

The removal of ammonia commences as soon as the crude gas leaves the retort and enters the hydraulic main, where, owing to the condensation of aqueous vapour, ammonia is absorbed by the water thus produced; but owing to the temperature being still fairly high, say about 140° Fahr., the amount of work done is not very great. On the gas passing through the condensers a considerable amount of cooling is effected, with the result that a large quantity of water is deposited, which takes up more ammonia, so that by the time the gas reaches the outlet of the condensers, about one half of the total amount of the contained ammonia is removed.

The remainder of the impurity is then got rid of by bringing it into contact with liquid contained in washers, scrubbers, or washer-scrubbers—frequently a combination of such apparatus. Theoretically, the liquid employed should be water, in which ammonia is very soluble, but practically the aim should be to use as little water as possible, in order to make strong liquor; and this is effected by first of all treating the gas in one portion of the apparatus with the liquor deposited in the hydraulic main and condensers, which is a very weak solution of ammonia, and therefore capable of taking up more of the gas and consequently becoming more concentrated, while at the same time it can combine with considerable quantities of carbonic acid and sulphuretted hydrogen. By this treatment the greater part of the ammonia will be removed, and the final traces can then be taken out in another portion of the plant, by means of a comparatively small quantity of clear water.

The relative quantities taken out when working in the manner indicated are:—

NH_3 removed by condensation . . .	42·7	per cent.
,, ,, first scrubber . . .	43·3	,,
,, ,, second scrubber . .	14·0	,,
	100·0	

(55) What are the points to be kept in view in the removal of ammonia?

The points to be kept in view in freeing gas from ammonia are to make as strong a liquor as possible, by avoiding using more water than is necessary to take out all the ammonia. The reason for this is obvious, since the more concentrated the liquor the less fuel will be required to convert a given bulk into sulphate of ammonia, or if the liquor is sold to a contractor the smaller will be the cost of carriage. The next point is to make the ammonia do as much work as possible in taking out the sulphuretted hydrogen and carbonic acid.

(56) Briefly describe the various forms of apparatus usually employed for the removal of ammonia.

The apparatus in which the ammonia is removed comprises the washer, the scrubber, and the rotary washer, commonly known as the washer-scrubber. The washer is usually a cast-iron rectangular vessel, in which the gas is caused to pass in a finely divided stream through a certain depth of ammoniacal liquor, the principal object being the removal of the floating particles of tar which have not been removed in the process of condensation, so that the gas may be quite free from tar before it enters the scrubbers. It also acts as a decarbonator, by reason of the ammonia in the liquor combining with the carbonic acid in the gas, and at the same time it performs a certain amount of work in the elimination of ammonia. The washer may be looked upon as a necessary adjunct to the scrubber, doing the preliminary work to render the gas fit to enter the latter. In order to do their work it is necessary that washers should give a certain amount of back pressure, which varies from 1 to 4 inches. The washers in principal use are those of Anderson, Livesey, and Walker. The tower scrubber, a sketch of which is shown in Fig. 7 (p. 45), is the apparatus most commonly employed in the elimination of ammonia. The distinctive difference between the washer and scrubber is that in the washer the gas has to force its way through a certain depth of liquor, while in the scrubber the gas passes over wetted surfaces, such as coke, drain pipes, boards, etc., which give a large area. The tower scrubber is a circular cast-iron vessel built up in sections, and varies from 3 to 12 feet in diameter and from 40 to 70 feet high, the usual relationship between the height and diameter being as 1 to 7. The vessel itself is simply a shell to contain the scrubbing material, whose object is to break up the gas into small streams, the surface of the material being kept constantly wetted by means of liquid which is run in at the top. The material commonly employed in filling the scrubber is coke; but this has the disadvantage of becoming clogged with tar, and consequently it requires frequent renewal. It has therefore of late years been the practice to use wooden boards about

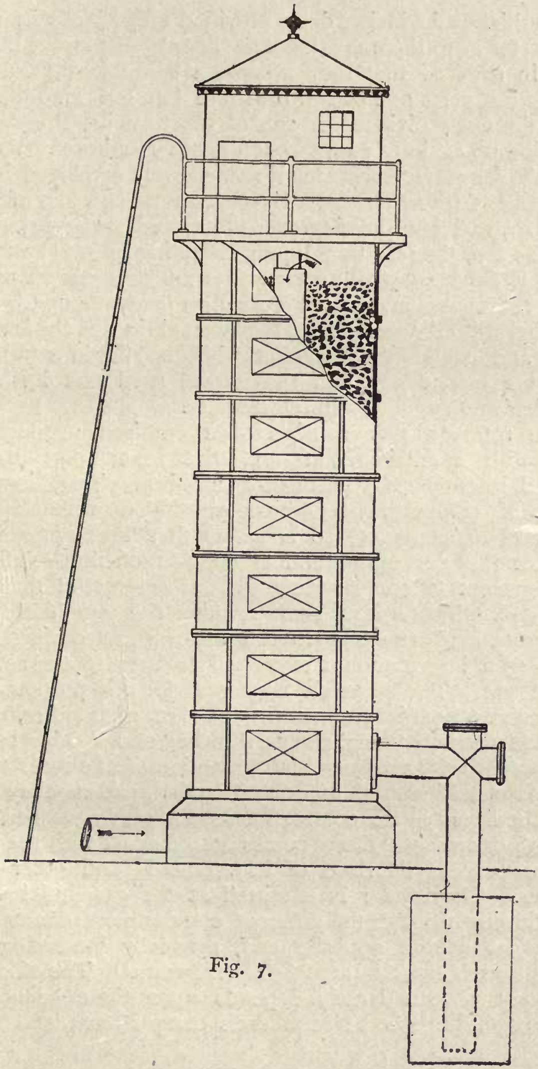

Fig. 7.

$\frac{1}{2}$ inch thick and 8 inches deep, provided with $\frac{1}{2}$ inch distance pieces to keep them apart. The boards are arranged on edge in rows so that they assume a spiral form, and at certain distances one or two rows are left out in order to allow the finely divided streams of gas to unite, afterwards breaking up again to pass through another series of boards. Green's canvas screens are also extensively employed as a filling agent for scrubbers. Gas enters the bottom of the scrubber, and after passing over the wetted surfaces leaves it at the top, the resulting liquor collecting at the bottom, where it flows away to the tar well through a sealed overflow. Scrubbers are usually worked in pairs, the first being supplied with the weak liquid deposited in the hydraulic main and condensers, together with the liquid obtained from the second one, and the second used as a finishing scrubber and supplied with clear water.

The rotary washer consists of a cast-iron rectangular tank with a semi-circular top, the lower part being divided internally, by means of cast-iron plates, into a series of compartments which are filled with liquid. The compartments are so arranged that the liquor supplied at the gas outlet end is capable of flowing from compartment to compartment until it emerges at the gas inlet end. There is a shaft running the length of the apparatus, and attached to this are various devices for exposing a large amount of wetted surfaces to the action of the gas. The materials employed for this purpose are thin wooden boards arranged in the form of bundles, with distance pieces between, circular brushes, and wooden balls. As these slowly revolve with the motion of the shaft they are completely wetted in every direction, and as they rise from the liquid in the compartments, the crude gas passing through or amongst them comes into contact with the wet surfaces and is deprived of its ammonia and other impurities. Clean water is admitted at the gas outlet end, and flowing through the different compartments meets the crude gas at the opposite end, gradually increasing in strength as it travels through the apparatus. The efficacy of rotary washers largely depends upon there being no slipping of the gas between each compartment, and this depends upon the faced joint between the division plates of each compartment and the revolving collar attached to the shaft being perfectly gas-tight.

(57) Discuss the various methods employed for distributing the water in scrubbers.

There are several methods for supplying scrubbers with water. A common arrangement consists of a pipe passing through the sides or crown of the scrubber, and having smaller tubes, pierced with holes, joined to it and radiating towards the circumference. The arrangement is sometimes capable of revolving, when its efficiency of action is increased. Another method consists in allowing a stream of water under a considerable pressure to impinge against a flat disc, the result being that the water rebounds off the disc in the form of a fine spray. In the Mann and Walker scrubber, in order to obtain an even distribution, the water is run into three funnels from an overhead tank. The funnels are attached to the ends of three vertical pipes, the other ends of which are sealed in small chambers by water. The water passes from these chambers by an overflow pipe into the interior of the scrubber, where it is discharged from revolving arms which are so arranged that they revolve more slowly when they are discharging water away from the centre of the scrubber, thus causing a more equal distribution of the water. This method of distribution involves the use of a small engine to give the apparatus the requisite slow rotary motion. To obviate the necessity for an engine, a Barker's mill is sometimes used for producing the necessary motion. The mill is either fed intermittently from a tilting box, or a vessel holding several gallons of water and fitted with a valve and float is employed.

(58) State the most advantageous manner of employing the plant used in the elimination of ammonia and the method of working same.

The best way of arranging the plant for ammonia purification is, first of all, to pass the gas through a tar extractor in order to break up the tarry globules, then through a scrubber supplied with the liquor deposited in the hydraulic main and condensers, and finally through a rotary washer supplied with clean water.

(59) Discuss the relative merits of rotary washers and scrubbers.

The disadvantages of scrubbers are that they are liable to become choked with tar, especially if filled with coke, and then their performance is unsatisfactory, owing to the water washing "rat holes" through the coke, so that instead of descending in a uniform stream, it runs in one or two main channels, whilst the gas is passing up through other parts of the scrubber without coming into proper contact with the descending water. But these defects can be remedied in a great measure by the employment of a tar extractor at the bottom of the first or foul scrubber, and by filling the scrubber with boards, or Green's canvas grids, in place of coke. The scrubber possesses the advantage that it is simple in construction and requires a very small amount of motive power to supply it with water. The advantages of a washer-scrubber are that it is better adapted for taking out the last traces of ammonia with the least quantity of water, and it is more under control and more certain in its action as an ammonia extractor. The motive power required is greater than that needed for the scrubber.

(60) What is the rule for arriving at the amount of scrubbing plant required? A works makes 500,000 cubic feet per day (maximum), what would be the scrubbing plant required?

Assuming that the whole of the ammonia is removed by means of scrubbers, the usual allowance is 9 cubic feet of scrubbing capacity per 1,000 cubic feet of gas made in 24 hours, on the basis of the heaviest day's work.

In the present example, the make being 500,000 cubic feet per day, the total scrubbing capacity required will be $500 \times 9 = 4,500$ cubic feet; and as scrubbers should, as a general rule, be worked in a series of two, this will represent two scrubbers, each having a capacity of 2,250 cubic feet, and as the ratio of the diameter to the height should be about as 1 is to 7, this capacity will be about obtained by allowing 7 feet 6 inches diameter and 50 feet high, thus—

```
         7·5
         7·5
        ----
         375
        525
       -----
       56·25
       ·7854
       -----
       22500
      28125
     45000
    39375
   ---------
   44·178750
          50
 -----------
 2208·937500
```

(61) Upon what basis is the amount of ammonia obtained in the form of gas liquor usually valued? What do you understand by the term 10-ounce liquor?

The strength of ammoniacal liquor is usually expressed in terms of ounces of sulphuric acid neutralised by a gallon of the gas liquor. When we speak of 10-ounce liquor, we mean that a gallon of such liquor would require 10 ounces of pure, strong sulphuric acid to neutralise the ammonia contained therein.

(62) What do you understand by the terms "free" and "fixed" ammonia?

By free ammonia is meant ammonia in combination with the two weak acids, carbonic and hydrosulphuric, which combination is decomposed at a temperature under that of boiling water, so that the ammonia can be expelled from the solution by the simple act of boiling. By fixed ammonia is meant ammonia in combination with certain acids, the salts not being decomposable by simple boiling, but requiring to be heated in company with an alkaline substance, such as lime or magnesia, for which the acids have a stronger affinity. The fixed ammonia in gas liquor consists principally of ammonium chloride, and exists to the extent of about one-fourth to one-fifth of the total ammonia. The chlorine that furnishes this ammonium chloride was originally contained in the coal, and is driven off on distillation as hydrochloric acid. This substance forms the "salts" that are often found mixed with tar in the hydraulic main when high temperatures are employed.

(63) State, approximately, the relative amount of free and fixed ammonia found in the liquor deposited in the hydraulic main, condensers and scrubbers, respectively.

The proportion of fixed ammonia in the liquor decreases with the process of condensation, being highest in the hydraulic main and lowest at the end of the washing process. In the hydraulic main it is 59 per cent., in the condensers 5 per cent., and in the washers 4 per cent.

(64) Discuss the part played by ammonia as a purifying agent.

Ammonia, being an alkali, is capable of combining with and neutralising the carbonic acid (CO_2) and hydrosulphuric acid (SH_2) in the crude gas, and consequently reduces the work of purification to be done by solid materials.

The reactions which occur may be represented by the following equations:—

(1) $2NH_4HO + H_2CO_3 = (NH_4)_2CO_3 + 2H_2O.$

(2) $NH_4HO + H_2CO_3 = NH_4HCO_3 + H_2O.$

(3) $2NH_4HO + SH_2 = (NH_4)_2S + 2H_2O.$

(4) $NH_4HO + SH_2 = NH_4HS + H_2O.$

Or, stated in words:—

(1) 2 molecules of ammonia combine with 1 of carbonic acid to form 1 molecule of ammonium carbonate.

(2) 1 molecule of ammonia combines with 1 of carbonic acid to form 1 molecule of ammonium bicarbonate.

(3) 2 molecules of ammonia combine with 1 of sulphuretted hydrogen to form 1 molecule of ammonium sulphide.

(4) 1 molecule of ammonia combines with 1 molecule of sulphuretted hydrogen to form 1 molecule of ammonium sulphydrate.

The purifying work is principally effected in the washers or foul scrubbers by means of the liquors deposited in the hydraulic main and condensers, which, though containing ammonia, sulphuretted hydrogen and carbonic acid, are not fully saturated, and are, therefore, capable of taking out additional quantities of these impurities, according to the equations given. The limiting factor in the amount of purifying work capable of being effected is the amount of ammonia in the gas, which seldom exceeds 1·5 per cent. by volume. One-fifth of this will be found in combination with hydrochloric and other acids, forming the so-called "fixed" ammonia, which is useless as a purifying agent. There will consequently be left only 1·2 per cent. to combine with the CO_2 and SH_2 present, and this 1·2 per cent. is only equal to the removal of 0·6 per cent. CO_2 and 0·18 per cent. SH_2; and as the combined impurities CO_2 and SH_2 in the gas average from 4 to 5 per cent., it will be seen how much more ammonia is required than is available.

The ammonia in the finished gas liquor is always fully saturated, and usually a little supersaturated.

It will be noticed from the above equations that ammonia forms two series of salts, one in which one molecule unites with one molecule of the acid radical, and another in which two molecules of ammonia unite with one molecule of the acid radical; and in practical working the aim should be to utilise the ammonia in such a manner as to obtain the compound requiring the least ammonia, since that would mean double the quantity of ammonia available for purifying work; but this is not practicable. 100 volumes of ammonia are usually found combined with about 62½ volumes of the two acids CO_2 and SH_2, the CO_2 being in excess of the SH_2 in the proportion (roughly) of 50:12½.

(65) Of what does the liquor obtained in a gasworks and as used in sulphate making consist? Give the composition.

The finished gas liquor, *i.e.*, the resulting mixed liquor obtained from all sources, consists principally of ammonia combined with carbonic acid and sulphuretted hydrogen, which constitutes what is usually spoken of as "free" ammonia, and ammonia combined with chlorine, sulphocyanogen, and thiosulphuric acid, also traces of other sulphur and cyanogen compounds, forming what is known as "fixed" ammonia, together with some tarry matters (phenols).

The following analysis of liquor from Leeds gasworks, made by Dyson, may be taken as typical :—

	Grams per Litre.
Ammonium sulphide	3·03
,, monocarbonate . . .	39·10
,, chloride	14·23
,, thiocyanide	1·80
,, sulphate	0·19
,, thiosulphate	2·80
,, ferrocyanide	0·41

(66) Ammonia is produced from the nitrogen in the coal. Assuming that the nitrogen in a particular coal is 1·7 per cent., and that 15 per cent. of this nitrogen is evolved as ammonia, show from these data how to calculate the amount of ammonia in the crude gas in grains per 100 cubic feet, the amount of the equivalent 10-ounce liquor, and the pounds of sulphate per ton obtainable from the coal, on the assumption that all the ammonia is recovered.

1·7 per cent. of 2,240 lbs. = 38·08 lbs., and 15 per cent. of 38·08 = 5·71 lbs. of nitrogen as NH_3 in 1 ton. Now, ammonia consists of 14 of nitrogen and 3 of hydrogen, or, in other words, every 14 of nitrogen are equal to 17 of ammonia. Consequently, as 14 : 5·71 : : 17 : 6·93 lbs. of ammonia, and as there are 7,000 grains in a lb., 6·93 × 7,000 = 48,510 grains in, say, 10,000 cubic feet, the equivalent of 1 ton of coal, and in 100 cubic feet, 485 grains. In order to express this in terms of percentage by volume, we first obtain the weight of a cubic foot of ammonia at 60° Fahr. and 30″ Bar., by multiplying the weight of a cubic foot of hydrogen, which is 37·15 grains, by half the molecular weight of ammonia = 8·5 = 315·77, and dividing this into the number of grains in 100 cubic feet, 485 = 1·53 cubic feet, or 1·53 per cent. by volume.

In order to arrive at the amount of 10-ounce liquor obtainable per ton from the nitrogen equivalent given above, it is necessary, first of all, to understand what 10-ounce liquor means. As explained in Answer 61, 10-ounce liquor means that a gallon of liquor requires 10 ounces of pure, strong sulphuric acid to neutralise the ammonia contained in it. So the first thing we require to know is how much ammonia would be required to neutralise the 10 ounces of acid. This is obtained from the equation $2NH_3 + H_2SO_4 = (NH_4)_2SO_4$, or 34 parts by weight of ammonia require 98 parts of acid, forming 132 parts of ammonia sulphate; and as already shown the ton of coal yields 6·93 lbs. of ammonia. Then by the following proportion:—34 : 6·93 : : 98 : 19·97, and as there are 16 ounces in a pound $19{\cdot}97 \times 16 = 319{\cdot}52$ ounces total, which is equal to 31·95 gallons of 10-ounce liquor per ton.

In order to get the pounds of sulphate per ton, since, as shown in the previous equation, 34 parts of ammonia are equivalent to 132 parts of sulphate, we find from the following equation that 6·93 lbs. of ammonia will yield 26·90 lbs of sulphate per ton. As 34 : 6·93 :: 132 : 26·9.

(67) Mention the materials usually employed in purification and their relative advantages and disadvantages.

The materials employed in purification are lime, oxide of iron, and, to a limited extent, Weldon mud. Lime is capable of taking out sulphuretted hydrogen, carbonic acid, and carbon bisulphide, while oxide of iron and Weldon mud are only capable of taking out sulphuretted hydrogen. Lime is therefore the most useful of the materials employed, so far as its power of dealing with the impurities is concerned; but it has the disadvantages of not being regarded as of any further service when it is spent, and when used for abstracting SH_2 it possesses a most objectionable odour; whereas oxide of iron and Weldon mud can be revivified and used over again for a considerable period, and the sulphur which is taken up can be recovered and sold. Weldon mud possesses the advantage of being more sensitive to sulphuretted hydrogen than oxide of iron is, and it is therefore of great service where the test for SH_2 is very stringent. It is also well suited for revivification *in situ*, but as its cost is much greater than that of oxide, it is not so generally employed.

(68) Describe the leading features of the materials referred to in the preceding question.

The lime employed in gasworks is obtained by the burning of limestone or chalk, which yields quick or caustic lime, by the driving off of carbonic acid. Thus, $CaCO_3 = CaO + CO_2$. When water is added to lime it enters into chemical combination with the latter, producing great heat and doubling its bulk. The resulting substance is a definite chemical compound known as calcic hydrate or slaked lime, having the chemical formula CaO,H_2O; and it must be in this condition before it is of any use in gas purification. The most suitable lime for gas purification purposes is that known as pure or fat lime, as this contains the maximum amount of CaO, on which the chemical activity of the lime depends.

The oxide of iron used in gasworks for purifying purposes is some form of hydrated ferric oxide, principally that obtained from the peat bogs of Ireland, and known as bog ore. Bog ore is a reddish brown looking material, and has the following composition :—

Moisture driven off at 212° Fahr.,	up to 50 per cent.
Fe_2O_3,H_2O	32 ,,
Peaty matter	18 ,,

It must be noted that only about two-thirds of the 32 per cent. of Fe_2O_3 is in the particular form required for taking out SH_2.

One of the points to be observed in dealing with this material is to see that it is not too wet, since it is then less sensitive to the action of SH_2. After passing gas containing sulphuretted hydrogen through bog ore to saturation point, the original brown colour of the material changes to a dense black colour, owing to the formation of iron sulphides, but on exposure to the air for a few days it regains its original colour, by the oxidation of the sulphides and the deposition of free sulphur. This material is capable of being alternately sulphided and oxidised for about sixteen times, when, owing to the gradual accumulation of free sulphur, amounting to about 55 per cent., it is no longer economical to work it, and it must be replaced with fresh material. In addition to the oxide above described, there are various artificial oxides in use. One of these which is extensively employed is obtained by means of a process patented by McDougall. Copperas (sulphate of iron) is decomposed by lime and mixed with a certain proportion of sawdust and burnt residue from spent oxide.

Weldon mud is a dark, purplish-looking material, obtained as a by-product in the manufacture of chlorine by the Weldon process. It contains from 23 to 29 per cent. of manganese dioxide, which is the active purifying agent. In using Weldon mud it is necessary to first remove the carbonic acid. Weldon mud behaves in a similar manner to oxide of iron when brought into contact with sulphuretted hydrogen, sulphide of manganese being formed, and, like the corresponding sulphide of iron, this can be oxidised to its original condition, and free sulphur deposited.

(69) Describe simple methods for ascertaining the value of lime and oxide as purifying agents.

In determining the value of a lime for purifying purposes it is usually sufficient to see how much available lime (CaO) it contains. One method of arriving at this information is by noting the amount of water taken up on slaking the lime, since the weight of water taken up represents the quantity which has entered into chemical combination with the lime, in accordance with the equation $CaO + H_2O = CaO,H_2O$. The method of carrying out the test is as follows:—An average sample of the lime is taken, and about 6 grams weighed out into a porcelain dish. Sufficient water is then added to thoroughly slake the lime, which is then placed in an air oven and dried at a temperature of 250° Fahr., and when dry, weighed. The increase in weight will be due to the water which has entered into combination with the lime to form the hydrate, as in the above equation, and from this the amount of available CaO in the lime can readily be calculated. It sometimes happens, however, that a portion of the lime may have already become converted into hydrate by absorption of moisture from the air, and, consequently, would not be capable of taking up any more water. Although the equivalent of CaO would still be present it would not be shown by the above test. It is advisable, therefore, to employ the following test where there is any doubt as to the condition of the lime. A fair sample is taken from the bulk and 2·8 grams weighed out and made into a paste with a little water by triturating it in a mortar until all coarse particles have disappeared. The contents of the mortar are then poured into a beaker and boiled; a few drops of phenol-phthalein are added and normal hydrochloric acid is run in from a burette until the pinkish colour just vanishes, which occurs when the hydrate is saturated. The number of c.c. of acid required will give the percentage of lime in the sample.

In determining the value of oxide of iron, a weighed quantity of dry oxide in the condition of fine powder is mixed with sawdust and placed in a stoppered **U**-tube, which is afterwards connected to a **U**-tube, containing calcium chloride, whose weight is known. A current of dry sulphuretted hydrogen is then passed through the apparatus until the oxide is saturated. The calcium chloride tube is then detached, a little dry air is passed through to displace the SH_2 and, finally, it is weighed. The increase of weight divided by 4 will give the amount of water present in combination with Fe_2O_3 in the sample taken. Since one molecule of Fe_2O_3,H_2O in reaction with SH_2 gives four molecules of water, thus $Fe_2O_3,H_2O + 3SH_2 = Fe_2S_3 + 4H_2O$, the weight of the molecule $Fe_2O_3,H_2O = 178$ will give 72 parts by weight of water, and each part of water obtained will, therefore, represent 2·472 parts of Fe_2O_3,H_2O.

(70) Describe the practical treatment necessary to put lime and oxide in a suitable condition for efficient purification.

In preparing lime for purification it should first be thoroughly slaked and then allowed to cool. It should not be used under two or three days after slaking, when it should be broken up and well watered until it assumes such a consistency as will allow it to cohere like snow when pressed in the hand. Lime in this condition is much more efficient for purifying purposes than when dry and powdery, when it is liable to cake and cause back pressure, in addition to being a wasteful method of using the lime, resulting in a large proportion of the material being unacted upon, so that when the vessel is changed the lime will be found unspent.

New oxide of iron should be mixed with sawdust or wood chips in order to lighten it; and when fouled for the first time it should be emptied as soon as the purifier is shut out, since new oxide sometimes absorbs oxygen so greedily as to generate sufficient heat to destroy the sieves in the purifier. This danger of ignition may be overcome by mixing new oxide with a proportion of old. When taken from the purifier the foul oxide should first be placed in a heap for about twenty-four hours, and then distributed on the revivifying floor in a layer of about 12 inches, afterwards being repeatedly turned over in order to bring fresh portions into contact with the air.

Since the heating of the oxide has a tendency to dry the material, it may be necessary, before returning it to the purifier, to moisten it sufficiently to render it damp enough not to run through the sieves and to cause too much back pressure.

(71) Describe the chemical reactions which occur in the purification of gas by means of lime and oxide.

The reactions which occur when crude gas comes in contact with lime are as follows:—

(1) The absorption of carbonic acid; thus

$$CaO,H_2O + CO_2 = CaCO_3 + H_2O.$$

(2) The absorption of sulphuretted hydrogen; thus

(*a*) $CaO,H_2O + 2SH_2 = CaH_2S_2 + 2H_2O.$

(*b*) $CaO,H_2O + SH_2 = CaHS,HO + H_2O.$

The compound known as calcium hydrosulphide, which is formed in equation 2*a*, possesses the property of absorbing carbon bisulphide, with a simultaneous liberation of SH_2, forming calcium thiocarbonate; thus

$$CaH_2S_2 + CS_2 = CaCS_3 + SH_2.$$

The $CaCS_3$ is a very unstable body, being easily decomposed by CO_2 and air.

In practical working, both CO_2 and SH_2 are in the first instance absorbed by the lime in the purifiers, a mixture of carbonate and sulphide of lime being formed as in the above equations, but CO_2 has the property of being able to decompose sulphide of lime; driving out the SH_2, and itself combining with the lime to form carbonate of lime. Consequently, when crude gas containing both CO_2 and SH_2 does not meet with sufficient free slaked lime to readily satisfy all the CO_2, the CO_2 begins to attack that portion of the lime which has already combined with SH_2, and turns the latter out, sending it forward again with the gas, while the CO_2 itself combines with the lime thus rendered available. This property is made use of in the elimination of CS_2, which requires lime fouled with SH_2 undisturbed by the presence of CO_2.

The reactions which occur when crude gas comes into contact with oxide of iron are

$$(1)\ Fe_2O_3,H_2O + 3SH_2 = Fe_2S_3 + 4H_2O.$$
$$(2)\ Fe_2O_3,H_2O + 3SH_2 = 2FeS + S + 4H_2O.$$

The first of these two is the predominating reaction. The sulphides of iron are capable of being oxidised on exposure to the air, with the deposition of free sulphur, so that finally the SH_2 in the gas assumes the form of free sulphur in the oxide, and the material regains its original state; thus

$$(1)\ Fe_2S_3 + O_3 = Fe_2O_3 + 3S$$
$$(2)\ 2FeS + O_3 = Fe_2O_3 + 2S.$$

(72) Describe an ordinary purifier, stating the leading points in its construction requiring consideration?

The ordinary type of purifier, a rough sketch of which is shown in Fig. 8 (p. 59), consists of an open cast-iron box or tank having a lute for water cast on to the side plates. It is provided with a movable cover made of mild steel, fitted with internal angle and T-iron framing in order to render it rigid. The sides of the cover dip into the water contained in the lute, and so form a seal, which prevents the escape of gas. The cover is provided with suitable fastenings in order to hold it down and prevent the pressure of gas underneath from lifting it up. It is also provided with an air valve. The purifier is fitted with T-iron bearing bars upon which rest wooden grids upon which the purifying material is placed.

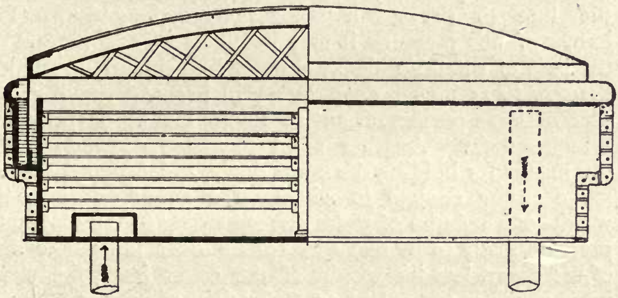

FIG. 8.

The gas usually enters at the bottom and leaves at the top of the vessel. In order to perform their work efficiently, it is necessary that purifiers should be worked in series. A common arrangement is a series of four connected by cast-iron pipes and worked by a centre valve, enabling one of the four to be shut out during the operation of emptying the purifier of fouled material and refilling with fresh. This method of working is not universal, however. A series of six purifiers is frequently employed, the first four being worked in rotation, while the last two are used as "check" or "catch" vessels in order to make certain that no traces of impurity are allowed to slip by. When a purifier has become fouled it is necessary to raise the cover before emptying it, and for this purpose various contrivances are employed, the most common being a double-purchase crab travelling on rails, resting either on wooden beams or iron lattice girders having their ends supported by the walls of the building or by outside columns. In charging a purifier, if the material is lime, it is usually placed in layers of from 4 to 8 inches in thickness, while oxide may be placed in two layers of from 15 to 20 inches deep each. It is necessary to see that both descriptions of material are well rammed in against the sides of the vessel, and also round the edges of the outlet pipe, in order to prevent "creeps."

There are two points requiring consideration in the construction of purifiers, viz., to provide sufficient seal in the lute to prevent a "blow," by making the seal in excess of any pressure it may be likely to encounter. In the case of small purifiers the water lute should not be less than 12 to 15 inches deep by 4½ inches wide, and in the case of large purifiers from 20 to 40 inches deep by 6 to 8 inches wide. Another point requiring consideration is the means for holding the cover down, the fastenings being made strong enough to withstand a strain equal to the weight of a column of water corresponding to the maximum pressure likely to be met with spread over the whole area of the cover, less the weight of the cover itself, the strain upon which is equivalent to the weight of such column of water.

(73) How do purifiers constructed on Green's principle differ from those in ordinary use?

Purifiers on Green's plan, in place of being constructed with a water lute, and a cover of the same size as the vessel, consist of a square or rectangular cast-iron box, the bottom, sides, and top being built up of cast-iron plates jointed internally, and instead of one large cover the top has a series of openings which are covered in with flat covering plates made of strong steel and angles. These are bolted to the flat top of the purifier, being made gas-tight by means of a strip of indiarubber, $\frac{1}{16}$ inch thick. In place of the heavy and expensive lifting gear usually provided, the covers are lifted by a light crane running on rails fixed on the top of the purifier itself, which also forms a floor upon which the men engaged in emptying and charging the vessels can work. When the covers are fastened down the vessel resembles a square or rectangular box.

The advantages claimed for this system over the ordinary type of purifier are reduction in first cost obtained by dispensing with large cumbrous covers and expensive lifting gear, together with gain of floor space and less wear and tear owing to the water lute and steel cover being dispensed with, the latter, as is well known, being liable to corrode at the point known as "between wind and water." Owing to the absence of the water lute, should it be necessary, the purifiers can be worked under much greater pressure than those of the ordinary type.

(74) Describe, with sketch plan, the usual method in vogue for purifying gas.

The most common method of purifying gas is that shown in Fig. 9 (p. 62), and consists of four vessels filled with oxide of iron having connections and a centre valve so arranged that three of the vessels are always in action, and one out of use for renewal of the purifying material. The system is worked as follows. The crude gas enters the series of three, and when SH_2 appears half way in the third vessel the first one is shut out and a fresh one put in after the third one. Then the purifier which was originally the second, becomes the first one, and so on, thus ensuring that the third purifier shall always be a clean one. The oxide purifiers are sometimes followed by two boxes containing lime for taking out carbonic acid, as shown. The lime in this case will be found in an inoffensive condition, as carbonate.

(75) What is the effect of the admission of atmospheric air to the crude gas before purification? What consideration places a limit on the amount of air which should be admitted?

The effect of admitting air to the crude gas varies with the material employed. In the case of oxide of iron and Weldon mud the effect is to revivify the material *in situ*, according to the equations previously given, but with lime the effect is to oxidise the combination of the lime with

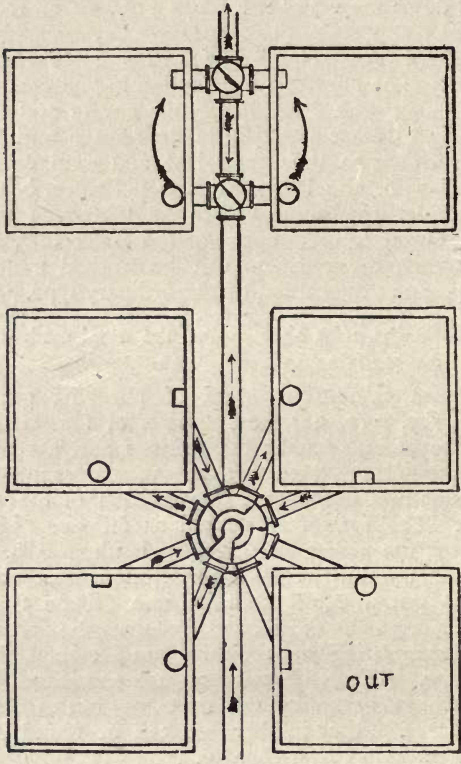

Fig. 9.

sulphuretted hydrogen, producing a stable material for the elimination of CS_2, and depositing free sulphur. The consideration which limits the amount of air admitted is the detrimental effect of air on the illuminating power of gas, 1 per cent. of air reducing its illuminating power by about 6 per cent., 4 per cent. reducing the illuminating power 25 per cent., and 45 per cent. causing the gas to burn with a non-luminous flame. An excess of air reacting with the sulphided lime would cause the material to be converted into calcium thiosulphate, which is useless as a purifying agent.

(76) State the rule for arriving at the size of purifiers and connections when worked in the usual manner. Show by calculation how to determine the size of a set of four purifiers in a works making 800,000 cubic feet of gas per twenty-four hours. What should be the size of the necessary connections for the same?

The rule for arriving at the size of purifiers is given by Mr. Newbigging in his "Handbook" as follows:—"Where there is intended to be four purifiers, three always in action, the maximum daily (24 hours) make of gas expressed in thousands multiplied by the constant 0·6 will give the superficial area in feet of each purifier." In the example given—

$800 \times 0{\cdot}6 = 480$ superficial feet area of each purifier.
$\sqrt{480} = 21{\cdot}9$, say 22 feet side of square of purifier.

The rule for the size of the connections is to make the internal diameter of the pipe in inches equal to the square root of the area of the purifier in feet, less $\frac{1}{8}$ for purifiers over, say, 16 feet square. Then $22^2 = 484$, $\sqrt{}$ of which is 22, and $22 - \frac{1}{8} = 22 - 2'9'' = 19'3''$, say 20″ as the size of the connecting pipes.

(77) What is the approximate amount of gas which lime and oxide should respectively purify?

When used alone for the purification of coal gas, 1 ton of lime will purify the gas from 30 to 40 tons of coal. One ton of new artificial oxide of iron used alone for the elimination of SH_2 will purify the gas from 200 to 250 tons of coal.

CHAPTER VII.

TESTING FOR IMPURITIES AND FOR VALUE OF BY-PRODUCTS.

(78) State how you would detect the presence of NH_3, SH_2 and CO_2 in crude gas.

Ammonia is detected by means of a reddened litmus paper, which turns blue, or by a yellow turmeric paper, which turns a reddish brown colour, in the presence of ammonia. Sulphuretted hydrogen is detected by means of a paper which has been dipped in a solution of lead acetate or silver nitrate, either of which is turned black by sulphuretted hydrogen, owing to the formation of lead or silver sulphides, respectively. Carbonic acid is detected by causing a fine stream of gas to bubble through lime water, which produces a white precipitate of carbonate of lime. Should SH_2 be present in the same gas, this must be first removed by passing the gas through a small purifier filled with oxide of iron.

(79) Give a simple method for determining the amount of SH_2 in crude gas.

A simple method for determining the amount of SH_2 in crude gas is that devised by Mr. Leicester Greville. A solution of ammoniacal sulphate of copper is prepared of such a strength that 1 cubic centimetre equals 0·05 grain SH_2. The gas to be tested is passed through two Harcourt colour-test tubes. One tube (the first) is charged with a solution of ammonia and distilled water in the proportion of 1 volume of NH_3 to 10 of water, and the second one with distilled water only, a piece of acetate of lead paper being placed on the outlet of the second tube so as to show that the absorption of SH_2 is complete. The gas is measured either by means of an aspirator or meter, the quantity used being one-tenth of a cubic foot. At the expiration of a test the contents of the two tubes are emptied into a white porcelain basin and titrated with the copper sulphate solution, which is dropped in from a 100 cubic centimetre burette. The solution should be added slowly, the contents of the basin being kept well stirred. As the two solutions meet, a slight brown tint will appear, and the reaction is complete when the black copper sulphide has separated out, and, settling down, leaves behind a colourless supernatant liquid.

The number of cubic centimetres of the copper solution required to effect the reaction multiplied by 50 will give the grains of SH_2 per 100 cubic feet of gas.

(80) Describe, with sketch, the Referees' sulphur test, stating the principles upon which it depends.

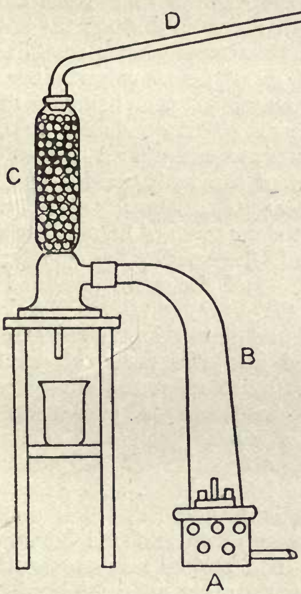

Fig. 10.

The Referees' sulphur test is shown in Fig. 10, and consists of the bunsen burner, A, having a steatite tip in which the gas is burnt, passing through a short cylindrical stand provided with a number of holes for the admission of air. The stand has a circular channel on its upper surface for the purpose of receiving the wide end of a trumpet-shaped glass tube, B, which is in communication with a glass cylinder, C, containing glass balls, known as the condenser, and provided at the top with a long glass tube, D, which serves as a chimney to create the necessary draught for drawing in air through the holes in the burner and also to provide an exit for the incondensable vapours. The inlet of the burner is connected to the outlet of an experimental meter which automatically shuts off the gas when 10 cubic feet has passed. In order to make a test with the apparatus the stem of the burner is surrounded with pieces of sesquicarbonate of ammonia. The burner is then lit, and when the index of the meter is just about on the zero mark the trumpet tube is placed in the channel on the burner and the top or narrow end of the tube connected to the tubulure of the condenser by means of an indiarubber connector, the long chimney tube being attached to the top of the condenser directly after. The gas is arranged to burn at such a rate that 10 cubic feet will have been consumed in fifteen hours, at which time the meter will automatically cut off the supply of gas to the burner.

In the process of burning, the sulphur in the gas combines with the oxygen of the air drawn in through the holes in the burner to form sulphurous acid, which, combining with the ammonia driven off from the sesquicarbonate of ammonia, forms sulphite of ammonia, this being in turn oxidised to sulphate of ammonia. This condenses in the glass cylinder and is deposited, together with the water resulting from the combustion of the hydrogen in the gas, in the glass beaker placed below the condensing cylinder.

At the expiration of a test the contents of this beaker are emptied into a glass measure, the condensing cylinder is washed out with distilled water and the washings added to the contents of the measure, the trumpet tube being similarly treated. The whole of the liquid in the measure is then well mixed and divided into two portions, one for treatment and the other for future reference, if required. The portion reserved for treatment is placed in a glass beaker, covered with a clock glass, and acidified with hydrochloric acid in order to drive off the carbonic acid. It is then raised to the boiling-point. An excess of a solution of barium chloride is next added, which throws down a precipitate of barium sulphate, and the boiling is continued for five minutes. The barium sulphate is then allowed to settle, after which as much as possible of the clear liquid is poured on to a Swedish filter paper, and after this has passed through, the remaining liquid and precipitate are poured on to the filter, and after the latter has passed through, the filter and its contents are well washed in order to get rid of the soluble ammonium and barium chlorides. This treatment is continued until a small portion of the final washings remains clear on the addition of a drop of a solution of silver nitrate.

The filter and its contents are then ignited in a tared platinum crucible, and when all black particles have disappeared, the crucible is cooled in a desiccator and weighed. The weight of barium sulphate, in grains, multiplied by 11 and divided by 4 will give the grains of sulphur per 100 cubic feet of gas, supposing the latter to have been burnt under the normal conditions of 60° Fahr. and 30″ Bar.: if the conditions differed, a slight correction would be necessary.

(81) Describe, with sketch how you would test a sample of spent oxide for sulphur. Upon what does the test depend? A sample of spent oxide weighing 100 grains, after drying was found to weigh 74·6 grains; the dried sample was then treated with CS_2 and the sulphur obtained weighed 46·4 grains. What was the percentage of the sulphur on the "dry" basis?

The amount of sulphur in a sample of spent oxide is determined by means of the apparatus shown in Fig. 11 (p. 68). 100 grains of a carefully-taken sample are weighed out and dried at 212° Fahr. in a water oven. The dried material is then placed in the drawn-out test tube, A, on a layer of cotton wool, which prevents the solid material from running through the test tube. Bisulphide of carbon is then blown from the bottle, B, into the test tube, A, on to the top of the spent oxide. The bisulphide gradually percolates through the material, dissolving out the sulphur in its passage, and the resulting solution of sulphur in bisulphide of carbon finds its way by gravitation into the flask, C, which is placed in a water bath. The bunsen burner is then lighted, and the heat of the latter quickly vaporises the bisulphide of carbon in the flask, C, the vapour given off passing by way of the connecting tube into the spiral condenser, where it is condensed to the liquid form again and is recovered in the receiver, D, under water, ready for further use. The sulphur is left behind in the flask, C, and

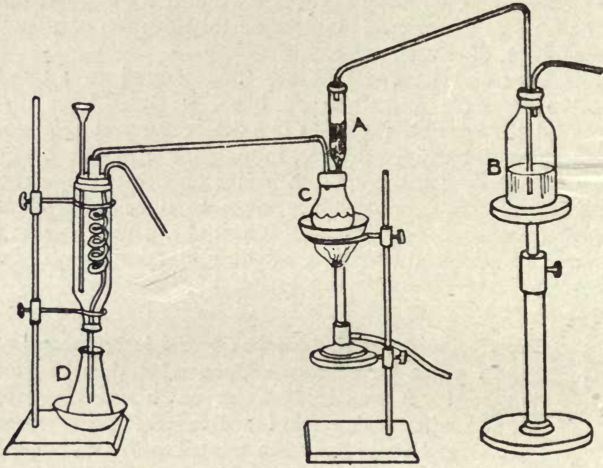

Fig. 11.

when all the bisulphide has been driven off the flask is weighed. It is then placed in the water oven and re-weighed at intervals until a constant weight is obtained. This, minus the weight of the empty flask, will give the weight of sulphur, and as 100 grains were originally taken, this weight will be the percentage on the "wet" basis. The test depends upon the solubility of sulphur in bisulphide of carbon.

In order to arrive at the percentage on the dry basis in the example we say :—

As 74·6 : 100 : : 46·4 : 62·2

(82) How would you determine the value of a sample of ammoniacal liquor? Give a sketch of the apparatus you would employ, and state the principles upon which the test depends.

In determining the value of a sample of ammoniacal liquor, what we wish to find out is the number of ounces of strong sulphuric acid required to neutralise the total ammonia (free and fixed) in a gallon of the liquor. As it would not be practicable to operate on so large a scale we arrive

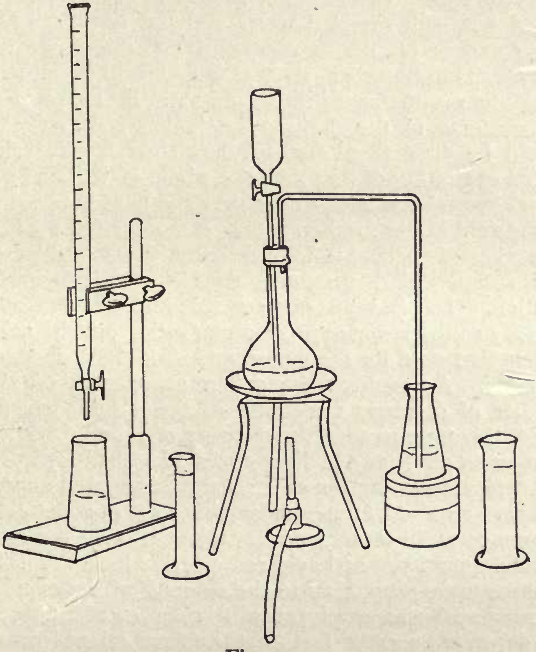

Fig. 12

at the same result by employing a dilute acid of such a strength, when used in conjunction with special measures, as will give a comparative test. The acid employed is made by adding 16 ounces by weight of pure sulphuric acid to a quantity of distilled water and, finally, making up the solution to the gallon. A solution of ammonia which will exactly neutralise its own volume of the acid solution is also required. The apparatus employed is shown in Fig. 12. The test is commenced by placing 2 ounces of the test acid in the conical beaker. The cork is then inserted in the flask, and the delivery tube placed in the beaker containing the acid as shown. The distilling flask is then charged through the funnel with 1 ounce of liquor followed by 1 ounce of strong caustic soda solution. The measures are rinsed out with distilled water and the rinsings added to the contents of the beaker and of the flask, respectively. The stop-cock on the funnel is then closed and the burner underneath the sand-bath lit so as to bring the contents of the flask to the boiling-point, at which it should be maintained for not less than fifteen minutes. At the expiration of that time the whole of the ammonia in the flask will have been driven over and have been absorbed by the acid in the beaker. The contents of the latter are then allowed to cool, coloured with a few drops of cochineal solution and titrated with the standard ammonia solution. The burette employed should be of the same capacity as the measure used in measuring out the acid and double that used for the liquor, and should be divided into 32 parts. As soon as the colour changes to purple the number of divisions remaining in the burette should be noted, this representing the quantity of ammonia which has been given off from the liquor and absorbed by the acid, which represents its ounce strength, since that amount of acid was required to neutralise the ammonia contained in one ounce of the liquor, and the acid was of such a strength that the quantity of real acid contained in the dilute solution bore the same proportion to the amount of liquor taken as if strong acid was employed with a gallon of liquor. The test depends upon the fact that the fixed salts of ammonia on being heated with an alkali are decomposed, the acid radicals combining with the alkali and setting free the ammonia.

(83) How does the saturation test differ from the distillation test? A sample of liquid tested 7·9 ounces saturation test and 9·5 ounces by the distillation test, what was the percentage of free and fixed ammonia in the sample?

The saturation test differs from the distillation test in not indicating the amount of fixed ammonia in the liquor, and also in the method of making the test. In place of driving off the ammonia into the acid and titrating back with a solution of ammonia, as described in answer No. 82, the acid, which is of the same strength as that employed in the test referred to, is added direct to the sample of liquor until the latter is neutralised; otherwise the principles of the test are the same.

In arriving at the percentage of free and fixed ammonia in the example, since 9·5 equals the total amount, 9·5 − 7·9 = 1·6, which represents the fixed ammonia; consequently

(1) As 9·5 : 100 : : 7·9 : 83·15 per cent. = free NH_3.
(2) As 9·5 : 100 : : 1·6 : 16·84 per cent. = fixed „

(84) How would you determine the amount of ammonia in purified gas?

In order to determine the amount of ammonia in clean or purified gas, it is first of all necessary to prepare two solutions, one a solution of sulphuric acid of such a strength that 25 septems are capable of neutralising 1 grain of ammonia, and the other a solution of ammonia of such a strength that 100 septems will exactly neutralise the 25 septems of the acid solution. The apparatus employed consists of a glass cylinder filled with glass beads, provided with a stop-cock at one end and a movable nose-piece at the other. The apparatus usually forms part of the sulphur-test apparatus, and is used in conjunction with the latter. The test is commenced by placing 50 septems of the test acid in the cylinder and connecting to the inlet of an experimental meter. Gas is passed through at the rate of about half a cubic foot per hour, and when 10 cubic feet have passed the meter shuts off the gas automatically.

At the expiration of the test the cylinder is disconnected and washed out with distilled water. The resulting washings are then well mixed and divided into two portions, one for treatment and the other for future reference. The one reserved for treatment is coloured with a few drops of cochineal solution and the standard ammonia run in from a 100-septem burette. As soon as the colour changes to purple the number of septems remaining in the burette is noted; this number multiplied by 2, and moving the decimal point one place to the left, will give the grains of ammonia in 100 cubic feet of gas, assuming the latter to have been measured under the normal conditions of 60° Fahr. and 30″ Bar.

(85) Give a brief description of Harcourt's colour test, and state its principal use.

Harcourt's colour test is used to determine the amount of impurities in crude gas by passing the gas into various solutions and comparing, according to the impurity to be tested for, the intensity of colour imparted to the solution with a standard tint corresponding to a definite quantity of the impurity in the gas. The quantity of gas required to give intensity of colour equal to that of the standard enables us to determine the amount of impurity in a definite volume of gas in, say, grains per 100 cubic feet. The test most frequently employed is that for determining the amount of carbon bisulphide in gas, and is based on the fact that when coal gas containing CS_2 is passed over heated platinised pumice, the bisulphide is more or less decomposed into sulphuretted hydrogen and marsh gas. The sulphuretted hydrogen being led into a solution of a definite volume of a salt of lead forms sulphide of lead, and on comparing the intensity of colour imparted to the solution with the standard tint corresponding to a definite quantity of sulphide of lead, we are enabled to arrive at the amount of CS_2 in the gas under examination. The apparatus consists of a glass bulb filled with platinised pumice, having inside a tube terminating in a fine point passing nearly to the bottom of the bulb. This tube conveys the gas to be tested into the interior of the bulb, and on heating the latter the platinised pumice attains such a temperature as to cause the decomposition of the CS_2 in the gas issuing from the inner tube, owing to its having to pass over the heated surfaces of the pumice. The sulphuretted hydrogen thus produced passes through an outlet pipe to a flat-bottomed test tube fitted with a cork having two holes, through one of which a glass tube having a capillary end dips into a solution of lead. The other has a tube bent at right-angles, which serves as an outlet for the gas, which next passes to an aspirator. In making a test the glass bulb is heated to the necessary degree, and the test tube filled to a fixed mark with lead solution. The outlet of the bulb is then connected to the capillary tube in the test tube and the latter connected to the aspirator, which is then put into action, so that the water runs from it in a gentle stream into a measuring cylinder. The standard test is placed by the side of the test tube in front of a sheet of white cardboard, and as soon as the lead solution has acquired the tint of the standard the aspirator is shut off and the amount of water which has run out into the measuring cylinder is noted. This represents the volume of gas which has passed through the lead solution, and this volume of gas contained a quantity of sulphur existing as CS_2 which has caused the lead solution to attain the same intensity of colour as the standard tint. The standard provided by the makers of the apparatus is so arranged that to impart this tint to this volume of liquid 0·0187 grain of lead sulphide must be present, containing 0·0025 grain of sulphur. The measuring cylinder supplied is graduated so that each division represents $\frac{1}{2000}$ cubic foot, so whatever the number of divisions obtained may be, say 50, $\frac{50}{2000}$ cubic foot of gas contain 0·0025 grain of sulphur, from which the grains of CS_2 per 100 cubic feet can readily be calculated.

CHAPTER VIII.

ASCERTAINING AND RECORDING PRESSURE AND EXHAUST.

(86) Describe, with sketch, an ordinary gasworks pressure gauge, and explain its use.

The simplest form of pressure gauge is shown in Fig. 13. It consists of a U-shaped glass tube of about $\frac{5}{8}$ths of an inch internal diameter. The tube is provided with a scale, which is fixed between the two limbs of the U and divided into inches and tenths of an inch, the zero point being in the centre, and the divisions extending above and below the zero point. The tube contains a solution of cochineal or soluble indigo to the level of the zero mark. One end of the tube is open to the air, the other end being connected to the gas supply. On allowing gas to enter the gauge the liquid in the limb connected thereto will be depressed, and will be raised to a corresponding extent in the opposite limb open to the atmosphere, the difference between the two limbs showing the amount of pressure.

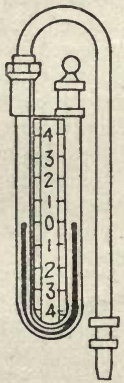

Fig. 13.

Pressure gauges are employed in gasworks for the purpose of indicating the pressure or exhaust at different points in the manufacturing plant, and serve to show whether the plant is in proper working order and the mains free from obstructions. For example, the gauge in direct communication with the hydraulic main will show if the amount of seal is being exceeded or if there is an excess of pressure on the retorts; the gauge on the inlet main to the exhauster will show if the condenser is clear; while the gauge on the outlet of the exhauster will show if there is a clear passage from the exhauster to the gasholder, and will also give some indication of the manner in which the charges are being placed in the retorts, since charging at irregular times, particularly if stoking machinery is employed, would be shown by heavy back pressure at one time and a comparatively light one at another. Then by observing the pressures on the inlet and outlet of each piece of apparatus one can see what pressure the apparatus is throwing and if there is a clear course for the gas.

(87) How does a gauge showing pressure differ from one showing vacuum?

In order to answer this question it is necessary to note that the pressure of the gas is pressure in excess of atmospheric pressure. Consequently the liquid rises in the limb open to the atmosphere. The reverse action occurs in the case of "vacuum," which is really pressure less than atmospheric pressure. In this case the liquid rises in the limb attached to the pipe in communication with vacuum and falls to a corresponding extent in the other limb, owing to the atmosphere exciting a greater pressure on that limb. From the relative positions of the liquid in the two limbs in relation to the atmosphere, it is always easy to tell whether a gauge is reading vacuum or exhaust.

(88) Describe the relationship between an ordinary gasworks pressure gauge and the gauges usually employed for water and steam pressures. A gasworks pressure gauge reads 6 inches; what would that pressure be in pounds per square inch?

The pressure gauges used on gasworks show the number of inches of water which the pressure will support, or which the vacuum will detract from the atmospheric pressure. Steam and water pressures are usually expressed in pounds per square inch, or by inches of mercury sustained in a vertical column. A vertical column of 34 feet of water corresponds to 15 lbs. on the square inch; consequently

$$(34 \times 12):6'' :: 15 \text{ lbs.} : x$$

$$x = \frac{15 \times 6}{34 \times 12} = \frac{90}{408} = 0{\cdot}22 \text{ lb. per square inch}$$

or, expressed in terms of inches of mercury, since mercury is 13·6 times heavier than water,

$$\frac{6}{13 \cdot 6}\ 6'' \text{ water pressure} = 0 \cdot 44'' \text{ mercury.}$$

The readings of a gasworks gauge are usually associated with pounds per square foot, as when making calculations for gasholders or weight on governor bells to give a certain pressure, etc. Since a cubic foot of water weighs $62\frac{1}{2}$ lbs., a square foot of water 1 inch high will weigh $62 \cdot 5 \div 12 = 5 \cdot 21$ lbs., or 1 inch water pressure $= 5 \cdot 21$ lbs. pressure per square foot.

(89) What is a differential gauge?

A differential pressure gauge is a gauge having one limb attached to the inlet and the other limb to the outlet of a piece of apparatus, such as a scrubber or station meter. The pressure shown indicates the pressure thrown by the apparatus, being the difference between the inlet and outlet pressures.

(90) Give a brief description, with sketch, of a King's gauge, and state where it is usually employed.

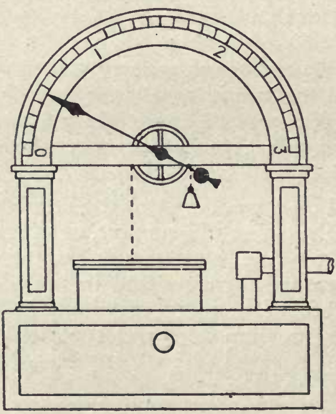

FIG. 14.

King's gauge is shown in Fig. 14. The lower portion or body of the apparatus forms a water chest, and is divided into two chambers communicating with each other at the bottom. The outer chamber is closed at the top and is in communication with the gas supply. The inner chamber, which is in connection with the outer one at the bottom, is open to the atmosphere at the top, and within it is a metallic float suspended by a cord passing over a pulley and having a counterbalance weight attached to the other end. On the pulley shaft is a pointer which travels in front of a semicircular graduated scale. When the instrument is charged with water to the proper level, on admitting gas to the outer chamber the water is depressed therein and raised in the inner chamber. This causes the float to rise and the pointer is moved in front of the scale. Since the travel of the pointer is considerable for small differences of water level, the dial can be so graduated as to cause it to show small variations in pressure, say hundredths of an inch. The instrument is used where we wish to measure pressures with great accuracy, as when reading the jet photometer and in making an ordinary photometrical test. It also serves to rapidly adjust the rate of burning when making a photometrical experiment.

(91) What is the difference between a pressure gauge and a pressure register? Describe, with sketch, the last-mentioned apparatus.

The pressure register differs from a pressure gauge in giving a record of the pressure at any time in the twenty-four hours, whereas a pressure gauge simply tells us the pressure at the moment of observation. The pressure register is shown in Fig. 15 (p. 78), and usually consists of a tinned iron tank containing a gasholder guided by rollers at the bottom and by a rod at the top, the latter passing into the chamber above, which contains a vertical drum. In the centre of the holder there is a float of such capacity that when the apparatus is charged with water to the proper level the holder is just buoyed, or lifted, from its bearings. A small pipe conveys the gas into the vessel, and the gas pressure causes the holder to rise. At the top of the apparatus there is a clock, and geared to this there is a rod which extends into the chamber beneath, containing the drum, to which it is connected so that the action of the clock causes the drum to make precisely one revolution in twenty-four hours. Coiled round this drum is a sheet of paper divided off into twenty-four vertical divisions corresponding to the twenty-four hours as shown by the revolutions of the clock fixed above. There are also thirty-six, or any other number of, horizontal lines, according to the capacity of the apparatus, corresponding with the pressure it is intended to record. These horizontal lines are numbered from the bottom, which is the zero point, and they indicate tenths of an inch pressure. For the purpose of recording the pressure there is attached to the top of the rod in communication with the holder, a pencil which is pressed by a slight spring against the ruled paper.

As the holder rises or falls according to the pressure of the gas, the pencil rises or falls and marks the paper, thus showing the pressure, and since the cylinder revolves in unison with the clock, the moment at which that particular pressure was given is shown, so that by this arrangement we have a continuous record of the pressure at any time of the day or night. In designing the apparatus, by varying the proportions of the holder in relation to the tank, the pressure actually given can be recorded to any desired scale.

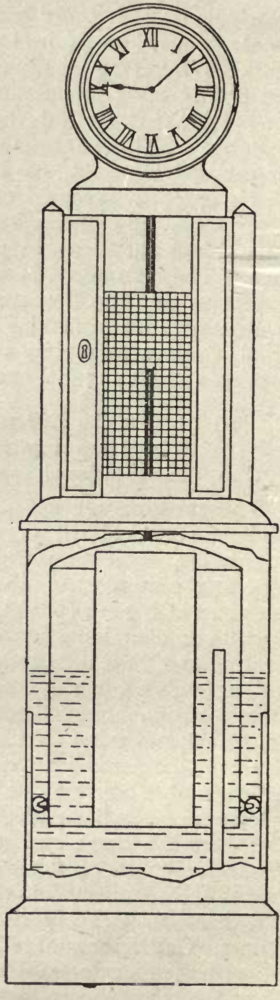

Fig. 15.

CHAPTER IX.

THE CONSTRUCTION OF GOVERNORS.

(92) What is the object of the station governor? Explain, with the aid of a sketch, the construction of the simplest form of the apparatus, and state the amount of pressure usually given in a district.

The object of the station governor is to ensure that the gas may be always delivered from the works at a steady and uniform pressure, independent of any fluctuations in the consumption. The apparatus is interposed between the gasholder, which gives the initial pressure, and the mains supplying the district, and fulfils the function of reducing the gasholder pressure to the extent just necessary for giving a proper supply to the district and no more, and keeping this pressure constant by automatically adapting itself to the varying fluctuations of consumption in the district.

The simplest form of governor is shown in Fig. 16 (p. 80), and consists of a small gasholder, called the bell, contained in a cast-iron tank, partially filled with water. From the centre of the bell a cast-iron parabolic plug is suspended, which, when at its full height, exactly fits into the open end of the inlet pipe, which terminates in a conical-seated flange, the size of the opening increasing or diminishing as the holder falls or rises. The outlet pipe is concentric to the inlet pipe, and rises a little distance above the level of the water. The bell is counterbalanced by means of an air chamber round its lower curb, as shown in the sketch, or by weights which are placed on a rod connected by means of chains and pulleys to the outside of the crown of the bell. The counterbalancing is so arranged that when the bell is just buoyed up no gas can pass through the governor, because the slightest pressure in the inlet pipe or underneath the bell causes the latter to rise to its full limit, and, consequently, completely closes the valve, so that, in order to give a pressure on the outlet we must increase the effective weight of the bell by placing weights on the crown of the latter. Consequently, if we require a pressure of, say, 15-tenths, it is necessary to place a weight equal to that of a column of water 15-tenths, or $1\frac{1}{2}$ inches, in height over the area of the bell. This being done, the pressure will remain practically constant under any variations of consumption, for in the event of an increased demand resulting in a sudden draught on the main, which would cause the pressure in the main leading from the governor to be reduced, since the governor is in communication with this main through the outlet pipe, the bell of the holder would descend, and in doing so would cause the parabolic plug to descend, and so increase the valve opening, thus causing more gas to pass to the outlet and restoring the equilibrium of the pressure to the original point. The reverse operations occur when the consumption slackens, since in this case the increased pressure in the main raises the bell and at the same time lifts the suspended plug higher into its seating,

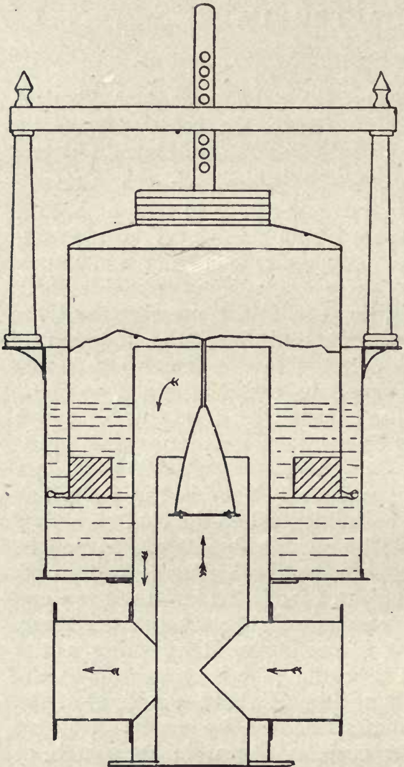
Fig. 16.

thus reducing the valve opening and consequently the pressure on the district. When it is desired to alter the initial pressure, as it is termed, the effective weight of the governor must be readjusted to the necsesary extent.

The pressure usually given is from, say, 7 to 13-tenths during the daytime, which is gradually increased at "turning-on time" to 20 or 30-tenths, according to requirements, this pressure being maintained during the first few hours of darkness, when the shops are all lit, which is the period of heaviest consumption, after which it is gradually reduced as the consumption slackens.

(93) What are the disadvantages of the instrument referred to in the preceding question, and how have these disadvantages been overcome?

The disadvantages attending the use of the governor described in answer No. 92 are that changes of inlet pressure caused by changing of holders, or when telescopic holders "cup" and "uncup," cause a movement in the bell of the governor, owing to the fact that the suspended parabolic plug is not in equilibrium, since the whole of the under side and a large portion of the upper surface is acted on by the inlet pressure, leaving only a small portion exposed to the action of the outlet pressure. Consequently, if there is any appreciable alteration in the inlet pressure, the bell of the governor will be set in motion and cause an unsteadiness in the pressure, or blinking, as it is termed. In order to overcome these defects various compensating devices have been introduced, the general principle upon which they work being that of causing the inlet pressure of the gas which acts upon the valve to also act in an opposite direction upon a portion of the bell of the governor having an equal area to the valve. In one form of compensating governor there are two parabolic plugs, one above the other, attached to the same rod. This causes the stream of inlet gas to be divided and to pass equally through the two valve openings, so that the inlet pressure acts on the top of one valve and on the bottom of the other, thus securing equilibrium. A governor which is extensively used allows the gas to enter from above the valve chamber in place of below, as is usually the case. Over the valve and of the same area as its base is a compensating chamber within the bell, which is supplied with gas through a small pipe which serves to enclose the valve rod. This arrangement causes the bell and valve to be in equilibrium. The only communication between the bell and the actuating outlet pressure is through a pipe of comparatively small diameter. In another well-known governor, in place of the ordinary parabolic plug, a hollow cylinder closed at the bottom but open at the top is employed. The inlet gas enters the valve through a series of conical openings or ports, which allows the governor to be in perfect action even when it is passing a very small volume of gas. A further advantage is that the valve is capable of a vertical movement only, by reason of its being accurately fitted on the seating which surrounds it, whereas the ordinary parabolic valve is free to move sideways.

The compensating arrangement of this governor consists of an annular tank fixed upon the crown of the bell of the holder, into which dips a smaller bell or gasholder, which is suspended from and fixed to the cross-bar of the governor guide. The diameter of this holder corresponds with the diameter of the valve below, and forms with the annular tank a water lute which encloses an area equal to that of the valve base. The gas below the base of the valve or from the inlet side of the governor is conveyed to the interior of the chamber on the top of the governor through the hollow rod suspending the valve, and exerts the same pressure above the bell of the governor, so that the pressure is the same on both sides of the valve. The gas from the outlet side enters the governor bell by means of a central tube, terminating a little above the water-line, through which the valve rod passes.

(94) Describe, with sketch, Hunt's governor, stating how it differs from those in ordinary use.

Hunt's equilibrium governor, which is shown in Fig. 17 (p. 83), consists of a throttle valve accurately balanced upon steel centres placed in the outlet main from the governor, the lever or radius arm by which it is worked being also inside the main, and attached to the disc or throttle. A small vertical pipe which is in communication with the bell is connected to the main, and serves to enclose the valve rod and to admit gas into the bell. This form of governor possesses the advantage of maintaining a steady outlet pressure under considerable variations of inlet pressure, and only requires a gasholder a little larger than the main it is intended to supply.

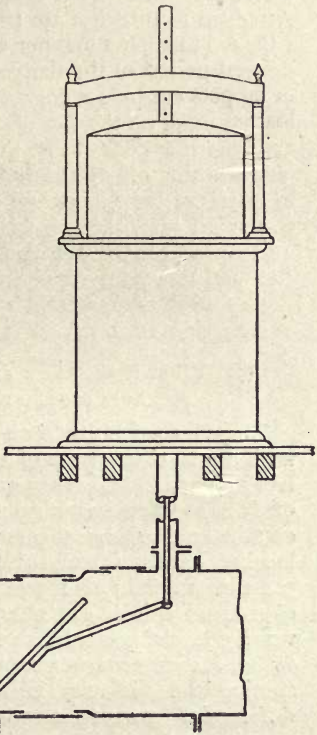

Fig. 17.

(95) Discuss the methods in use for varying the pressure according to requirements

The changes of pressure required are usually effected by the adding or taking off of weights, but this is not at all a good plan, as even with the greatest care the changes are rendered apparent on the district, whereas they should be so made as to be almost imperceptible. A better plan, and one which is now frequently employed, is that under which water is used as the weighting agent. The water is run into a tank fixed on the crown of the governor bell, and the tank is supplied with a syphon for the purpose of slowly running out water when a reduction of pressure is necessary. Another method effects the pressure - changing automatically. The apparatus consists of a clock geared to a disc which is caused to make one revolution in 24 hours. Attached to this disc are two series of tappets which can be adjusted in such a manner as to come into operation at any desired period of the daily revolution of the disc. One set of tappets controls a cock which supplies the water to the loading tank on the top of the governor, while the other set controls the cock which withdraws water from the tank. The shutting off of the water, when the necessary changes in pressure have been produced, is effected by means of two small gasholders which are in communication with the outlet gas from the governor. One of the holders, in rising, shuts off the water supply, while the other, in falling, closes the syphon cock which withdraws the water, the holder being weighted to rise or fall at any desired pressure.

(96) What is the effect of altitude on the pressure of gas, and how are the resulting irregularities controlled?

The effect of altitude on the pressure of gas is to cause an increase of pressure of one-tenth of an inch for each 10 feet of rise, and a corresponding decrease for each 10 feet of fall, so that assuming the pressure in the mains at a certain level to be sufficient, should the main, owing to the locality, have much of a rise, then there will be an excess of pressure in the upper portion of the district. In order to counteract this defect, when gas is supplied to districts of varying levels, it is advisable to have separate leading mains with a station governor upon each. Another plan for overcoming the difficulty is the employment of district or differential governors, which automatically reduce the pressure at the higher portions of the district so as to cause the outlet pressure to be so much less than the inlet as will ensure the average pressure in the district being given at that particular point.

CHAPTER X.

MAIN AND SERVICE LAYING.

(97) Describe, with sketches, the principal joints used in main-laying, and discuss their relative advantages and disadvantages.

The joints principally used in the laying of gas mains are the open socket, shown in Fig. 18, and the turned and bored, shown in Fig. 19 (p. 86). In the open socket system the pipes, which are made of cast-iron from $\frac{3}{8}$ inch to $1\frac{1}{4}$ inch in thickness, have the inner diameter of one end (the socket) larger than the outer diameter of the other (the spigot), and the latter consequently fits loosely into the former. For pipes up to 8 inches in diameter this open jointing space is $\frac{3}{8}$ inch, and for pipes of a larger diameter $\frac{1}{2}$ inch wide all round, the depth of the socket ranging from

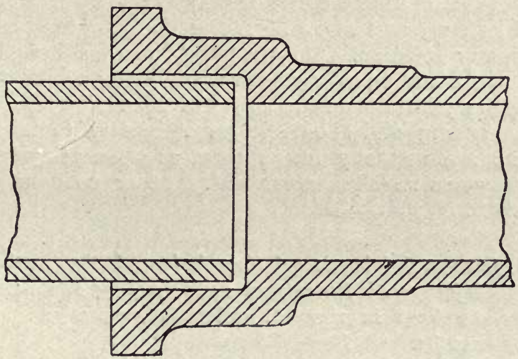

Fig. 18.

3 inches to 6 inches. In order to enable the socket to resist the tendency to split when setting up the joint, the

throat of the socket is cast with a slightly thicker body of metal than the rest of the pipe. In making the joint with this description of pipe, the annular space previously referred to is filled with molten lead. In the turned and bored system the socket and spigot are made to fit tightly against one another, the spigot being turned in the lathe so as to have a slight amount of taper and the socket bored out to suit. In laying pipes of this description both socket and spigot are first well cleaned and smeared over with red lead paint, and the spigot is then driven into the socket by means of a wooden mallet.

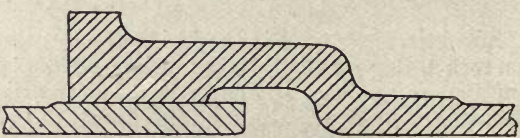

Fig. 19.

The following are the relative advantages and disadvantages of the two systems. The open socket pipes are cheaper in the first instance, and owing to its superior elasticity the joint adapts itself to exigencies of settlement or subsidence in unstable and treacherous ground with less risk of leakage, and also allows the pipes to turn curves with greater freedom. On the other hand, although the turned and bored pipes themselves are dearer, the labour in making the joint is considerably less than with the open socket system; and should it be necessary to take the pipes up again at any future time, as when relaying the main, they can be taken apart with little or no damage to themselves.

(98) Give a brief general description of the method of laying an ordinary gas main, stating the points to be kept in view in order to ensure satisfactory results.

In laying a gas main, which it is assumed is of the open socket description, it is first necessary to excavate a trench, which should be deep enough to allow the main to have a sufficient depth of covering, and wide enough where the sockets come to allow the main-layer free access all round the socket when setting up the joint. The ground at the bottom of the trench should be compact, so as to allow the pipes to rest without fear of settlement, and at the various points where the sockets come the ground should be scooped out so that the body of the pipe may lie solid throughout its length. The pipes are lowered into the trench by means of a block and tackle suspended from sheer legs spanning the trench. The spigot end of one pipe is inserted into the socket of the last pipe laid, and a portion of spun yarn is placed round the pipe and driven into the annular space between the spigot and the socket by means of a caulking tool. This operation is repeated several times, according to the size of the pipe, so that ultimately the yarn fills about half the depth of the socket. The object of the spun yarn is to prevent the molten lead entering the pipe; and it also allows a certain degree of play to the joint in the direction of its length. The spun yarn packing having been inserted and well caulked, a lump of clay is placed upon a smooth board and well kneaded with water so as to form a tough, plastic mass. This is then rolled out to the length necessary to enable it to completely encircle the face of the socket, against which it is firmly pressed so as to form a fence to prevent the molten lead from escaping. The latter is poured in through an opening or lip formed on the upper side of the pipe where the two ends of the clay meet. As soon as the socket is entirely filled with lead the clay is removed, and when the lead is cool it is set up all round by means of a hammer and blunt caulking tool, the superfluous lead left in the lip of the clay being cut off by means of a chisel.

It is important in making joints of this description that the ladle out of which the lead is poured should be large enough to contain as much metal as will fill the vacant space in the socket at one operation; or if this is not practicable, owing to the size of the pipe, then it should be poured from two ladles simultaneously. The precautions to be taken to ensure satisfactory results in main-laying are to see that the pipes are laid at a sufficient depth to give them a covering of at least 24 inches of soil, in order to protect them from breakage by steam rollers, the influence of heavy traffic, and low temperatures. In refilling the trench the soil should be deposited in layers and rammed carefully round the pipes. In roads made up with ashes, chemical refuse or scoriæ, the pipes should be embedded in good common earth, or, as an alternative, puddled round with clay, the upper portion of the pipe in particular being protected by a thick covering of the material. (When laying mains in gasworks, spent lime which has been "weathered" by exposure to the atmosphere will be found a good covering.) Each pipe should be laid with a proper amount of fall, and a syphon provided where necessary. In running the joint, there must be a sufficiency of lead, but care should be taken to avoid an excess on the outer part of the joint, as this might cause the socket to split when setting up. The same damage may be done if the joint is not full enough, through the wedging in of the caulking tool. Care must be taken that the main-layer goes all round the pipe when setting up, more especially the under side, which is more difficult of access, particularly in the case of pipes of large diameter.

(99) Describe, with sketch, the jointing of a main by means of a collar, stating the circumstances under which it would be employed.

The method of jointing a main by means of a collar is shown in Fig. 20. The contrivance is used when special connections are being made, as when coupling up the two ends of a main forming part of an apparatus or replacing a broken length of main. In any position where odd lengths of main require joining together, the collar is found very useful, as by the insertion of a "plain piece" of pipe into the socket of one end of the

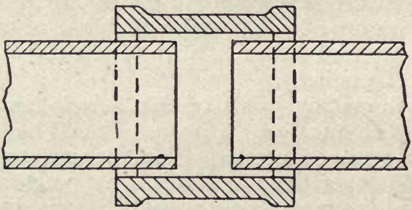

Fig. 20.

main it is easy to couple up the other end, the cutting of the necessary length of pipe being all that is necessary, in place of using special castings, which are frequently very difficult to arrange. The joint is made by filling up the annular space between the pipe and collar with yarn and molten lead, in a similar manner as when making an open socket joint.

(100) For what purpose are syphons employed in gas distributing mains? Sketch the construction of one, and state the position in which it should be fixed.

Syphons, or receivers as they are frequently termed, are employed in gas distributing mains for the purpose of collecting the condensed aqueous vapour and other liquids, which are deposited by the gas in its travel, and which, if they were not got rid of, would ultimately block up and clog the main. The syphons, which are cast-iron cylindrical vessels, as shown in Fig. 21, are placed at suitable intervals in a line of mains, the latter being arranged with a slight incline (say, 1 foot in 400 yards) to the syphon, so that the deposited liquids may drain into the vessel. A wrought-iron pipe extends nearly to the bottom of the syphon, and to this a pump is attached for the purpose of periodically emptying the syphon of its contents.

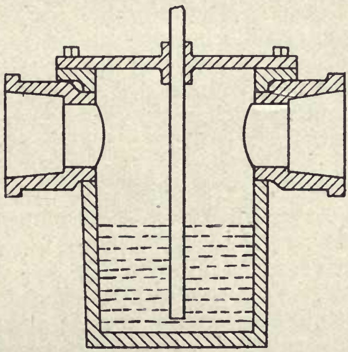

Fig. 21.

(101) How would you relay a length of main while keeping up the supply of gas on either side of the portion being relaid?

In relaying a line of main while keeping up the supply of gas on either side of the portion that is being relaid, it is necessary to temporarily exclude the gas from the portion that is being relaid. This is effected, in the case of small mains, say up to 6 inches diameter, by means of a bullock's bladder, which has been turned inside out and well soaked in oil in order to render it supple. The bladder has inserted in its neck a piece of $\frac{3}{8}$-inch brass tubing about 7 inches long, fitted with a stop-cock at one end and having a screw thread at the other for the purpose of securely attaching it to the bladder by means of fine copper wire. A $\frac{3}{4}$-inch hole is drilled in the main close to the point where it is required to temporarily cut off the supply. The bladder is inserted through this hole to within about two inches of the neck, and when in that position it is inflated by means of air, by blowing with the mouth, and when full the stop-cock is closed. The bladder will then completely fill the inside of the pipe. The same operations are then performed beyond the other end of the portion to be cut out; the result being that the passage of the gas is cut off and the work of relaying can be safely proceeded with. When the work is finished the cocks on the bladders are opened, which will allow the bladders to collapse, when they can be withdrawn and the holes plugged up. In the case of large mains, indiarubber gas bags are employed in place of bladders. The same operations are gone through; but it is necessary to furnish a pair of bellows for the purpose of inflating the bags. In order to keep up the supply of gas, in the event of the system of mains not being connected so as to give a supply on both sides of the portion of dead main, it will be necessary to make a temporary connection uniting the two live ends of the main and by-passing the dead portion.

(102) Describe some method for determining the amount of leakage on a line of gas main, and state what amount of leakage you would consider a fair quantity to allow.

In testing mains for leakage it will be necessary to divide the main into sections, either by means of gas bags or valves or by cutting and plugging the main. A portion of the main, say 200 yards, is cut out and plugged with yarn and clay. About 18 inches of, say, 1-inch pipe is used to connect the live main with one end of the dead portion. The small pipe is fitted with three cocks, one being in the centre, which acts as a by-pass and serves to shut off the live from the dead portion of the main. A small portable bellows is connected to the cock on the live side of the main, and this pumps gas into a small gasholder whose outlet is connected to a test meter, whose outlet, in turn, is connected to the dead portion of the main on the other side of the by-pass. A minute clock is also provided. The bellows pumps gas into the holder, and this is weighted to give a pressure of, say, 3 or 4 inches. The gas passes through the meter into the dead portion of the main, and by taking readings every minute the quantity passing per hour in the leakage is shown, the location of the leaks being discovered by pricking the ground at the joints of the main, and over the service pipes. A fair average leakage account may be taken as being 5 per cent. of the gas made.

(103) State the rule for determining the quantity of gas capable of passing through a length of main of a given size, when the specific gravity and pressure of the gas are known. A gas main is 12 inches in diameter and 1,000 yards long, the specific gravity of the gas is 0·4, and the pressure 15-tenths, give the necessary calculations for arriving at the quantity of gas the main will pass per hour, and state the general effect of pressure on the discharge of gas through mains.

The quantity of gas that can be delivered through a gas main of a given size, when the pressure and specific gravity of the gas are known, is arrived at by means of the following formula :—

$$\text{Quantity per hour} = 1350d^2\sqrt{\frac{hd}{sl}}$$

l = length of pipe in yards.
d = diameter of pipe in inches.
h = pressure of gas in inches of water.
s = specific gravity of gas, air = 1.

This formula, expressed in words, would read :—

First multiply the diameter of the pipe in inches by the pressure of the gas in inches. Next divide the product last obtained by the specific gravity of the gas multiplied by the length of pipe in yards. Then extract the square root of the quotient, and multiply this result by the constant 1,350, and this result by the square of the diameter of the pipe in inches. The final product will be the number of cubic feet discharged per hour.

In the example given

$$12 \times 1·5 = 18$$
$$1,000 \times 0·4 = 400$$
$$18 \div 400 = ·045.$$

Then, in order to extract the square root of ·045, we proceed as follows :—

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         ·045(·2121 = square root
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   41)    50
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       ·2121
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      6363
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    286·3350
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    11453400
   11453400
   2863350
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  41232·2400 = 41,232 cubic feet per hour.
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Mr. Newbigging, in his table of deliveries of gas under various conditions, gives the discharge of gas under the conditions mentioned as 41,212 cubic feet per hour.

Increasing the pressure of gas four times doubles the quantity discharged.

(104) Of what materials are service pipes usually made? State the principal factors involved in the laying of service pipes and the necessary precautions to be observed.

The services which convey the gas from the mains to the consumers' meters and to the public lamps are of wrought iron or lead. The services play an important part in the economical distribution of gas, since a considerable amount of the unaccounted-for gas is traceable to defective services, due either to the material of which they are composed being attacked by the soil in which they are laid, or to their being imperfectly connected to the main. If wrought iron is the material employed, it is sometimes advisable, in place of using the ordinary gas tubing, to substitute the tubing used for steam, which is of a stronger section. A wrought-iron service is made up of various parts, such as the bend which enters the main, followed by short pieces, ordinary lengths of tubing, tees, elbows, sockets, etc., all of which are joined together by means of male and female screws. As a general rule, no service should be of a less diameter than $\frac{3}{4}$ inch. In connecting the service to the main, a hole is first carefully drilled in the latter; this is then rimered out to the exact size, and tapped so as to have a thread of the same pitch as the bend, whose projecting threaded portion, having been previously smeared with a mixture of red and white lead paint, is tightly screwed into the hole in the main. The next operation is to couple up to the bend, in doing which the aim should be to have as few joints as possible; and each projecting thread should be smeared with red lead paint before insertion into the socket, etc., to which it is connected. The service should be firmly bedded throughout its length in order to avoid risk of settlement. Wherever possible, the service should fall to the main; but if this is not practicable, then a small cast-iron syphon (Fig. 22, p. 94) should be placed at the lowest point,

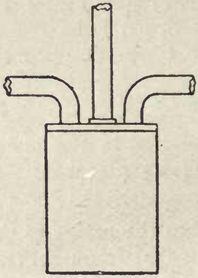


Fig. 22.

to allow any condensation to drain into it. Since wrought iron is extremely liable to oxidation, it is very important to see that the ground in which services of that material are laid is of such a nature as will not damage the pipe. Ashes, clinker, and chemical refuse are particularly destructive in their action. In order to make quite certain that nothing of the kind will occur, it is a better plan to place the pipe in a V-shaped wooden trough, which is afterwards filled with melted pitch. Lead services are more expensive than wrought iron, but the labour in laying them is less, since fewer joints are required. They are also more durable in most soils; and when they require replacing the old material is of considerable value, since it can be remelted and so used again. The objections to their use are the risk of sagging and of their consequently becoming water-logged. This defect can be overcome, however, by laying them, for their whole length, in a wooden trough and embedding them in pitch, as in the case of the wrought-iron service. In coupling up lead services to the main, the latter is drilled and tapped in the manner described for wrought iron, a brass ferrule is then inserted, and the lead pipe is soldered to a union-joint provided with the ferrule. The lead tubing employed for services weighs, for a $\frac{3}{4}$-inch pipe, 4 lbs. per yard.

CHAPTER XI.

TESTING FOR ILLUMINATING POWER.

(105) **Mention the instruments chiefly used in gasworks for approximately arriving at the quality of the gas being made, and describe the instrument most generally employed for that purpose.**

The instruments principally used for arriving at the approximate value of gas are Sugg's illuminating-power meter, Thorp and Tasker's jet photometer, and Lowe's jet photometer, the last-mentioned being the instrument most generally used. The principle of the jet photometer is based upon the fact that the quantity of gas which will pass through a small aperture under a constant pressure varies with the density of the gas. In the case of gases of different qualities, the quantity which will pass at a given pressure is inversely as the densities; and as the richer the gas the greater the density, so will the quantity of gas passing through the jet vary with the quality. A rich gas passed through at a given rate will give a longer flame than a poor gas passed at the same rate. The length of flame given by equal volumes of different gases varies in a great measure with the amount of oxygen required for their combustion. The jet photometer, or, as it is sometimes termed, the inferential photometer, consists of a delicate King's gauge, fitted at the top with a steatite tip pierced with a fine hole. The gauge is provided with two dry governors for regulating the pressure and with a contrivance for adjusting the water level. It is enclosed in a glazed wooden case, to which a perforated zinc chimney is attached for the purpose of getting rid of the products of combustion. The instrument may be used in two ways, viz., by observing the length of flame yielded by the gas under a given pressure, or by keeping the flame length constant at 7 inches and observing the pressure required to give this flame—the richer the gas the less pressure required. In order to get an idea as to the relationship between the readings of the instrument and the actual quality of the gas, it is advisable to compare the readings from time to time with the results obtained from the same gas on the ordinary bar photometer. A jet photometer is usually placed in the exhauster house and connected to the gas supply on the outlet of the exhauster. This serves the purpose of controlling the work of the retort house, by indicating if air or furnace gases are being drawn in with the gas, or if the "draws" are not being done at regular times. Since at the point mentioned the gas dealt with is in its crude state, it is necessary to pass it through a small oxide purifier before allowing it to enter the photometer.

(106) What are the defects of the instrument referred to in the preceding question and the causes of such defects?

One defect of the instrument is that, being a specific gravity test, any alteration in the composition of the gas will affect the readings of the instrument. But since, with the same class of coal and the same method of working, the composition of the gas being made from day to day does not vary much, except under special circumstances, when air may be accidentally drawn in, this defect does not count for much. But there are two influences always at work which tend to make the readings unreliable, viz., the daily changes of temperature and pressure, which cause an alteration in the density of the gas.

The late Mr. John Methven overcame the last-named defects by supplying the instrument with water at a constant temperature of 80° Fahr. and adjusting the height of the flame to suit the height of the barometer at the time of taking a reading. Pressure affects the indications of the jet in two ways. With a high barometer, the molecules of the gas are compressed, with the result that a greater quantity of gas passes through the orifice of the jet under a given pressure, consequently producing a longer flame, while the higher density of the atmosphere in which the gas issuing from the jet is consumed tends to shorten the flame. The reverse effects occur under a low barometer.

(107) **Explain the physical law on which ordinary photometry depends.**

The physical law on which the science of photometry depends may be stated as follows:—The amount of light received on the surface of any body varies inversely as the square of the distance from the source of light to the body. This law can be most simply demonstrated by the following illustration:—

Imagine a candle placed at the centre of a hollow sphere 2 feet in diameter. The candle will be 1 foot distant from every point in the sphere, and its light will fall upon the whole internal surface of the sphere, and it will equally illuminate every part, since it is equidistant from every part. Now, imagine the candle placed in a sphere 4 feet in diameter. It will then be 2 feet distant from every point, and it will still illuminate every part equally. But the surface of the second sphere is four times greater than that of the first one, by reason of the surfaces of spheres being to each other as the squares of their radii. In the present instance, as $1^2 : 2^2 = 1 : 4$. Consequently each inch of the surface of the larger sphere will receive only one-fourth of the light which illuminated each inch of surface of the smaller sphere. Yet the light is only twice as far from the surface of the larger as it was from the surface of the smaller. In the same way, if the diameter of the sphere is 8 feet, the distance of the candle from the surface becomes 4 feet, *i.e.*, four times as great as it was from the surface of the sphere 2 feet in diameter; and as the surface of the 8-feet sphere is sixteen times greater than that of the 2-feet one, each inch of the 8-feet sphere will receive but $\frac{1}{16}$th of the light which illuminated each inch of the 2-feet sphere. The same reasoning applies to any increase in the sizes of the spheres, or to any surface which is illuminated, flat or otherwise.

(108) **Explain the principle of the bunsen photometer.**

Bunsen's photometer is based on a discovery made by the late Professor Bunsen. The principal item in this type of photometer is the bunsen disc, which consists of a piece of white paper saturated with melted sperm, with the exception of a portion in the centre. When a paper so treated is held up between the observer and a light, the portion treated with sperm will appear brighter than the rest of the paper, because the greased portion of the paper is more transparent, and so admits of more light passing through than does the portion which has not been so treated. But if the observer stands with his back to the light and holds the paper so that the light falls on it, the greased portion will appear darker than the ungreased portion in the centre. This is due to the fact that the light which now reaches the eye of the observer is reflected light. The greased portion allows more light to pass through than does the centre portion. Consequently, the greased portion cannot reflect as much light to the eye of the observer; and it appears darker by contrast.

Bunsen made use of this property in the following manner. A paper prepared as above described was placed between the two lights to be compared and moved until it was equally illuminated on both sides, the equality of illumination being known by both sides of the paper appearing alike. The distance of each light from the paper was measured, when, on squaring the distances, the value of one light was obtained in terms of the other, in accordance with the law of inverse squares.

(109) **Give a description of an ordinary bar photometer and accessories, and explain the method of using the instrument.**

The ordinary bunsen bar photometer consists of a polished bar of pine wood, having a scale divided according to the law of inverse squares, the divisions representing candles. Sliding on the bar is a disc-box, fitted at the back with two mirrors and containing a bunsen disc, the mirrors being set at such an angle as to enable them to reflect each side of the disc. The box is provided with a pointer which shows the divisions on the scale when the disc is equally illuminated. A gas pillar is fixed at one end and a candle-balance, arranged to hold two candles, at the other. In addition to the above, the following apparatus is provided :—A wet meter so arranged that an observation of one minute enables the rate of consumption per hour to be ascertained; a clock for ascertaining the rate, and also the time occupied in the burning of the candles; a delicate governor for regulating the pressure; and a King's gauge for indicating the latter. The apparatus is fitted with blackened wood screens in order to prevent any but the lights to be compared falling on the disc, and also to avoid loss of light; and for the same reason the instrument is usually placed in a room painted dead black. The apparatus is used in the following manner :—The gas burner is screwed on to the gas pillar, a clean chimney being used if the burner is of the argand type. The gas is then lit so as to get rid of air and stale gas, and the candles are prepared and placed in the holder of the candle-balance. The gas, which should burn at least 15 minutes before making a test, is next rated to 5 cubic feet per hour, and the candles, which have been counterpoised by means of shot, so as to compensate for their loss in burning during the preparatory stage, are allowed to burn until the pointer of the balance comes to zero, when a 40 grain weight is placed in the candle-pan, and the clock, which has previously been placed at zero, is started. The experiment has now commenced. The disc-box is moved to and fro between the candles and the gas until the disc appears the same on both sides, as reflected by the mirrors. The readings on the scale are noted, and five readings taken at intervals of about a minute. The disc-box is then reversed and five more readings are taken, the last one being read off at the expiration of about 9½ minutes, when attention should be given to the candle-balance. When the pointer of the balance comes again to zero the clock is stopped, and the experiment is concluded. The time taken to burn the 40 grains of sperm is noted, together with the temperature of the meter and the height of the barometer. We have now all the data for arriving at the illuminating power of the gas, which is obtained in the following manner :—The readings are totalled up and averaged. The result is multiplied by 2, on account of 2 candles being used and the bar being divided in terms of one candle. Should the 40 grains of sperm have taken a longer or shorter time than 10 minutes to burn (40 grains in 10 minutes for 2 candles being equal to 120 grains per hour for one candle), it will be necessary to correct, by proportion, the result obtained for any divergence from the normal rate of 120 grains per hour, and should the temperature and pressure at which the gas has been measured have varied from the normal of 60° Fahr. and 30″ Bar. the last result must also be corrected by means of the Referees' tabular number. The net result will be the corrected illuminating power of the gas in terms of standard candles.

(110) **Give a brief description of, and discuss the relative merits of the principal standards used in gas testing.**

The principal standards used in gas testing are the sperm candle, Methven's screen, and Harcourt's 10-candle pentane lamp.

The sperm candle, which is the most general official standard in use, is made of sperm mixed with a small percentage of beeswax, in order to render it less brittle, or less liable to break the grain, as it is termed, and to assist in forming a good cup when burning. The standard candle weighs six to a pound, is 8¾ inches long from the base to the shoulder, and is supposed to burn at the rate of 120 grains per hour.

Methven's screen, which is extensively used as a non-official standard, consists of an upright rectangular metallic plate fixed in front of a "London" argand burner. The upright plate has a slot covered by a thin plate of silver, and this silver plate has a vertical slot of such dimensions that it allows exactly light equivalent to that of two standard sperm candles to pass through when the height of the flame of the argand burner is 3 inches.

Harcourt's 10-candle pentane standard lamp burns air saturated with pentane vapour. Pentane is a product from the distillation of petroleum. The instrument consists of a burner on the argand principle, made of steatite, supported by a hollow rod communicating with the lower part of the burner. From the top of the rod a bracket projects which supports the vessel containing the pentane, known as the carburettor. The carburettor is provided with a cock for the admission of air; and the resulting mixture of air and petroleum vapour flows by gravity through a piece of black indiarubber tubing to the burner. Fixed above the burner is a long brass tube, which serves as a chimney to draw the flame into a definite form. The portion of the flame which forms the standard is naked. Surrounding the tube previously referred to is another tube, which, being heated by the products of combustion in the inner tube, causes air to be drawn up, and this outer tube being connected at the top with the rod supporting the burner, which is hollow and in communication with the centre of the burner, a continuous current of air is given to the interior of the flame. In the base of the brass chimney tube there is a mica window with a horizontal brass bar across its centre. The tube must be turned round so that no rays of light fall upon the instrument corresponding to the bunsen disc of a bar photometer, known as the photoped, but the height of the flame can be observed by reflection from a mirror.

The flame of the burner which, as previously remarked, is naked, is of the right height when the mean of the tips of the flame is between the bottom of the mica window and the middle bar. The flame is shielded by a conical shade, so placed that the whole of the flame can be seen through the photoped opening.

The objection to the candle as a standard is principally due to the behaviour of the wick, since irregularities in its texture, and in its curvature during burning, cause the light emitted from it to be far from constant. Methven's screen, although extremely convenient, possesses the disadvantage of relying upon a small portion of the flame of gases ranging in quality from 14 to 18 candles. Any gases outside this range affects the standard, more especially if they contain carburetted water gas. In the latter case, it is necessary to pass the gas through a carburettor and to employ a different sized slot to the one generally used

Harcourt's lamp is undoubtedly the most scientific of the several standards described. It is convenient, and it gives a flame of a constant value.

(111) Give a brief description of the table photometer, and state how it differs from the ordinary bar photometer.

The table photometer derives its name from the fact that the whole of the apparatus appertaining to the instrument can be arranged on a table, 5 feet 6 inches by 3 feet 6 inches by 2 feet 5 inches high. The apparatus comprises the standard light, which is Harcourt's 10-candle pentane standard; a gas pillar fitted with a standard argand burner; experimental meter, governor, and minute clock; and what is known as the photoped, corresponding to the bunsen disc of the bar photometer. The standard lamp and burner, which, in this form of photometer, are both on the same side of the photoped, are arranged in accordance with the law of inverse squares, so that when the surface of the photoped is equally illuminated the gas light is equal to 16 candles. The distance from the lamp to the photoped is 1,000 millimetres, and the distance from the burner to the photoped is 1,265 millimetres; consequently, on squaring these numbers and dividing the lesser number into the greater and multiplying by 10 (the value of the lamp) we get 16 as the value of the gas light. The standard lamp and burner are fixed at definite angles to the photoped, so that all their light falls upon the latter. The illuminating power of the gas is deduced from the quantity of gas required to give the 16-candle flame, in place of rating to 5 cubic feet, as when testing the candle-power by the ordinary bar photometer. Instead of a bunsen disc, a piece of white unglazed paper is clamped in the photoped, and the gas flame is adjusted until the surface of the photoped paper is equally illuminated. It is necessary that the room in which the experiments are made should be darkened, and any extraneous light which might interfere with the light thrown upon the photoped must be shut out by means of suitable screens. The difference between the table and the bar photometer is that of the general principle.

Bunsen's system of the opposing lights being on opposite sides of the bunsen disc is abandoned, and the value of the gas is arrived at from the quantity burned, in place of keeping the quantity constant and noting the quality.

CHAPTER XII.

CORRECTING THE VOLUME OF GAS FOR TEMPERATURE AND PRESSURE

(112) State the rules for correcting the volume of gas for temperature and pressure.

In correcting gas for temperature and pressure we make use of the following laws:—For temperature—Gases expand and contract $\frac{1}{492}$ part of their volume at 32° Fahr. for every rise or fall of 1° Fahr. For pressure—The volume of any gas is inversely as the pressure to which it is subjected.

And in using these laws we proceed as follows:—Since gases expand in the proportion of $\frac{1}{492}$ part of their volume at 32° Fahr. for every rise of 1° Fahr., it follows that 492 volumes at 32° Fahr. would occupy 492 volumes + or − the difference between the observed temperature and 32°. Consequently, 492 + or − the number of degrees difference will give the volume at that temperature; so that 492 volumes at 32° would equal at a temperature of, say, 50° Fahr., 510 volumes. As in gasworks it is usual to correct gases to 60° Fahr., we proceed as follows: Supposing we wish to correct 500 cubic feet of gas measured at a temperature of 70° Fahr. to the normal temperature of 60° Fahr. We first of all get the relationship between the two volumes by adding to 492 the number of degrees by which the temperatures differ from 32°. $70-32=38$ and $60-32=28$; $492+38=530$ and $492+28=520$. So that 530 volumes at 70° Fahr. would equal 520 at 60° Fahr. Consequently, by making the following proportion we see what 500 cubic feet would occupy at 60°:—

$$530 : 520 :: 500 : 490{\cdot}6.$$

With regard to pressure, since the volume of gases varies inversely as the pressure to which they are subjected, the calculations involved are extremely simple. In correcting gases for pressure the gases are assumed to be under normal pressure when the barometer is at 30 inches; consequently, if the barometer at the time of making an experiment is higher than 30 inches, the corrected volume will be increased, and if it is lower it will be reduced, the amount of the change in volume being obtained by simple proportion. For example: Supposing 1,000,000 cubic feet of gas to be measured under a barometrical pressure of 30·4 inches, the temperature remaining at 60° Fahr., then, since the volume at 30·4 would be greater at 30, we say:

As 30 : 30·4 : : 1,000,000 : 1,013,333 cubic feet.

Should the barometer be lower than 30 inches, say 29·6, then 29·6 would take the place of the 30·4 in the proportion.

(113) A station meter registered 2,000,000 cubic feet of gas at a temperature of 45° Fahr., and under a barometrical pressure of 29·42″; show the necessary calculations for reducing this volume to the normal temperature of 60° Fahr. and 30″ Bar.

In making this calculation the gas is assumed to be measured in the dry state.

$$\text{As } \frac{30}{505} : \frac{29{\cdot}42}{520} :: 2{,}000{,}000 : 2{,}019{,}590,$$

the corrected volume being 2,019,590 cubic feet.

(114) Explain how the Metropolitan Gas Referees' tabular numbers are obtained.

The Referees' tabular number is based on the principles described in Answer 112, and is embodied in the formula $\frac{17{\cdot}64\,(h-a)}{460+t}$, h being the height of the barometer at the time of observation, and t the observed temperature; a will be explained immediately.

Now, on referring to the answer to Question 113, it will be noticed that 30, the standard barometrical pressure, and 520 ($=460+60$, or $492+60-32$), the volume at 60° are opposed to each other in the statement. They always occupy the same position in every calculation, so by cancelling out we get a constant figure of 17·333. This is on the assumption that the gas is measured in the dry state. But since the gas, on passing through a station meter or lying in a gasholder, is always in a moist condition, a different set of conditions prevail, by reason of the water vapour exerting a pressure in the opposite direction to the barometrical pressure. The amount of this, or its tension, as it is termed (which varies according to the temperature), has to be deducted from the barometrical pressure. In the case of the standard temperature of 60° Fahr. we find the tension to be 0·518 of an inch, corresponding to *a* in the formula given above, which, being deducted from 30, leaves 29·482 as the figure to divide into 520, in place of 30, and this gives the quotient 17·64.

Now, if we compare the figures in Question 113 we can see the points of resemblance between the latter and the Referees' formula. Having disposed of the two common numbers 30 and 520, there remains the observed height of the barometer (less the tension of the aqueous vapour at the temperature) to be multiplied by 17·64. This result is multiplied by the volume, which, in the Referees' number, is unity, and this result is divided by 460 plus observed temperature = 492 + temperature − 32, which, in Question 113, is 505. The following example will make the subject clearer. Obtain the Referees' tabular number for 46° Fahr. and 29·8″ Bar.

$$\frac{17·64 \times 29·8 - ·311}{460 + 46} = \frac{17·64 \times 29·49}{506} = 1·028,$$

which agrees with the number in the Referees' table, the original volume being supposed to be unity.

APPENDIX.

In the following pages, answers are given to the questions set at the 1909 and the 1910 Examinations in the Ordinary Grade in Gas Engineering of the City and Guilds of London Institute.

1909 EXAMINATION.

(1*a*) By the aid of a sketch or sketches, explain the construction of a regenerative furnace and discuss briefly the advantages of this (if any) over an open-fired furnace.

Fig. 1 shows a cross section, and Fig. 2 a longitudinal section through the regenerators, Fig. 3 a longitudinal section through the producer, and Fig. 4 the tiles of which the regenerator is constructed, which are Gibbons' patent.

The generator or producer (A, Fig. 1) is filled with fuel, which rests upon the fire-bars. Underneath this the air necessary for combustion, known as the primary air, enters. The producer or generator shown is of the inside type, and such producers, which are usually rectangular in cross section, vary in size from 8 to 10 feet deep, 2 to 3 feet wide, and from 4 to 6 feet long. The producer arch is frequently formed of two or more rings of $4\frac{1}{2}$-inch arch bricks, struck to the proper radius; the sides are usually 9 inches thick. Generators should have about 2 feet of grate area per 20 feet length of retort to be heated, and a depth of 4 feet 6 inches of fuel. The gas nostrils in the crown of the producer vary both in position and size. When there is a low centre retort, as in the case of a setting of nine, it is preferable to have a nostril on each side of the arch, so that the intensely hot flame passes between the retorts instead of impinging directly upon them, which would be detrimental to their durability; but in the case of settings of 6, 8 or 10 retorts, one large nostril may be employed. Their longitudinal positions on the crown of the producer arch depend upon their position relative to the division walls.

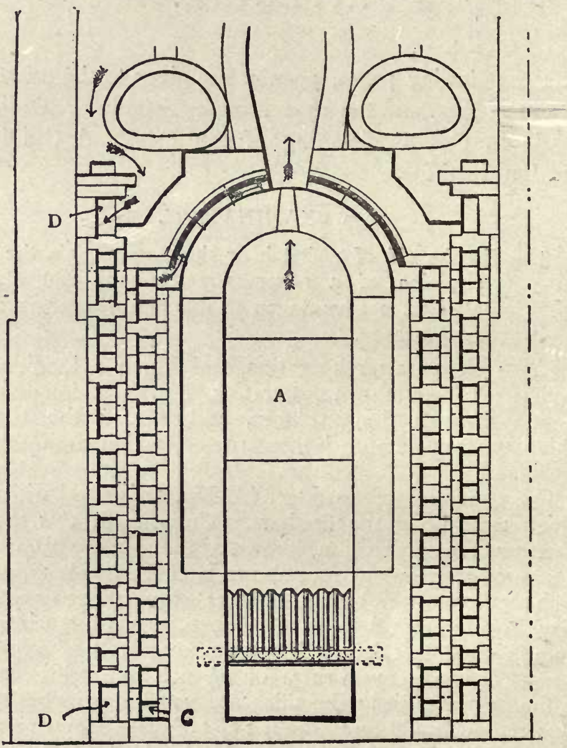
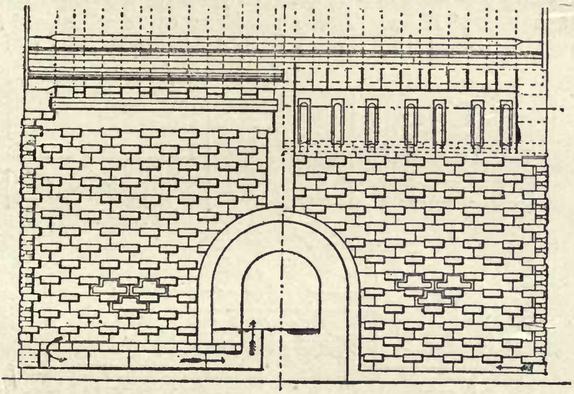


FIG. 1.

They should, if possible, always come between the piers; they should not taper downwards, since if they do, any brickwork or fireclay used in patching which might drop into them will block the passage of the combustible gases and cause bad heats at the particular spot.

The reactions taking place in the producer are as follows: The combustion of the carbon in the coke and the oxygen of the primary air first produces carbonic acid gas, CO_2, thus $C + O = CO_2$, and this, on passing through the upper portion of the fuel, is converted into carbonic oxide, CO, thus, $CO_2 + C = 2CO$, and, at a temperature of about



Spent Gases. Secondary Air.

FIG. 2.

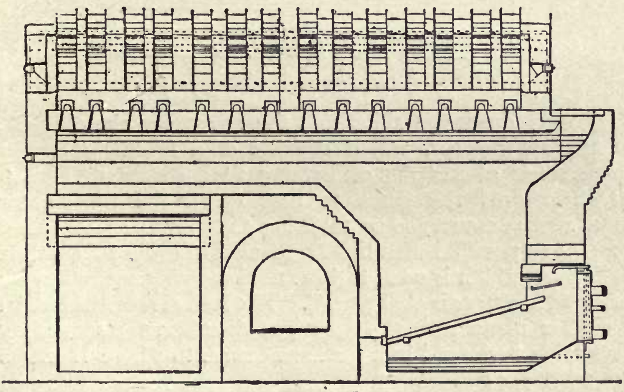


FIG. 3.

2,000° Fahr., travels to the nostril holes of the producer and is termed producer gas. At this point the gas meets the secondary air, which has been raised to a temperature of about 1,800° Fahr. by passing through the secondary air chamber, C, of the heated regenerator, the result being that the CO is burned to CO_2, thus, $CO + O = CO_2$; the resulting products of combustion yielding a temperature of about 2,500° Fahr. These products of combustion then circulate round the retorts and, descending over the top

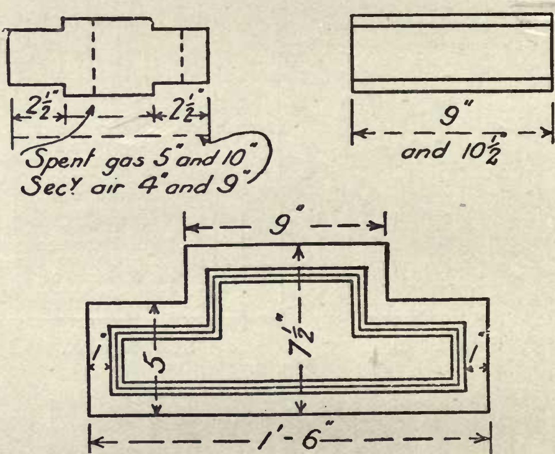


FIG. 4.

ones, pass down the sides into the spent gas chamber, D, of the regenerator, which consists of a fireclay chamber constructed of a series of baffling tiles, shown in Fig. 4, which compel the gases to pass down the regenerator in a zig-zag course, so as to bring them into as extended contact as possible with the brickwork, in order to abstract their heat, which is used to heat the incoming secondary air in the secondary air chamber, C. The latter is constructed in a similar manner to the spent gas chamber, the secondary air having to ascend in a tortuous course to where it meets the producer gas.

The advantages claimed for the regenerative system of heating retorts are:—Great saving in fuel, amounting in some cases to as much as 50 per cent., due to better control of the air supply; increased make of gas, due to good and regular heats; increased life of retorts (with equal heats), due to avoidance of cutting draughts, necessitated by increased amount of damper in the case of direct-fired retorts; easy clinkering of furnaces; saving of labour in clinkering due to the fires requiring cleaning much less frequently; saving on the wear and tear of fire-bars and fittings.

(1*b*) Describe briefly any coke-handling plant from retorts to coke yard with which you are acquainted, and compare, in general terms, the advantage and disadvantages of various mechanical systems and hand work.

By the term "acquainted" it is assumed that the examiner means practically acquainted. The writer is acquainted with, amongst others, a coke conveying plant on the De Brouwer principle, *i.e.*, a chain composed of alternate links and blocks having steel scraping pieces, which drag the coke along a smooth path. Such a conveyor is fixed in the coke hole of a retort house about 140 feet long. The chain works in a trough which is kept supplied with water. After leaving the retort house the coke ascends a short inclined conveyor about 30 feet in length, and then drops down a flat screen on to another short inclined conveyor, which takes it on to a horizontal conveyor fixed at right angles to the house, and about 160 feet in length. The breeze is screened out by dropping down the screen already mentioned, and falls into a breeze hopper below. The long horizontal conveyor is fixed above a series of hoppers, into which the coke drops through sliding doors in the bottom of the conveyor, and these can be closed at will. In order to minimize the effect of the drop when the hoppers are empty, the coke does not fall into the hopper direct, but down a shoot. The hoppers are fixed at such a height from the ground as will allow carts or railway trucks to pass underneath them, to be loaded therefrom. About 20 feet from the end of the conveyor a sliding door covers an opening which will allow of the coke dropping into a small supplementary hopper and on to an inclined conveyor, which takes the coke on to the hopper of a coke crusher. The crusher coke falls down a flat screen, which intercepts the breeze, and the broken coke falls into its own separate hopper. The construction of the above plant is of the simplest character. The coke conveyor chain runs over sprocket wheels at the ends, and the motion is given by suitable chain drive. Provision is made for keeping the chain tight by tension gear. The advantage of any system of coke loading plant is the saving in wages, both in the retort house itself and in loading up in the yard. The disadvantages are the heavy wear and tear due to the running of the plant and the damage to the coke, in the form of excess of breeze, caused by its travel and by its dropping into the hoppers.

(2) Sketch a cross section of a hydraulic main with a dip-pipe in position, and show an arrangement by which the seal on the dip-pipe can be regulated and the dip-pipe seal be maintained in water without the tar rising too high in the hydraulic main.

Fig. 5 shows such an arrangement. The tar flows down into the lower portion of the apparatus, by opening the plug valve, thus enabling the dip-pipe to be always immersed in liquor.

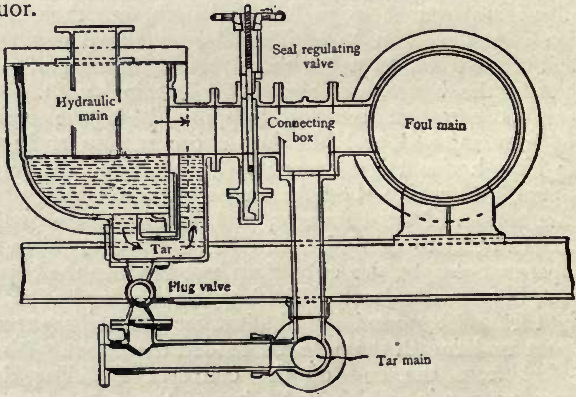


FIG. 5.

(3*a*) Theoretically, the primary and secondary air supply to a generator furnace should be in equal volume. Why, in practical working, has the primary air damper to be more open than the secondary air one?

The reason for the difference in the extent to which the two dampers require to be open is found in the fact that the secondary air has practically a free passage into the setting, whereas the primary air has to encounter the resistance of the fuel; and this resistance, in the case of a fire which is heavily clinkered over, is frequently very considerable.

(3*b*) What are the general effects of low and high temperature in the retorts on the quality and the quantity of the gas produced from the retorted coal?

Speaking generally, the higher the temperature the lower the quality and the higher the make of gas, and the lower the temperature the higher the quality and the lower the quantity. The effects were strikingly shown in a series of experiments conducted by Mr. L. T. Wright, F.C.S, who, operating on four portions of the same coal, which were subjected to various temperatures, ranging from a dull red heat to the highest temperature capable of being attained in an iron retort, obtained the following results:—

Temperature.	Cubic Feet of Gas Per Ton.	Illuminating Power (Candles).	Total Candles Per Ton.
(1) Dull red . .	8,250	20·5	33,950
(2) Hotter . . .	9,693	17·8	34,510
(3) ,, still . .	10,821	16·7	36,140
(4) Bright orange .	12,006	15·6	37,460

(4) Describe the practical working of a carburetted water gas plant, and name the special points which require watching if a uniform gas is to be the result.

Assuming that the plant is in good working order and the generator filled with fuel, the length of blow being 3 minutes and the run 5 minutes, the first operation is to put on the blast, which is done (the stack valve being open) by first lifting the generator blast valve, then the carburettor, and finally the superheater, if required. At the expiration of the time allowed for the blow, the superheater blast valve is first shut, then the carburettor, and finally the generator. The steam valve is then opened and the stack valve is closed, the pressure gauges being watched for back pressure on the plant. The oil is next turned on at such a rate as will admit the required quantity in four minutes, leaving the last minute of the run for purging out any oil remaining in the carburettor. At the end of the five minutes the steam is turned off, the stack valve raised, and the operation of blowing up repeated as before. The fires will require clinkering about every four hours; and if the plant is arranged so as to be worked with an up and down run, allow one down run to every four up runs in the first three hours. See that the scrubber is always kept supplied with water. The principal points to be attended to, in order to obtain uniform results, are to have coke of good quality and of uniform size, to have a good pressure of steam, say not less than 120 lbs. per square inch, and to have a blast pressure of not less than 20 inches water pressure. Attention must be paid to the distribution of the oil, to see that it is evenly and finely distributed, and that the checker bricks in carburettor and superheater are in good condition and their temperature suitable for the proper cracking of the oil. The steam inlet must also be kept in good working order, and the nozzles of the steam spray always kept clear. A jet for sampling the quality of the gas being made, as indicated by the colour, should be provided. When the plant is in good condition the gas will be a rich yellow, almost golden; if the gas is whitish it shows that it is not properly fixed, and if it is brown it is being overcracked, while, if the plant is making lamp black, the gas will be dark brown, and may even be black. The same information can be obtained by placing a piece of white paper in the gas stream and noticing the colour and character of the "stain" obtained.

(5*a*) After the greater part of the water has separated itself from the tar in a tank by natural settlement, the tar, when pumped for distilling purposes, still contains water. Describe the process by which the percentage of water left in the tar can be accurately determined.

The water in a sample of tar can be determined by distilling, say, 100 c.c. in an asbestos bound glass or copper flask, and collecting the distillate in a graduated measure. The water comes over first, and the change is readily distinguishable by the colour. In order to avoid frothing, a few pieces of glass or porcelain are frequently placed in the flask.

(5*b*) How would you test the value as a purifying agent of a sample of oxide of iron? Give the approximate results which you would expect to obtain from an average sample of any particular oxide with which you are acquainted.

A simple way of ascertaining the value of a sample of oxide of iron is to foul it with sulphuretted hydrogen and ascertain the amount of sulphur taken up at each fouling. The method of doing this is to take a small sample, bring it to what you consider is the requisite degree of moisture, place it in a Gas Referees' sulphur cylinder, and connect it to the outlet of the scrubbers for a period of twelve hours. A part of the same sample (moistened) is retained, so that the amount of moisture may be determined. The oxide is then revivified by exposing it to the air, until all traces of iron sulphide have disappeared; it is then dried, and a sample kept, from which the amount of sulphur contained in it is determined. The remainder of the sample is again rendered moist, a sample kept for the percentage of moisture, and the previous operations of fouling and revivification repeated three or four times, which will usually be sufficient to give a good idea as to the amount of SH_2 which the oxide will take up in the purifying vessels. The tests for sulphur in spent oxide are always made on the dried sample, and as the percentage of moisture is known, the percentage amounts can be stated either on the wet or the dry basis.

Another method for determining the value of an oxide is to estimate the total amount of ferric oxide which it contains. The determination is made by taking, say, 2 grammes of the oxide, in which the total moisture (free and combined) has been ascertained. This is placed in a beaker and digested with moderately strong hydrochloric acid until the whole of the iron has been extracted, which is indicated by the disappearance of the red colour from the material. But in order to make certain that the extraction is complete, it should be tested by treating a drop of the solution with a solution of thiocyanate of potassium, which should show no red colouration. As soon as the iron is all extracted, distilled water is added and the solution filtered, the filtrate and washings being made up to a definite quantity. The next operation is to reduce the iron, which is in the condition of a ferric salt, to the ferrous state, by placing a known quantity of the filtrate and washings in a flask of special construction and adding a few fragments of zinc free from iron. The neck of the flask is closed by a stopper having a hole into which is inserted a piece of glass tubing, and slipped over this is a piece of thin india-rubber tube, with a slit in it, the end of which is closed. The object of this arrangement is to give egress to and prevent the ingress of air, so as to maintain the solution in the ferrous state. The solution is then gently heated until all the zinc is dissolved; the colour changes to pale green, showing that the reduction to the ferrous state is complete. In order to make certain that it is complete, it is usual to place a drop of the solution upon a white porcelain tile and to add a drop of a freshly prepared solution of potassium ferrocyanide, when, if the reduction is complete, the colour will turn blue. The solution is then cooled, out of the presence of air, and titrated with a decinormal solution of potassium bichromate, and tested by a solution of potassium ferrocyanide, as described above. But as what we now wish to know is when the ferrous solution of iron has been oxidized to the ferric state, we must, in this case, watch for the appearance of a brown colour.

1 c.c. of $\frac{N}{10}$ solution of potassium bichromate = 0·0056 gramme Fe, consequently the number of c.c. of decinormal solution of bichromate used in converting the iron in the solution from the ferrous to the ferric state multiplied by 0·0056 will give the amount, in grammes, in the quantity of solution operated on, and ascertaining the percentage amount is simply a question of proportion. If we wish to know the amount of iron in terms of ferric oxide (Fe_2O_3), we multiply by 0·0080 in place of 0·0056, and if in terms of monohydrated oxide of iron (Fe_2O_3,H_2O), we multiply by 0·0089.

The approximate results which should be obtained with an oxide with which the writer is familar (an Irish bog ore containing 61·5 per cent. Fe_2O_3 on the dry basis), and admitting $1\frac{1}{2}$ per cent. of air with the gas, are—

First	fouling	18	per cent.	(round numbers).
Second	,,	30	,,	,,
Third	,,	40	,,	,,
Fourth	,,	48	,,	,,
Fifth	,,	56	,,	,,
Sixth	,,	60	,,	,,

whilst a ton of the material should purify the gas from 200 to 220 tons of coal.

(6*a*) Describe, with sketches, any form of atmospheric condenser with which you are familiar, and state the advantages claimed for an arrangement by which the path of the gas through the condenser can be reversed at will.

Fig. 5 (p. 25) shows a form of atmospheric condenser which is frequently met with, and which is known as the horizontal condenser. The apparatus consists of a series of pipes laid horizontally, with a slight fall from the gas inlet to the outlet. The gas enters at the top and leaves at the bottom, the condensed products flowing gradually along the condenser to a sealed pipe at the lower end. Its action depends upon the physical effects of heat conduction and radiation. The heat is conducted from the interior through the iron of the pipes to the exterior, where it radiates into the surrounding atmosphere, thus effecting the condensation of the gas.

The advantages claimed for what is known as the "reversible" condenser are that it is "self-cleansing"; in other words, that any solid matters deposited by the gas when it is flowing in one direction are, by reversing the flow, softened out or dissolved by the tar. The pipes are thus periodically cleared.

(*6b*) Discuss the relative advantages of tower scrubbers and mechanical washers. Explain, with sketches, the most efficient methods of distributing the water in a tower scrubber.

Mechanical washers are more compact and, generally speaking, ensure a more intimate contact with the washing medium, than tower scrubbers; they also lend themselves as agent for the removal of naphthalene. Tower scrubbers, owing to their liability to choking up with tar, are not so efficient as a final cleanser, but are well adapted for the preliminary washing with liquor. Further, in many cases they do not require any motive power to drive them, which is a decided advantage. The best way to arrange the washing plant is to pass the gas through a scrubber supplied with weak liquor first, and to finish with a mechanical washer fed with clean water.

One of the most efficient methods of distributing the water to a scrubber is that known as Green's, shown in Fig. 6. In the centre of the scrubber, and close under the top plate, is a large fixed spur wheel. Passing through a stuffing-box in the centre of the top plate and down through the spur wheel, but not attached to it, is a central water supply pipe, having at its upper end a funnel, below which is keyed, on to the supply pipe, a bevel wheel. A rotary motion is given to this wheel by bevel gearing from a convenient source of power. The central supply pipe rests in a footstep, and from it branches a pipe set at a V-angle, which forms a liquor trap to prevent the escape of gas. The branch pipe serves also as a bracket to carry a socket bearing, in which works, swivelwise, the axis of a small pinion gearing into the large fixed spur wheel.

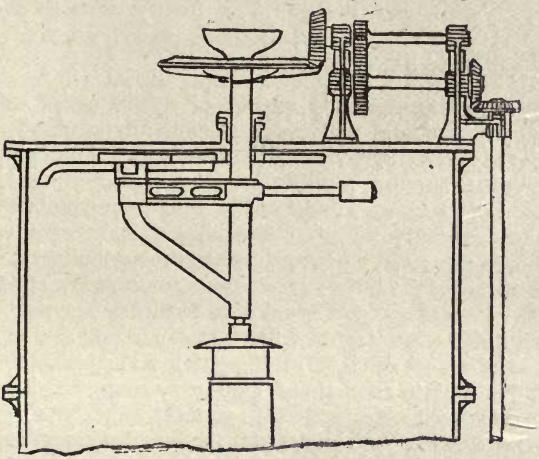


FIG. 6.

The axis of the pinion has a passage or port formed through it communicating with a short discharging pipe. The central supply pipe, as it revolves, causes the branch pipe to revolve also, and, in addition, the small pinion which is geared into the fixed spur wheel also rotates. The number of teeth in the spur wheel is so arranged as not to be exactly divisible by the number in the pinion, thus ensuring a slight variation in the position of the discharging orifice of the arm each time it is open.

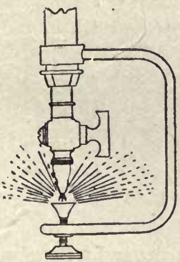


FIG. 7.

Another, and exceedingly simple, water distributing arrangement is shown in Fig. 7, and is known as Gurney's jet. The water, as it issues, impinges on a metallic button, causing the liquid to assume the form of a very fine spray.

(7*a*) What are the principal constituents in saturated gas lime? Does prolonged exposure to the air, before being used for agricultural purposes, improve or deteriorate the gas lime, from a farmer's point of view? If any changes take place, state briefly and generally what those are.

Spent gas lime usually consists of a mixture of calcium carbonate, calcium sulphide, calcium hyposulphite and calcium thiocyanate, the carbonate and sulphide usually predominating, the proportions varying according to the method of purification adopted. Speaking generally, prolonged exposure to the air, known as "weathering," improves the value of spent lime to the agriculturist, since, by its agency, the injurious sulphur compounds contained in the material are converted into fertilizing agents. The oxygen of the air destroys the offensive smell and changes the sulphide of calcium in the gas lime first into sulphite and, finally, into sulphate of lime or gypsum, which is well-known as a valuable fertilizing agent.

The following is an analysis by the late Professor Voelcker of a sample of gas lime which had been exposed to the air for a period sufficiently long to enable it to be used with safety as a manure:—

	Per Cent.
Water of combination and a little organic matter	7·24
Oxides of iron and alumina, with traces of phosphoric acid	2·49
Sulphate of lime (gypsum)	4·64
Sulphite of lime	15·19
Carbonate of lime	49·40
Caustic lime	18·23
Magnesia and alkalies	2·53
Insoluble siliceous matter	0·28
	100·00

(7*b*) Give the chemical reactions which occur in lime and oxide when unpurified coal gas is passed through them.

For answer to this question, see pp. 57–58.

(8*a*) How would you remove the SH_2 present in the gas after condensation? Give the chemical reactions.

The most economical method of removing sulphuretted hydrogen is by means of monohydrated oxide of iron, Fe_2O_3,H_2O. This is placed on wooden grids in vessels known as purifiers, generally in layers of from 6 inches to 10 inches thick. The purifiers are usually arranged in a series of four, and worked by a centre valve, so that three purifiers are in operation, whilst another one stands ready for putting to work when required. The gas passes through the material, and in its passage the sulphuretted hydrogen combines with the oxide of the iron to form sulphide of iron. As the material becomes exhausted, the sulphuretted hydrogen passes forward, and when it reaches the top of the second vessel, as shown by a lead test, the first vessel should be shut off, and the clean vessel, in readiness, placed so as to be the last one in the series. In order to ensure economical working, about $1\frac{1}{2}$ per cent. of air is frequently admitted with the gas, with the object of effecting what is known as revivification *in situ*. The vessel which has been shut out is then emptied and refilled with fresh material, so as to be in readiness when the next change is required. The spent material is placed upon the ground, first in a heap, and afterwards in a layer of about 12 inches in thickness, and exposed to the action of the air, by repeatedly turning it over. This has the effect of causing the sulphur, which has combined with the iron to form iron sulphide, to be deposited in the form of free sulphur, while the iron is reconverted into iron oxide, the process being known as revivification. The chemical reactions are given on pp. 57–58.

(8*b*) Explain briefly how the amount of nitrogen present in purified gas is usually estimated.

Nitrogen is usually determined by difference. In the analysis of a sample of gas in a gas analysis apparatus, the absorbable constituents are first removed. The residual gases, consisting of hydrogen, methane and carbon monoxide, are then determined by exploding with oxygen. After the explosion, the usual precautions are taken for ensuring a correct reading for the amount of contraction. The gas is then passed into the laboratory vessel, and treated with a small quantity of a solution of caustic potash, for the purpose of absorbing the CO_2 produced by the explosion. After absorption, the gas is passed back to the measuring tube and its pressure read. The difference between this reading and the previous one gives the volume of CO_2 produced by the explosion. It is sometimes the practice to return the residual gas to the laboratory vessel, for the purpose of absorbing the excess of oxygen employed in the explosion, by means of pyrogallate of potash, the volume absorbed being afterwards ascertained from the pressure exerted by the residual gas when returned to the measuring tube. Another method of determining the excess of oxygen is by exploding it with an excess of pure hydrogen and noting the amount of contraction. In any case, the readings obtained provide the data for calculating the composition of the gas after the absorption of the hydrocarbons. The volume of nitrogen is the residue remaining after the absorption of the excess of oxygen, and the percentage of nitrogen may be directly calculated from a knowledge of this fact taken in conjunction with the original volume of oxygen taken for the explosion determination. Or, if the excess of oxygen has been determined by exploding with excess of hydrogen, and the amount of contraction noted, the amount of this contraction divided by 3 will give the volume of the excess of oxygen, and this deducted from the volume of gas before the admixture of hydrogen will give the volume of nitrogen, which may then be calculated as a percentage on the gas taken for the explosion determination, and knowing the proportion of this to the total volume of gas taken for analysis, the total percentage can be obtained.

Another method of determining nitrogen is to burn 100 c.c. of the gas with hot copper oxide, remove the CO_2 formed by means of caustic potash, and measure the residual nitrogen.

(9*a*) If a spiral guided (Gadd and Mason) telescopic holder be constructed in a concrete tank, why is it not necessary to provide radial movement on the guide rollers attached to the holder itself, and equally necessary to provide this on the guide rollers fixed to the tank?

The answer to this question depends upon a knowledge of the effects of temperature on steel structures, and the reasoning would equally apply to a holder guided in the ordinary way. The various lifts expand and contract under similar temperatures in the same proportion, consequently the guide rollers and the edges of the guide rails will keep their relative positions, and it is, therefore, not necessary to provide for radial movement. But variations in temperature will cause a considerable difference between the diameter of the outer lift and the diameter of the tank, upon whose circumference the outside ring of guide carriages is bolted. It is, therefore, necessary to allow a considerable amount of radial movement upon the rollers in the carriages attached to the tank, since the diameter of the lift is more affected by variations in temperature than is the diameter of the tank.

(9*b*) A holder does not give the required pressure, and it has been decided that machinery must be employed to take the gas from the holder and deliver it to the governor house. The work can be done by either enclosed "open" fans, or by ordinary exhausters. Irrespective of first cost or cost of running, which would you employ? Give reasons for your preference.

The question of choice greatly depends upon the pressure under which the gas has to be pumped. Fans are not suitable for heavy pressures. The ordinary form of rotary exhauster also is not well suited for high-pressure distribution, owing to the low efficiency obtainable, due to the slip which occurs when running against heavy pressures. Also, its construction is not suited for running against the heavy loads involved in compressing gas to pressures from 5 lbs.

to 40 lbs. per square inch. The most suitable plant is a modified rotary exhauster, which, while retaining all the advantages of an exhauster, is specially designed for high-pressure work.

(10) What is meant by correcting the volume of a gas to standard temperature and pressure? A volume of gas measures 500 cubic feet when measured at 65° Fahr., with the barometer at 29·5 inches, what volume would this be when corrected to standard temperature and pressure?

Gases have the property of expanding and contracting with changes of temperature and pressure. It is, therefore, necessary, in order to compare results, to reduce the volume of gases to some common standard temperature and pressure, and the one adopted in gasworks measurement is 60° Fahr. and 30 inches Bar., and in scientific work the standard is 0° C. and 760 mm. pressure. Before one can reduce the volume of a gas at other temperatures and pressures than the standard, it is necessary to know the effect which changes of temperature and pressure cause in the volume of gases. With regard to temperature, gases expand or contract $\frac{1}{492}$ part of their volume at 32° Fahr. for each degree Fahr., expanding with an increase of and contracting with a decrease of temperature. So that if we require to know the volume which 500 cubic feet of gas measured at 65° Fahr. would measure at 60° Fahr. we would proceed as follows:—492 volumes measured at 32° Fahr. would measure $492 + (60 - 32 = 28) = 520$ volumes at 60° Fahr., and $492 + (65 - 32 = 33) = 525$ volumes at 65° Fahr. Consequently, the volume of a gas measured at 65° Fahr. would bear the same ratio to the volume which it would occupy at 60° Fahr., as 525 does to 520, so we have the following proportion sum :—As 525 : 520 : : 500 : 495·2 cubic feet.

With regard to pressure, the amount of decrease or increase in volume is inversely as the pressure, so that in order to ascertain what volume 500 cubic feet of gas measured under a barometrical pressure of 29·5 inches would measure at the standard pressure of 30 inches, we say

As 30 : 29·5 : : 500 : 491·6 cubic feet.

Now, correcting at once for temperature and pressure

$$\frac{500 \times 520}{525} \times \frac{29{\cdot}5}{30} = 487 \text{ cubic feet.}$$

It should be noted that the figure 30 (standard barometrical pressure in inches) always occupies the first term, and the figure 520 the second term; consequently if we divide the one into the other we get a constant (17·333), which enables the labour of calculating to standard temperature and pressure to be much reduced. This is done by making use of the constant 17·333 in the following formula :—

$$\frac{17{\cdot}333 \times h \times v.}{460 + t}$$

where h represents the height of the barometer when the gas is measured and t the temperature.

The above calculations are based on the assumption that the gas is measured dry, but since, in a gasworks, gases are stored over water they become saturated with water vapour, whose amount varies as the vapour tension of water at the particular temperature, and consequently the actual pressure exerted by the gas is that due to the barometric height minus the vapour tension of water at that particular temperature, the rest of the total pressure being exerted by the water vapour. The formula for correcting gases to standard, taking into account this tension of aqueous vapour, is

$$\frac{17{\cdot}64\ (h - a)}{460 + t}$$

h being the height of the barometer and a the tension of aqueous vapour at the temperature at which the gas is measured (t).

(11) Describe the different joints and jointing materials with which you are acquainted which might be employed in connecting together the straight lengths of a cast-iron gas main laid in a road or street. Under what circumstances might it be desirable to lay a wrought-iron main in preference to a cast-iron one; and if this were done, when would it be most desirable to specially protect the wrought-iron of which the main would be composed?

The joints principally employed in laying cast-iron gas mains are the socket and spigot and the turned and bored. In the socket and spigot joint, the spigot of one pipe is inserted in the socket of another, leaving an annular space of about $\frac{3}{8}$ inch between the two pipes. Spun yarn is rammed into the back of the socket to the extent of about half the depth of the latter. The opening at the front is then temporarily closed by a band of clay, leaving a small space, known as the "lip," through which molten lead is passed; the excess overflowing at the lip. The band of clay is then removed, and when the lead has cooled it is "set-up" all round with a caulking tool and hammer, any superfluous lead being trimmed off with a cold chisel. The turned and bored joint is chiefly suitable for connecting straight lengths of pipe. The socket and spigot are made so that the one fits tightly into the other, the spigot being cast with an extra thickness of metal, so as to allow of its being turned down in the lathe with a very slight amount of taper, the socket being bored to suit. The joint is made by smearing both socket and spigot with white or red lead paint, and then smartly driving the spigot into the socket by means of a wooden mallet. Other jointing materials which have been employed for the same purpose are portland cement, lead wool, and, latterly, lead wire.

A wrought-iron main might be employed with advantage in crossing a bridge, where it is nécessary for the weight to be carried to be as small as possible, and the pipe with as few joints as possible. Wrought-iron and steel mains can also be employed where the ground is liable to subsidence, since such pipes will bend or flatten, but not break. They have also been extensively used in high-pressure distribution. It is necessary to protect the pipes when they are laid in ground containing slag, cinders, and bodies of an acid character.

1910 EXAMINATION.

(1) With what impurity in coal is arsenic likely to be associated, and how can this impurity be eliminated from the coal, or the proportion reduced?

Arsenic is usually associated with sulphur in iron pyrites, and the quantity can be reduced by washing the coal, and thus separating from it the shale and iron pyrites. All systems of coal washing depend upon the difference between the specific gravity of the coal and that of its accompanying impurities.

(2) How is the temperature of a setting of retorts and working of the furnace affected by the quality of fuel used for firing? What percentage of ash in the fuel would you consider satisfactory, and how could the furnace be adapted to give high temperatures with fuel containing a high percentage of ash?

The temperature of the retort setting and working of the furnace depend entirely upon the quality of the fuel, since it is the carbon in the latter which gives out heat, during the process of combustion in the furnace. The more carbon and the less ash the better the value of the fuel, and, in consequence, the amount of heat developed in the furnace. A satisfactory figure for the amount of ash in coke is about 5 per cent. The furnace could be adapted to burn a fuel containing a high percentage of ash, by making it wider than usual, spacing the fire-bars at wider intervals, and arranging the steam supply in such a manner as to reduce the formation of clinker as much as possible.

(3) Sketch a front and side elevation of a self-sealing retort mouthpiece, and describe two methods of attaching the mouthpiece to the retort. What jointing material is used for the retort and mouthpiece, and for the ascension pipe?

Figs. 1 and 2 show the front and side elevation of a self-sealing retort mouthpiece. The mouthpiece is attached

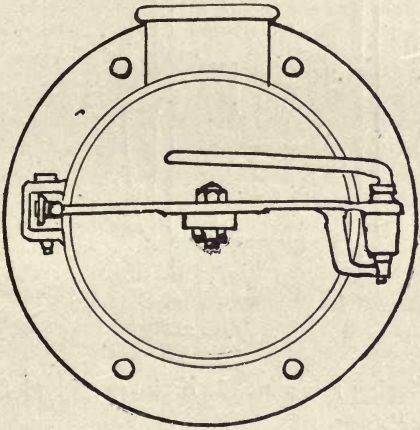


FIG. 1.

to the retort either by bolts and nuts or by an **H**-iron, which covers the lower and upper flanges of two tiers of retorts, and is connected at the ends to the buckstays forming the cross bracing of the setting. The material used for joining the clay retort to the iron mouthpiece is composed of three-fourths, by weight, of fire-clay and one-fourth, by weight, of iron borings, and when required for use the ingredients are mixed with ammoniacal liquor. Another mixture for the same purpose is 20 parts gypsum (sulphate of lime) made into a pulp with water, 10 parts iron borings saturated with a strong solution of sal ammoniac, the whole to be well mixed together, to a consistency fit for use. The usual jointing material employed in connecting the ascension pipe to the socket of the iron mouthpiece is iron borings and sal ammoniac.

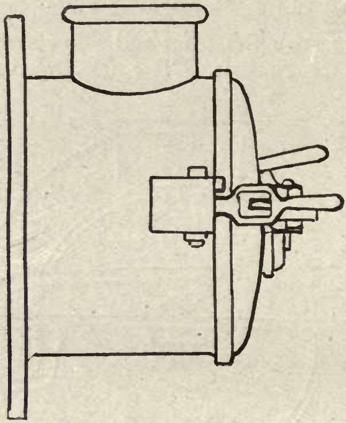


FIG. 2.

Mr. Newbigging recommends ordinary ground fire-clay for the same purpose.

(4) Describe the essential difference between a retort house and a "district" governor. In what position relative to the retorts would you fix the former, and why?

By a "district" governor it is assumed that the examiner means a governor for controlling the pressure in the district, usually spoken of as a station governor. The action of a retort house governor is the exact opposite of that of a station governor, since the retort house governor controls the inlet, and the station governor the outlet. In the retort house governor, the governor valve is opened by any increase of pressure, whereas the valve of the station governor is closed when the pressure is increased. A retort house governor is usually fixed on the foul main, as close as possible to the retort bench, in which position it is capable of controlling the total volume of gas as it comes direct from the hydraulic main, and thus ensures equalization of the vacuum generally.

(5) **Describe the method of collecting and accurately testing the waste or flue gases from a gas fired setting of retorts. From what part of the setting would you collect the sample of flue gases, and what precautions would you take to ensure accuracy?**

Flue gases may be conveniently determined by means of Bunte's burette, shown in Fig. 3. The sample is taken by means of a water-cooled porcelain or platinum tube (the latter being encased in a wrought-iron tube, which is perforated with a series of holes near the end, to admit the gas to the platinum tube), and the whole inserted into the flue, the hole through which it enters being well covered over with clay, to prevent ingress of air. The projecting end of the platinum tube is connected by india-rubber tubing to the end of the upper stopcock of the burette and the nozzle of the lower stopcock to an aspirator. In making a test, the upper tap of the burette is turned so as to be in communication with the gas, and the lower stopcock is opened and the aspirator put in operation. When the water or air in the burette is completely displaced with gas, the upper and lower stopcocks are closed, and the burette is disconnected. After the sample has been taken, the stem of the upper stopcock may be closed by a short piece of india-rubber tubing, plugged by a piece of glass rod. The burette is placed in its support, and allowed to remain for about fifteen minutes, so as to enable the contained gas to reach the temperature of the room. The funnel at the top is then filled with water from the water bottle shown, which is fixed a few feet above the top of the burette. On opening the upper stopcock, some of the water will flow into the burette, and on turning the lower stopcock, the capillary tube below the bottle will be filled with water. While the water is still flowing, the end of the tube attached to the water bottle is placed on the projecting tube of the lower stopcock and the gas in the burette displaced until the water rises in the burette to the zero mark. The readings should always be made with the water filling the funnel to one of the marks upon it, and all subsequent readings should be made with the water at the same level in the funnel.

The constituents to be tested for in a flue gas are CO_2, O_2 and CO. In order to do so, the upper stopcock of the burette is turned off, and the india-rubber tubing of the aspirating vessel, D, is attached to the nozzle of the lower stopcock, the top of the latter is opened and the water in the burette is drawn down until the level stands only a few millimetres

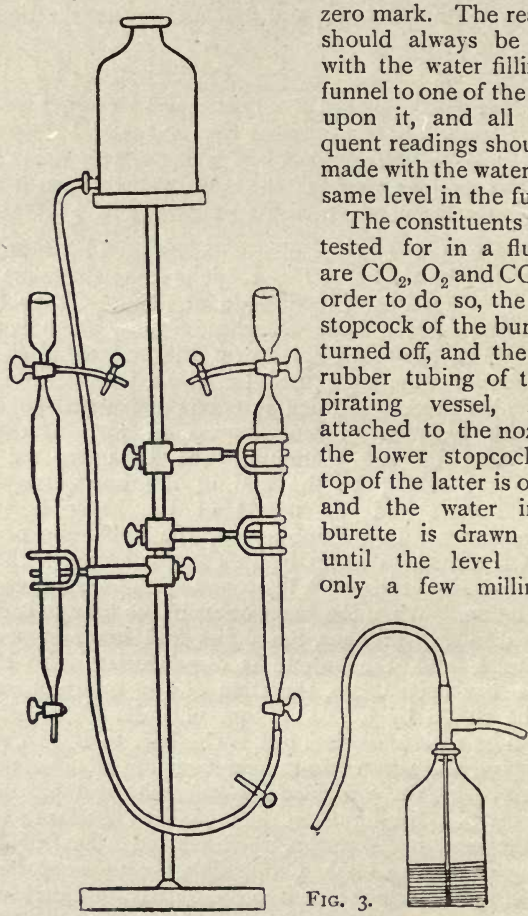


FIG. 3.

above the cock, which is then closed. A small vessel, nearly filled with a solution of caustic potash, is then brought underneath the nozzle of the lower stopcock, which is immersed in the solution. The cock is then turned on, when the solution will rise into the burette. As soon as it has risen as far as it will go, the top of the stopcock is closed, and the burette is taken from its stand and well shaken, so as to bring the contained liquid into intimate contact with the gas. After shaking for a few minutes, the burette is replaced on its stand, the funnel filled with water, and the upper stopcock opened, so as to allow the water to flow into the burette; the level of the water in the burette is read off, and the diminution of the volume of the gas compared with the original reading (100 c.c.) will give the percentage of CO_2. The upper stopcock is then closed and the liquid partially drawn from the burette by means of the aspirating bottle, and a freshly-made solution of pyrogallic acid is drawn up into the burette, in the same manner as the caustic potash was drawn up. The burette is then taken off its stand and again agitated, but for a longer period, and the succeeding operations are gone through as before, and the further diminution noted. This will represent the O_2 in the sample of gas. The last constituent to be determined is the CO, and in order to estimate this the liquid in the burette is entirely removed by alternate suction and flowing in of water from the funnel. A solution of cuprous chloride in hydrochloric acid is introduced into the burette, which is then agitated at intervals for some time. After absorption is complete, using more of the absorbent if necessary, the cuprous chloride is run out and the acid vapours thoroughly washed out by opening the top and bottom stopcocks and allowing water to flow from the funnel, which should never be allowed to run dry. When the acid vapours have been removed, a reading is taken, when the diminution in volume compared with the previous reading will give the percentage of CO. The sample should be taken from the last spent gas flue of the setting or the waste flue going to the main flue. The precautions to be observed are that the collecting tube be of such a material as will prevent the gases being decomposed and that no air enters the flue from the outside while the sample is being taken, that in the handling of the burette it is not heated by the warmth of the hand so as to affect the volume of the enclosed gas, and that in reading off, the temperature shall always be as nearly as possible the same.

(6) What conditions in the process of carbonization are favourable to the production of the following :— Ammonia, cyanide, sulphuretted hydrogen, carbon bisulphide and other sulphur compounds? Briefly describe the methods usually adopted for removing these impurities from the gas.

The highest yield of ammonia is obtained by the employment of medium temperature and the highest yield of cyanogen by the employment of high temperatures. High temperatures are favourable to the production of sulphuretted hydrogen and carbon bisulphide. The amount of the latter is also increased when the charge is allowed to remain too long in the retort after being burnt off. Ammonia is removed in the scrubber and washer-scrubber by means of weak liquor, finishing with water. The easiest way of removing cyanogen is by means of a solution of ferrous sulphate in a rotary washer. Sulphuretted hydrogen is removed in the purifiers by means of monohydrated oxide of iron, as per the following equation :—

$$Fe_2O_3,H_2O + 3H_2S = Fe_2S_3 + 4H_2O.$$

Carbon bisulphide is removed by means of slaked lime which has been rendered foul with H_2S in the absence of CO_2, thus :—

$$CaH_2O_2 + H_2S = \underset{\text{Calcium sulphide}}{CaS} + 2H_2O$$

and on passing CS_2 into this

$$CaS + CS_2 = \underset{\text{Calcium sulphocarbonate.}}{CaCS_3}$$

(7) How would you test the specific gravity of tar, and how would you determine the percentage of water occluded?

The simplest way of testing the specific gravity of tar is to take a small flask similar to those employed in collecting the solution of sulphur in bisulphide of carbon in the spent oxide test, and place over the top a small strip of wood, having two notches cut in it, one at each end, to enable it to rest on the edge of the flask. In the centre of the strip of wood an ordinary pin is inserted, after cutting off about a quarter of its length. When the flask is filled with tar or other liquid, it is extremely easy, by means of this contrivance, to always adjust the height of the liquid to the same level, which is shown by the lower end of the pin coming into contact with the liquid. The flask is first weighted perfectly clean and dry, and it is then filled with distilled water at a temperature of 62° Fahr. and again weighed. The difference = weight of water. It is then emptied of the water, thoroughly tried and filled with tar to the same level as the water, and weighed. This weight, minus the weight of the flask = the weight of the tar, and dividing this by the weight of water = specific gravity.

The percentage of occluded water is determined by taking 100 c.c. of the tar in a flask, connecting to a Liebig's condenser, and collecting the distillate in a graduated measure divided into c.c. On heating the tar, the water will come over, the conclusion of the operation being shown by the change of colour and the fact that the oil which comes over next, floats, owing to density, on the top of the water.

(8) Describe the Referees' sulphur test and give the chemical formulæ on which the test is based. If the condensed liquor from 5 cubic feet of gas, measured at normal temperature and pressure, gives 10·6 grains of barium sulphate, how many grains of sulphur would 100 cubic feet of the gas contain? (Ba = 137; S = 32; O = 16).

The apparatus employed in this test is described in Chapter VII., *ante*, p. 65.

In the example given, the combustion of 5 cubic feet yields 10·6 grains of barium sulphate ($BaSO_4$), and the molecular weight of the latter is 233. Thus $Ba = 137$, $S = 32$, $O = 16 \times 4 = 64 = 233$, and this is equal to 32 of sulphur, so in order to get the equivalent amount of sulphur in 10·6 grains $BaSO_4$, we say

$$\text{As } 233 : 10{\cdot}6 :: 32 : 1{\cdot}46,$$

or 1·46 grains of sulphur have been produced by the burning of 5 cubic feet of gas. In order to obtain the quantity in 100 cubic feet, we simply multiply by $20 = 29{\cdot}20$ grains.

As to the chemical formula on which the test depends, upon burning the gas it combines with the oxygen of the air to form first of all SO_2, thus $S + O_2 = SO_2$, and ultimately SO_3, by taking up another atom of oxygen. Ammonia being present, this combines with the SO_3 to form ammonium sulphate, $(NH_4)_2SO_4$.

$$SO_3 + H_2O = H_2SO_4$$

$$\text{and } H_2SO_4 + 2NH_3 = (NH_4)_2SO_4.$$

On adding barium chloride, after driving off carbonic acid by means of HCl, we have

$$(NH_4)_2SO_4 + BaCl_2 = BaSO_4 + 2NH_4Cl.$$

The latter, being soluble, passes through the filter paper.

(9) Give a simple sketch, with measurements, of the cup and grip of a telescopic gasholder. State what considerations regulate the depth of the cup when designing a gasholder.

Fig. 4 shows the drawing asked for. The considerations which determine the depth of the cup are that it should be of sufficient depth to establish an equilibrium between the internal and external pressures. It ought, further, to have an excess of depth, to allow for irregularities in the level of the water lute during the movement of the bell of the

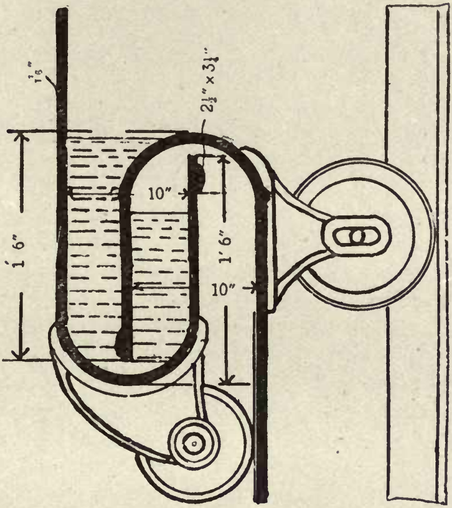


FIG 4.

holder, and there ought to be a sufficient margin of depth to allow for loss by evaporation in hot weather.

(10) Describe a method for automatically regulating the speed of an exhauster to maintain a steady vacuum with a varying volume of gas, and a varying resistance on the outlet.

The most efficient method of automatically regulating the speed of the exhauster is by means of a governor whose action is controlled by a pipe coming direct from the hydraulic main, and which is in communication with the steam throttle valve of the engine that drives the exhauster.

[NOTE.—Only eight questions were to be answered, and in the 1909 examination only one or other of the alternative questions (*a*) (*b*).]

AMMONIA RECOVERY, WITH SPECIAL REFERENCE TO THE APPARATUS EMPLOYED THEREIN.

Paper read by Mr. W. H. Johns, Superintendent of the Saltley Gasworks, Birmingham, before the Midland Junior Gas Engineering Association, 12th November 1910.

THE absence from our "Transactions" of any paper dealing with the subject of ammonia recovery, as well as the scarcity of such papers read before other Associations, has led me to comply with the President's request to submit to your notice a paper which I trust may be of some small service to the members. At the same time, I realize the impossibility of dealing completely with so important a subject within the limits of an ordinary paper.

Ammonia may be obtained from sewage, bones, horn, leather, coal and other substances. It is produced in coke ovens, producer gas and blast-furnace plants; but it is the recovery of the ammonia that is liberated from the coal in the manufacture of coal gas with which we are particularly interested, and to which I will, therefore, confine my attention.

Ammonia is produced in the destructive distillation of coal by the union of the nitrogen with the hydrogen— $N + H_3 = NH_3$. The average amount evolved may be taken as $1\frac{1}{2}$ per cent. by volume, or about 480 grains per 100 cubic feet of gas; and by the time the gas has reached the outlet of the condensers, it will contain about 0·70 per cent. by volume, or 220 grains per 100 cubic feet of gas—the difference being accounted for by elimination in the hydraulic main and absorption in the condensers and cooling mains by the deposited aqueous vapour previously held in suspension in the hotter gases.

It will, therefore, be seen that the removal of ammonia commences as soon as the crude gas enters the hydraulic main from the retort, where it comes in contact with the liquor forming the seal. Owing to the temperature at this point being fairly high—from 140° to 150° Fahr.—not so much ammonia is arrested as would be the case if the liquor could be maintained at a lower temperature; but by the time the gas enters the washers and scrubbers, from one-third to one-half of the total ammonia it previously contained will have been deposited. Mr. Charles Hunt gives the following results as work done by the various apparatus:—

Ammonia removed by condensation . .	42·7	per cent.
,, ,, in first scrubber . .	43·3	,,
,, ,, in second scrubber . .	14·0	,,
	100·0	,,

The removal of the ammonia from coal gas depends upon the solubility of ammonia in water, which, at 60° Fahr. and 30-inch barometer, is capable of absorbing 783 times its own volume of ammonia gas; the amount of absorption increasing as the temperature of the water is lowered, and *vice versâ*. But temperatures lower than 50° Fahr. should not be worked, otherwise the candle-power of the gas will be seriously affected. It should, however, be noted that the quantity of ammonia which water will absorb is not entirely dependent upon the temperature of the water, as the solubility varies directly in proportion to the pressure of the ammonia gas.

If we were dealing with ammonia uncombined with other gases, the whole would be absorbed at normal atmospheric temperature and pressure, to the extent of over 700 times the volume of water employed; but since the gas, as previously pointed out, contains only about 0·70 per cent. by volume of ammonia at the inlet to the washers and scrubbers, very little ammonia is dissolved per volume of water, due to the small pressure exerted by the ammonia, though when taken up by the former it is retained, owing to the water being at atmospheric pressure. It will now be seen that time-contact between the ammonia and water plays a very important part in the process of ammonia recovery, and should be taken into account when new plant is being designed.

Advantage should be taken of the affinity which ammonia has for combining with, and neutralizing, the carbon dioxide (CO_2) and sulphuretted hydrogen (SH_2) in the crude gas, to form carbonate and sulphide of ammonia, respectively; the latter, in turn, being capable of absorbing some of the carbon bisulphide (CS_2); all of which operations are to be desired, as the cost of dry purification is thereby reduced in proportion to the amount of the impurities (CO_2, SH_2, and CS_2) removed in the scrubbers—more especially the CO_2 and SH_2, for CS_2, at the majority of gasworks, is not now specially eliminated, beyond what is taken out in the washers and scrubbers, although it is very desirable to keep it below 40 grains per 100 cubic feet.

The following reactions occur when carbon dioxide and sulphuretted hydrogen combine with ammonia in the washers and scrubbers.

$$(1)\ 2NH_4HO + H_2CO_3 = (NH_4)_2CO_3 + 2H_2O$$
$$(2)\ NH_4HO + H_2CO_3 = NH_4HCO + H_2O$$
$$(3)\ 2NH_4HO + SH_2 = (NH_4)_2S + 2H_2O$$
$$(4)\ NH_4HO + SH_2 = NH_4HS + H_2O$$

There is a limit to the amount of work which can be done through the agency of the ammonia, since, as already stated, it is only present in the gas to the extent of 1·5 per cent. by volume. About one-fourth is "fixed," or combined in the ammoniacal liquor as ammonium sulphate, ferrocyanide, chloride, thiocyanate, and thiosulphate, and is quite useless as a purifying agent for CO_2 and SH_2. Therefore only 1·2 per cent. of NH_3 by volume is left to combine with these two impurities, which are present in the gas to the extent of from 0·9 to 1·5 per cent. of sulphuretted hydrogen and 1 to 2 per cent. of carbon dioxide—quantities greatly in excess of the amount which the ammonia will neutralize.

In order to eliminate from the gas as much of these acid impurities as possible by means of ammoniacal liquor, it is necessary that the gas should be brought into intimate contact with a strong solution of ammonia; and this can be efficiently carried out in one of the various forms of washers—such as the Livesey, Cockey, "Standard," or Walker washer, in which apparatus the gas is caused to pass through a strong solution of ammoniacal liquor by means of a number of seals, the depth of which may be adjusted according to the make or volume of gas which is to be treated, so that the back-pressure at any time does not exceed 3 inches. In the washer, the gas is divided up into small streams. The contained liquid is consequently agitated by the pressure, and the gas thereby brought into intimate contact with the liquid. The washer was one of the earliest forms of apparatus employed for removing ammonia; but owing to ignorance of the principles upon which it should work, it was discarded—partly due to the great amount of back-pressure thrown in some of the older types, and also to the disastrous effect it had upon the candle-power of the gas, owing to the gas having to force its way through a tar seal.

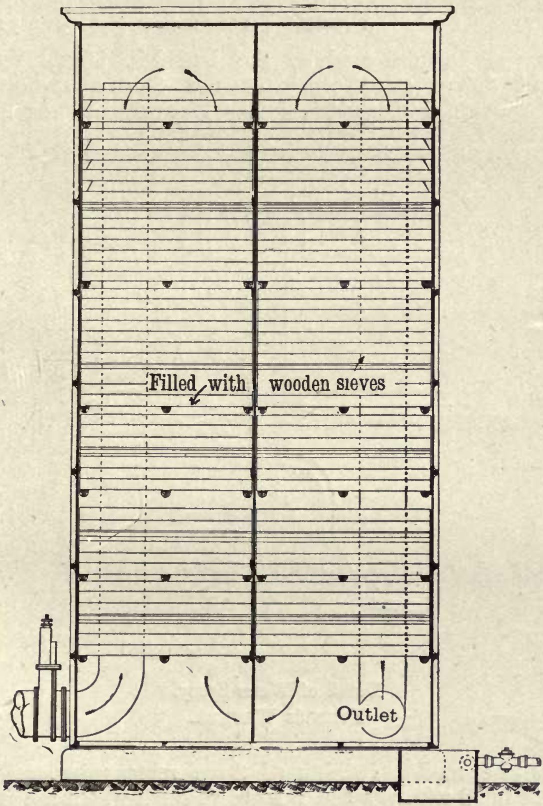
In modern works, all tar should be eliminated in the condensers or in tar extracting plants—such as the Pelouze and Audouin, the "Cyclone," or other type of extractor—before it enters the ammonia washers, thus leaving the latter free to deal with the ammonia, and consequently increase their efficiency.

An Early Type of Washer.

An early type of washer consisted of a rectangular cast-iron vessel, about 3 feet 6 inches deep (the length and breadth of which varied according to the required capacity per twenty-four hours), divided into two sections, by means of a plate forming a division or false bottom, fixed about 6 inches from the cover, and drilled with holes about 1 inch diameter, spaced 3 or 4 inches apart. Into these holes short pieces of gas tubing were fixed, the lower ends of which were sealed in liquor contained in the lower portion of the washer; the depth of seal being regulated by means of a suitable weir valve. The gas entered the upper division, passed down the 1-inch tubes and through the liquor, agitating the same, and then bubbled to the surface. From this point, it travelled under the division plate to the outlet, thus coming in contact with the foam formed by the gas when bubbling through the liquor seal.

Anderson's Washer.

This consisted of a rectangular cast-iron outer vessel containing a number of trays, having on their lower sides a

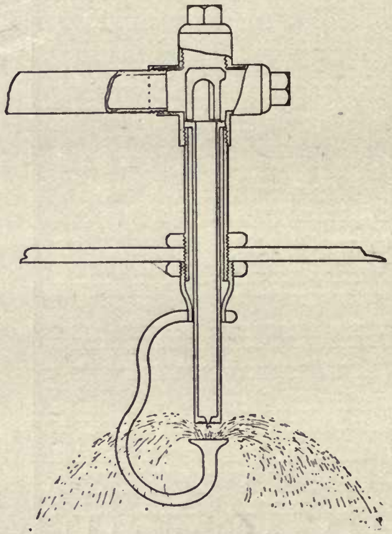


Section.
YOUNG'S WASHER.

series of serrated bars arranged at right angles to the flow of gas, and which were sealed in liquor. The gas, having to pass through the serrated bars, was divided up into very fine streams; and being constantly made to dip under the same, it was brought into intimate contact with the liquor. This was a very efficient apparatus; but it has given place to newer and cheaper, though not less efficient, forms of washers.

Young's Washer.

The washer designed by the late Mr. Hugh Young is still doing good work at the Saltley station of the Birmingham Corporation Gas Department. At these

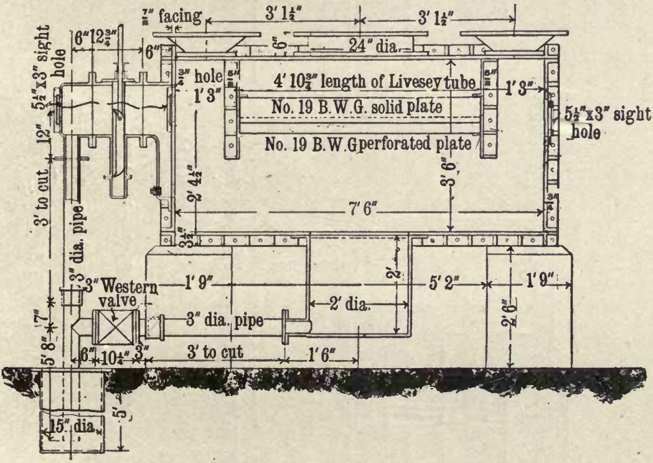


Detail of Water Spray.
YOUNG'S WASHER.

works, the washer consists of three rectangular cast-iron vessels filled with wooden boards, through which the gas is made to pass. Ammoniacal liquor is pumped over the top of each vessel, through which it descends and overflows to the liquor well. These washers give no trouble in working, and never get blocked with naphthalene, which is, no doubt, due to the method of liquor supply adopted, by which system any deposit is readily and quickly washed down to the bottom. They are, however, costly to instal, owing to their great height, and occupy more ground space than modern types of washers designed for dealing with the same quantity of gas.

The Livesey Washer.

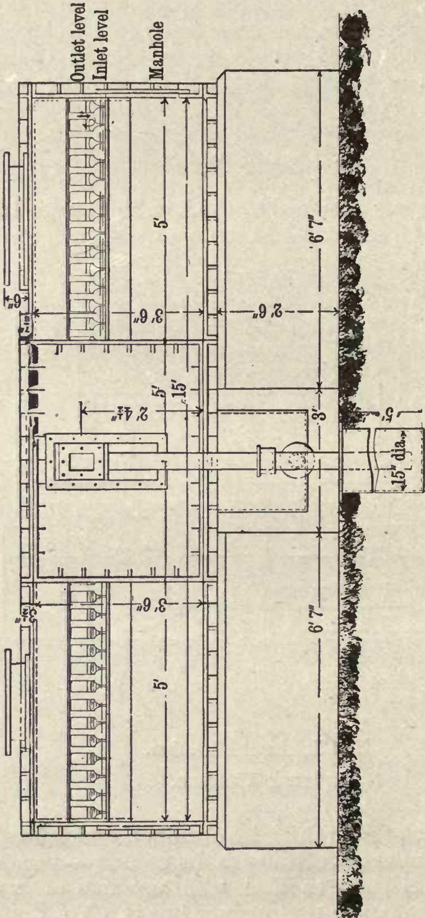
This washer was designed by the late Sir George Livesey, and consists of a rectangular cast-iron outer case, the upper



End Sectional Elevation.

LIVESEY WASHER.

portion of which forms the inlet chamber, and is fitted with one or two outlets, according to its capacity—usually two for washers designed to deal with upwards of 750,000 cubic feet of gas per twenty-four hours. To the lower portion of the inlet chamber, specially shaped wrought-iron tubes, having holes $\frac{1}{20}$th of an inch in diameter, are fixed, the interior of the tubes being in free communication at the

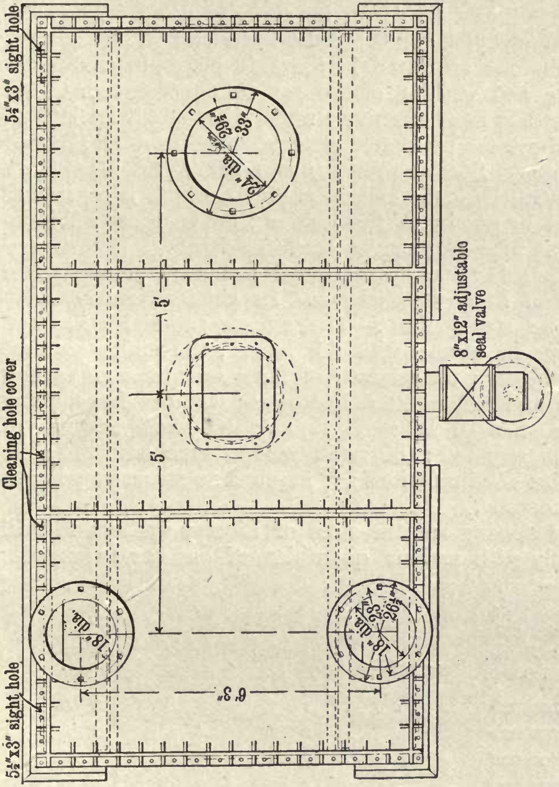


Side Sectional Elevation.

LIVESEY WASHER.

(Capacity, 3,000,000 cubic feet per day.)

ends with the outlet chambers, but the spaces between the tubes at the ends are securely closed up. The gas has free access from the inlet chamber to the intermediate spaces, passing down them as shown in the drawings, depressing the



LIVESEY WASHER.
Plan.

liquor until the gas escapes through the inclined portion of the perforated plate into the first space, which is filled with liquor, up through which it bubbles, until it comes in contact with the horizontal part of the perforated plate, carrying some of the liquor with it to the upper surface of the same. The bubbles of gas pass through this liquor into the tube space above, and convert the surface into foam, which flows along with the gas into the outlet chambers. The washer is provided with suitable overflow pipes, by which the liquor level can be easily adjusted. The inlet liquor supply pipe is fixed in the lower part of the washer. Glass windows are fitted in the side plates, to enable the bubbling and washing of the gas to be observed. This washer works most effectively when it has nearly an inch of liquor above the perforated plate, which gives about 3 inches of pressure. Special provision is made in the lowest part of the washer for the collection of tar, which is separated, and falls by gravity to the bottom; being drawn off independently of the liquor once or twice daily.

This washer has found much favour in gasworks, on account of its great efficiency. Its chief advantages may briefly be stated thus:—The minute sub-division of the gas, twice in contact with the liquor; the entire removal of all the tar; the removal of large quantities of carbon dioxide and sulphuretted hydrogen; facilities for working up the strength of weak liquor; the small amount of attention required; the small ground area occupied; the small cost of foundations; it requires no steam or pumps; it is automatic.

The following are the sizes of Livesey washers to deal efficiently with various quantities of gas per twenty-four hours:—

Quantity of Gas Per 24 Hours. Cubic Feet.	Length. Ft. In.	Breath. Ft. In.	Depth. Ft. In.
100,000	1 3	3 8	2 6
250,000	2 11	4 0	2 6
500,000	3 6	5 0	2 6
750,000	4 0	6 0	3 0
1,000,000	5 0	7 6	3 6
2,000,000	10 0	7 6	3 6
3,000,000	15 0	7 6	3 6
4,000,000	20 0	7 6	3 6

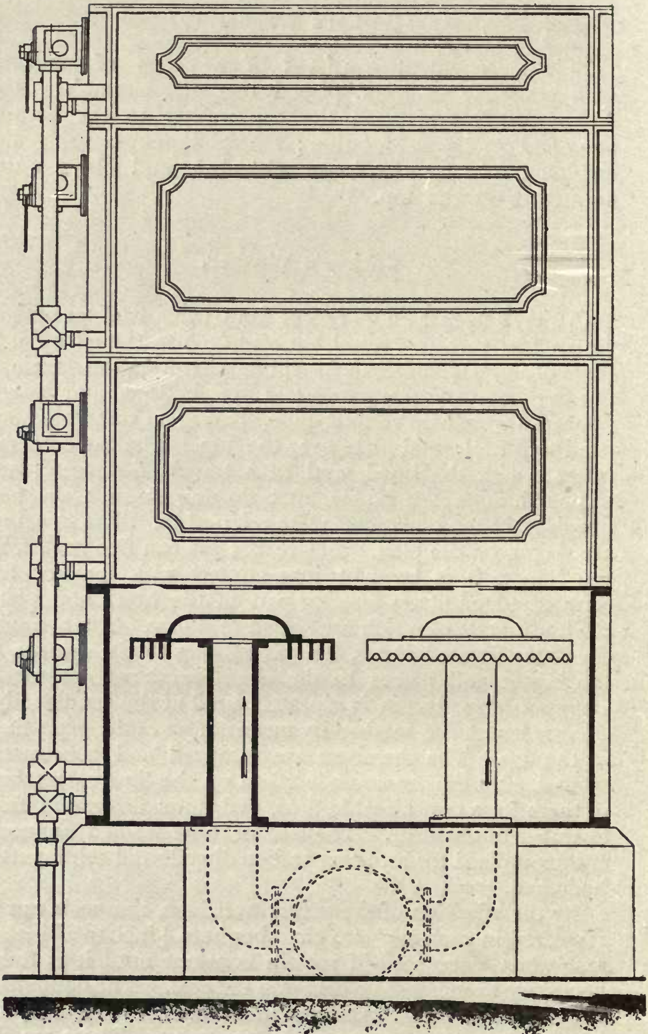
Cathel's Washer.

This arrangement consisted of a series of washers, each complete in itself, placed one above another, the liquor overflowing from the top washer to the second one, and so on in rotation; strong liquor meeting the incoming gas at the lower chamber, and clean water flowing in at the top.

Cockey's Washer.

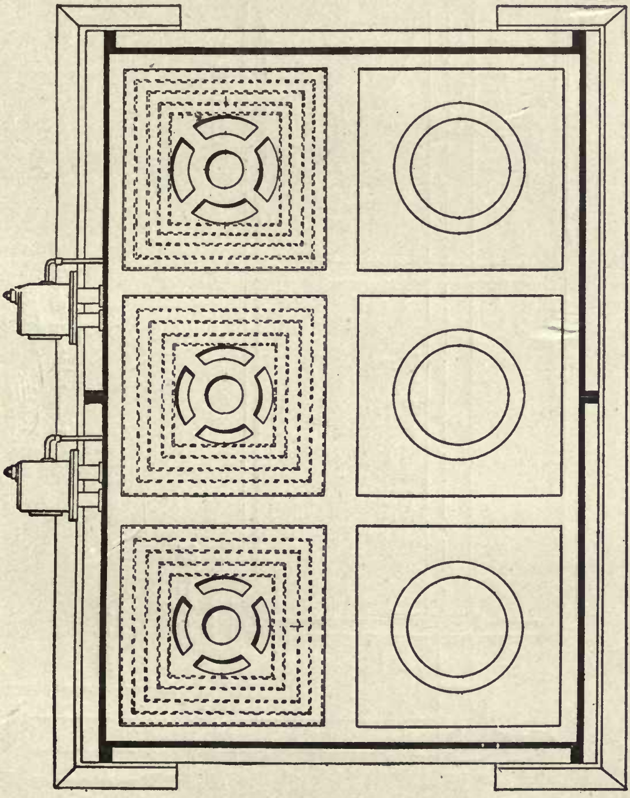
Cockey's washer, in its recent form, consists of an upright rectangular cast-iron vessel horizontally partitioned off into three or more chambers. As will be seen from the drawings, the gas enters the apparatus at the bottom, and travels upward through a vertical pipe, having a cast-iron hood fixed to a horizontal plate over the top. The gas comes in contact with the hood, and then travels downward, and passes through the liquor, after flowing through the four openings in the horizontal plate referred to. The openings are shown on the plan. Before the gas can free itself from the liquor, it is brought into contact with four or five serrated edged plates forming part of the horizontal plate, the lower ends of which are sealed in liquor. After passing the outer serrated plates, the gas bubbles to the surface of the liquor and passes to the chamber above, where the same washing process is repeated, until at the last chamber the gas leaves the washer by means of an outlet pipe fixed at the top. The chambers are arranged and constructed so that, after the ammonia is taken up, the liquor is retained in them for a considerable time, and flows downward from chamber to chamber. The free or uncombined ammonia is thus utilized for arresting carbon dioxide and sulphuretted hydrogen.

By the adoption of the patent overflows, the seals can be regulated in each separate chamber from $\frac{1}{4}$ inch to $2\frac{3}{4}$ inches, and when once set will remain constant until it is found necessary to increase or decrease the seal. The liquor from each upper chamber overflows into the next lower one, and so on from top to bottom of the apparatus. There are also



End Elevation.
COCKEY WASHER.

a series of draw-off taps, by which any upper chamber can be entirely emptied into any lower one, or its contents drawn away from the apparatus without interfering with the passage of the gas. This washer occupies little space, requires no motive power, is continuous, reliable in action, and will work with a minimum of pressure.

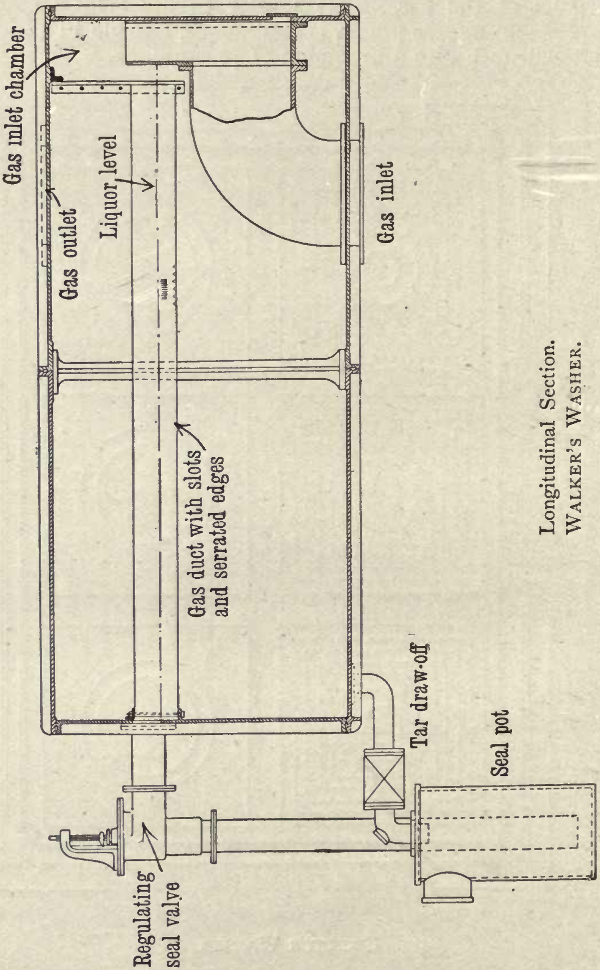


Plan.

COCKEY'S WASHER

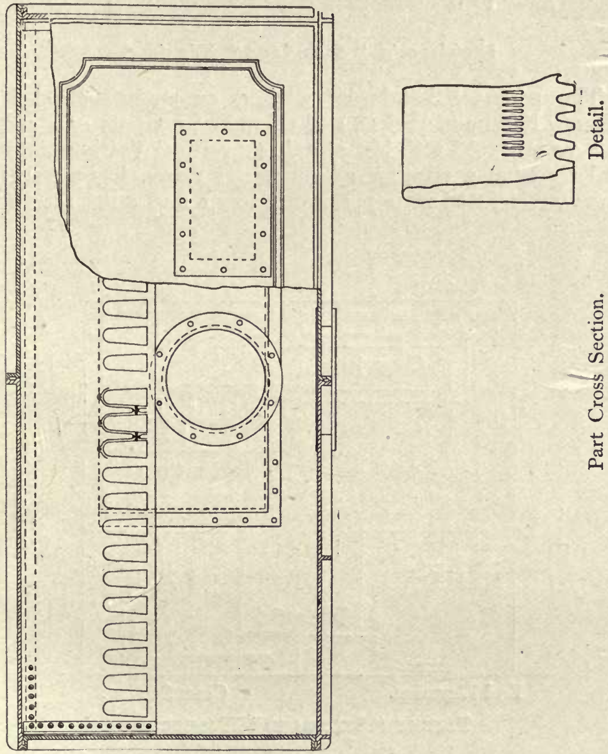
Walker's Washer.

This washer is constructed in a similar manner to the Livesey, except in one or two details. It is built up of



Longitudinal Section.
WALKER'S WASHER.

cast-iron plates, usually made rectangular in form, and fitted with the usual tar and liquor overflows and seal regulating valves. The gas inlet pipe is brought through the bottom



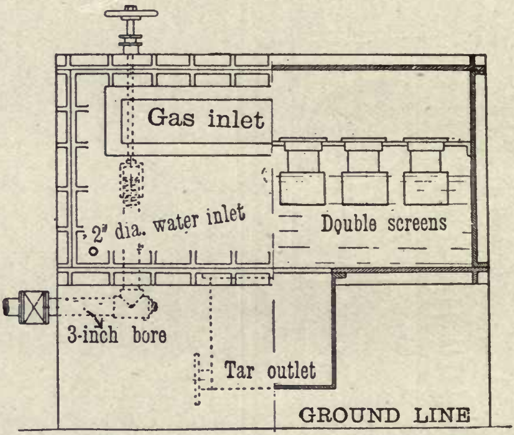
Part Cross Section.
WALKER'S WASHER.

plate of the washer, and the gas enters an inlet chamber, from which branch off a number of longitudinal passages or inverted troughs, closed at the far end, but open at the bottom. The lower ends of the inverted troughs are slotted with peculiarly shaped slots, which extend from end to end;

and these are sealed in liquor when the washer is at work. The gas passes into the top portion of the troughs above the liquor, forces its way through the slots after displacing the liquor, and bubbles in small streams to the surface and passes away to the outlet.

Kirkham's "Standard" Washer.

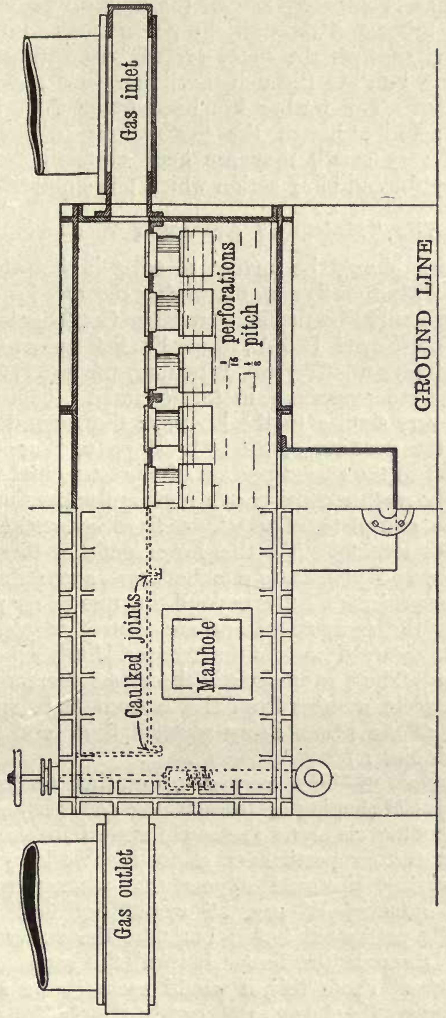
The patent "Standard" washer, as manufactured by Messrs. Kirkham, Hulett, and Chandler, consists of a cast-iron vessel fitted with horizontal and vertical division plates, and contains a number of sheet-iron tubes, having their lower ends fitted with perforated inner and outer screens,



End Elevation. Cross Section.

PATENT "STANDARD" WASHER.

and their upper ends fitted with machined cast-iron rings and wrought-iron lifting handles; the latter being provided to facilitate the withdrawal of the tubes. The tubes are dropped through faced circular holes, cast in the horizontal division plate, and secured to the latter by studs. The lower ends of the tubes are sealed in ammoniacal liquor;



Side Elevation. Longitudinal Section.

PATENT "STANDARD" WASHER.

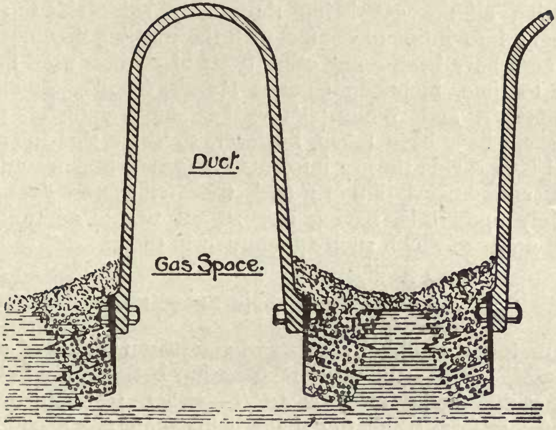
and the gas is admitted above the division plate, passes down the tubes and through the perforations in the inner screen, impinges on the outer screen, passes through the perforations, bubbles through the liquor, and passes away to the outlet. This washer has been found to do its work very well; and although the perforations in the sealed tubes are very small, they are kept perfectly free from choking by the bubbling action which takes place.

The "Multiple" Ammonia Washer.

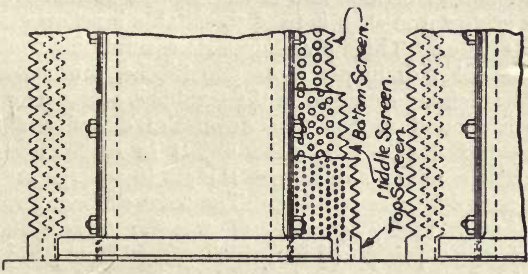
Reference should be made to what is known as the improved "Multiple" ammonia washer recently introduced, and manufactured by the Western Gas Construction Company, of Fort Wayne, U.S.A., whose English agents (Messrs. W. C. Holmes and Co.) are, I believe, prepared to make and erect similar washers in this country. This type of washer is very similar to the Livesey; the main difference being in the position of the "breaking up" or washing perforations in the sealed portion of the horizontal tubes or ducts. The washer consists of a rectangular cast-iron outer case, to the end plates of which are fixed inverted U tubes, running horizontally. To the lower ends of these tubes three perforated plates are attached, one above the other. Each plate projects a little beyond the one below; but all are bent to the same angle, and are secured at intervals by bolts to the enlarged ends of the inverted U tubes previously referred to. The perforations in the plates decrease in size and increase in number from the bottom plate upwards; the edges of the plates being serrated from end to end. (See sketch No. 1.)

This appears to be a very cheap washer to construct, since no special shaping of the washing plates is necessary, beyond bending them to the angle shown in sketch.

Without further particulars as to the working of this form of washer, it would appear that when passing the maximum quantity of gas, all would not find its way through the perforated holes, but take the easier course, and pass through the liquor beyond the serrated edges of the plates. From this, it would seem to be a better plan to arrange the plates as shown in sketch No. 2; thus

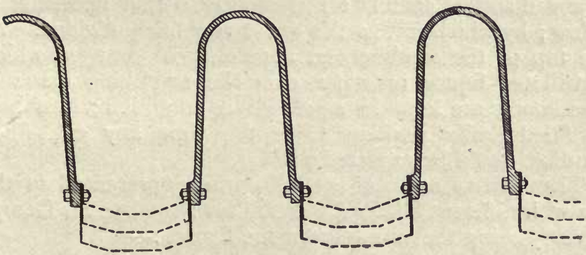


Sectional Elevation.



Plan.

Sketch 1.—"Multiple" Washer.



Sketch 2.—Suggested Modification of "Multiple" Washer.

ensuring all the gas being thoroughly sub-divided and brought into intimate contact with the washing medium.

There have been many other types of washers used from time to time, including Charles Hunt's, Good's, Saville's, Dempster's, and Whimster's washer and exhauster, etc. Sufficient have been taken, however, to show that the aim in all is to divide the gas into small streams while in contact with ammoniacal liquor; and their efficiency depends entirely upon this, having due regard to the amount of back pressure which such apparatus will throw.

Scrubbers and their Capacities.

The tower scrubber consists of a cast-iron vessel of considerable height—the usual relationship between the height and width being as 7 is to 1—either rectangular or circular in form (the latter shape being preferable), built up in sections and divided into bays. At the bottom of each bay, a grid or iron shelf is fixed to suitable brackets cast on the side plates. The shelves support the scrubbing medium, such as coke, drain pipes, wooden blocks, brushwood, or boards which are arranged in the scrubber, and over which liquor is allowed to flow in a downward direction against the upward flow of gas. The object in employing such material for filling is to subject the gas to as large an area of wetted surface as possible. The most efficient scrubber filling undoubtedly consists of wooden boards, about 11 inches in depth, $\frac{3}{8}$ to $\frac{5}{8}$ inch thick, spaced from $\frac{1}{2}$ to $\frac{3}{4}$ inch apart by distance pieces; the whole being made up in the form of a sieve, with the boards set on edge, and the tiers arranged so that each is set crosswise to that immediately below; by which means the gas is very finely divided. At the top of the scrubber, an apparatus is arranged which distributes liquor or water over the scrubbing material. The boards are kept in a very clean condition; scrubbers so filled easily working twice the time any coke-filled scrubber could be expected to work.

The relative areas of wetted surfaces presented to the gas with different fillings are as follows; the late Sir George Livesey being the authority for the figures:—

Coke	$8\frac{1}{2}$	square feet per	cubic foot.
3-inch diameter drain pipes .	17	,,	,,
2-inch ,, ,, ,,	21	,,	,,
Boards	31	,,	,,

It will thus be seen that board-filling presents practically four times the area of coke-filling. The first cost of board-filling is, naturally, higher, but as this filling can be used over and over again, in the long run it is the cheaper, besides being a more efficient material for scrubbing purposes.

Tower scrubbers are usually worked in pairs; the gas passing through them in succession. The first scrubber is supplied with ammoniacal liquor, and the second, or finishing scrubber, with clean water. In small works where only one scrubber is employed, arrangements are sometimes made for the top half to be supplied with water and the lower half with liquor; the gas being brought in contact with strong liquor at the bottom and with clean water at the outlet or top portion—thus obtaining, as far as possible, the advantages of a pair of scrubbers.

According to the various authorities given below, the capacity of tower scrubbers should be :—

(1) W. R. Chester (1892), Nottingham: Scrubbers and washers, 4·1 cubic feet per thousand cubic feet maximum make per day. Time contact, 6 minutes.

(2) W. R. Herring (1892), Huddersfield: 9 cubic feet per thousand cubic feet maximum make per day.

(3) T. Newbigging (1898). 9 cubic feet per thousand cubic feet maximum make per day.

(4) H. O'Connor (1897). 120 cubic feet per ton of coal carbonized per day (maximum).

(5) V. Wyatt (1887), London: 100 cubic feet per ton of coal carbonized per day (maximum). Time contact, 15 minutes.

The tower scrubber possesses the advantage of being of simple construction (though its great height adds to its cost). It requires very little motive power; and this only for the water distributors (which will be described before passing to the apparatus which is better adapted for removing the last traces of ammonia—namely, the rotary washer-scrubber).

Water and Liquor Distributors.

In order to ensure thorough distribution over the whole area of a scrubber, a good distributor must be arranged. One method of supplying a scrubber with liquor or water is that known as Gurney's jet, which consists of a jet under great pressure impinging on a small plate or disc, which causes the water to spread out in a very fine spray.

Barker's mill consists of a pipe which passes through the top of the scrubber, from which radiating pipes pierced with small holes are suspended, and caused to revolve simply by the action of the water pressure, in a similar manner to an ordinary lawn sprinkler.

Another arrangement is the well-known tumbler method, which consists of a tumbler constructed to hold a certain quantity of water or liquor, which is supplied from an overhead tank. The tumbler is mounted in such a manner that when filled with the liquid, it overbalances and empties its contents through a sealed pipe, and returns to its original position. In some tumbler arrangements, gear wheels and an index are fixed, which registers the quantity of water used. Several radial arms are also rotated by means of a pawl and ratchet attachment fixed to the tumbler spindle.

In the Mann and Walker type, as made by Messrs. C. and W. Walker, of Donnington, a brushwood wheel is fixed in the top of the scrubber, and is caused to revolve by means of bevel wheels worked from a vertical shaft attached by means of brackets to the outside of the plates forming the scrubber, and driven by a small steam engine fixed at the scrubber base. Water or liquor from an overhead tank is supplied through funnels and down-pipes and sprayed over the brushwood wheel by means of revolving distributors, which work eccentrically, travelling rapidly when nearing the centre and slowly when traversing the outer circumference, consequently causing the liquor or water to be dashed or sprayed all over the brushwood. This arrangement is at work on the 15 feet and 20 feet diameter scrubbers at the Saltley works, and, beyond daily regulation of the water flow, requires very little attention. Three distributors are fixed in each of the apparatus referred to. The liquor overflows at the bottom of the scrubbers, through the ordinary seal-pot arrangement.

If liquor is employed, care should be taken to have the overhead liquor tanks perfectly air tight, to prevent loss of ammonia through evaporation and agitation. The temperatures should be controlled, and maintained as nearly as possible at 60° Fahr. Where deep well water is available, it is an advantage to use this in the summer months, as its temperature will, in all probability, be found to be lower than that of the town supply. (This has been my experience.) At the Saltley works, well water is employed in the summer, on the finishing scrubber, and town water in the winter months. Well water would be used all the year round, for economical reasons; but trouble has been experienced with incrustation or precipitation, owing to the softening action of the ammonia. Hence the reason for not employing it for longer periods. There is, however, a decided advantage in using it in the summer, on account of its greater power for absorbing ammonia, due to its low temperature.

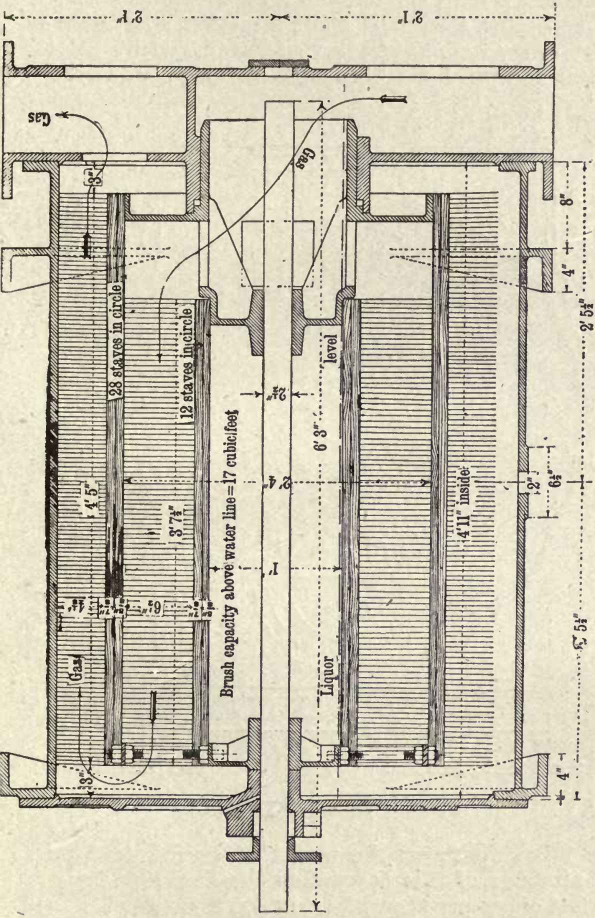
Rotary Washer-Scrubbers.

A very simple and efficient mechanical washer-scrubber was that known as the Anderson scrubber, which consisted of a tower divided into separate compartments, in each of which a drum of whalebone fibre was fitted, and revolved by suitable gearing. The drums exactly fitted the spaces allotted to them, and, when revolved, dipped into the liquor contained in the several compartments of the scrubber, while the gas passed through the wetted fibres and escaped from a lower to a higher compartment, through an uptake fitted to the side plates, where it met another brush, which revolved in the opposite direction to the one in the compartment below. This scrubber was fitted with a washer at the base. It was a very simple arrangement, and was improved upon by Mr. Creeke, of Messrs. Henry Balfour and Co., of Leven, Fife.

Creeke's Annular Brush Scrubber.

When first put on the market, Creeke's brush scrubber consisted of two or more steel cylinders with closed ends, placed horizontally and arranged one above the other. Each was provided with a gas inlet port at the centre and one end, while, at a lower level, and on either side of the inlet, were provided two outlet ports. The outlets in the lower cylinder communicated, by means of suitable connecting pipes, with the inlet of the cylinder immediately above. In each of the cylinders a compound or annular brush was fitted, formed with a cast-iron ring at either end and secured to a central shaft carried on suitable bearings at the end. The rings had two ledges—one at the outer circumference, the other at a suitable distance towards the centre—to which wooden staves were secured, and which, in turn, carried the fibrous scrubbing material ; thus forming two cylindrical brushes, one inside the other. The annular space between the brushes was in direct communication with the inlet port at the end of the containing cylinder, the other end of the annular space being left open ; but both ends of the drum on which the inner brush was fixed were closed gas-tight.

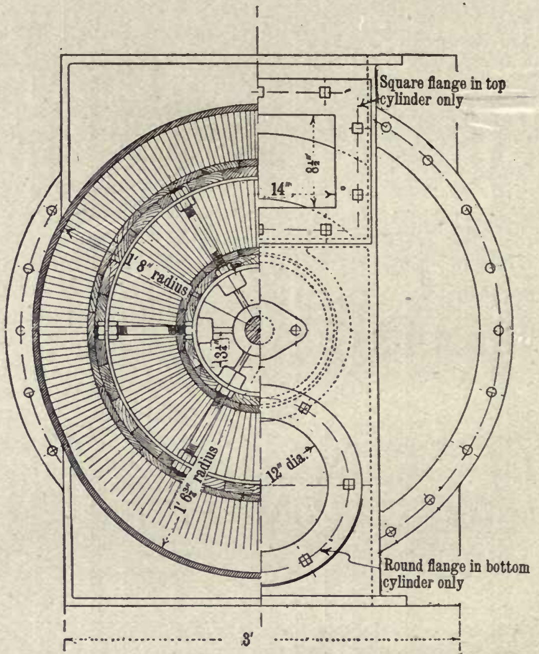
The apparatus worked as follows :—From the inlet, the gas passed along through the inner annular space, escaping at the end, whence it returned along the surface of the outer brush, through the annular space, and down to the outlet ports, and so was conducted to the inlet of the brush immediately above it, where it passed along the annular space, and so on over the outer brush to the outlets, as before, until finally leaving the scrubber at the main outlet. Each cylinder was filled with liquor up to the level of the inlet mouths of the inner brushes, which acted as overflows, allowing it to run in rotation from the top to the bottom brush. The brushes revolved in the liquor, and were constantly presenting wetted surfaces to the gas. The foul gas entered the bottom of the first cylinder, and was met by the strongest liquor, and brought in contact with clean water at the top cylinder. In the early type described, the brushes were revolved by means of Ley's patent chain gearing ; and the lower brush made two revolutions to each revolution of the upper brushes. Since its early days, this scrubber has been



Sectional Side Elevation.

CREEKE'S WASHER-SCRUBBER.

considerably modified; and in those made to-day, the gas passes up a casing at one end of the vessel, instead of through pipes leading from the outlet ports previously referred to, and bevel gearing has taken the place of the chain drive. I have entered into a rather full description of this apparatus, since it is really a modern adaptation of the first rotary washer-scrubber, as introduced by Mr. G. Anderson, and which is still capable of doing good work.



Sectional End Elevation. End Elevation.

CREEKE'S WASHER-SCRUBBER.

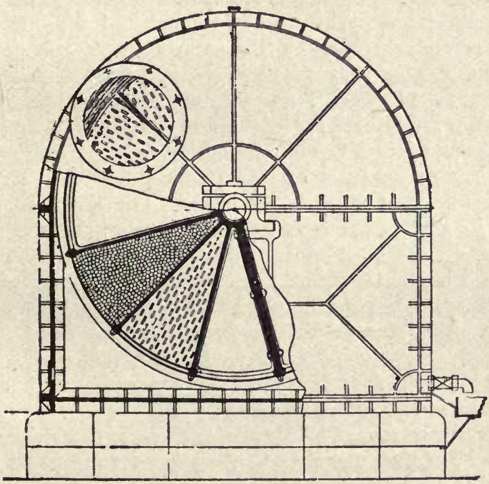
The following shows the results of several tests on a brush scrubber of this description, dealing with 800,000 cubic feet of gas per twenty-four hours, from which it will be seen that strong liquor can be produced and the gas entirely freed from ammonia.

Gallons of water per ton of coal carbonized:	12	11	10	
Division.	Ozs.	Ozs.	Ozs.	
In washer	13·8	16·0	18·0	Percentage efficiency for ammonia, sulphuretted hydrogen, and carbon dioxide not tested; but clean tests with litmus and turmeric papers were obtained.
1st brush	11·8	14·0	15·2	
2nd ,,	4·3	5·4	7·4	
3rd ,,	1·1	2·2	3·0	
4th ,,	0·3	0·4	0·8	
5th ,,	—	—	0·1	

The drawings show one complete cylinder, from which it will be noticed that additional cylinders may be easily added when required.

Laycock and Clapham's "Eclipse" Washer-Scrubber.

This washer-scrubber is of the horizontal rotary type; the previous mechanical washer-scrubbers described being



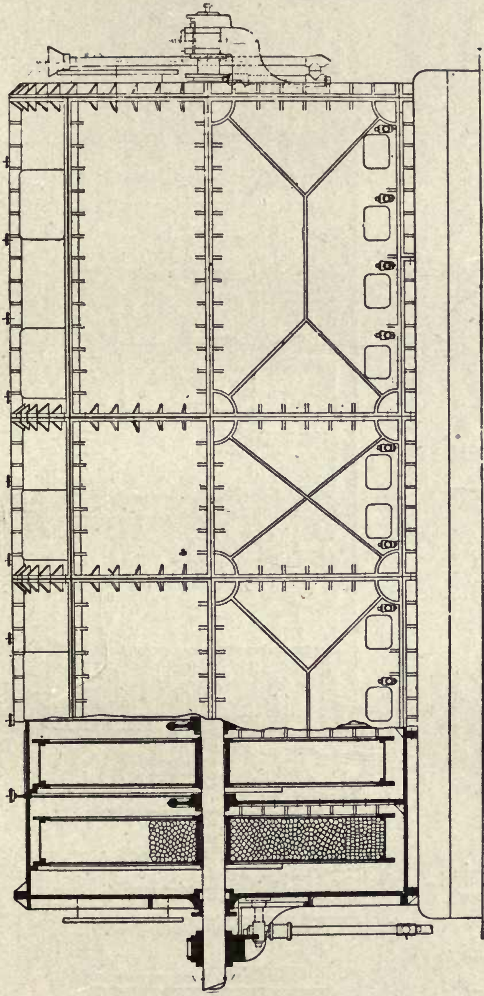
End Elevation (Part Section).

LAYCOCK AND CLAPHAM'S PATENT "ECLIPSE" WASHER-SCRUBBER.

of the vertical type. The "Eclipse" washer-scrubber is made by Messrs. Clapham Brothers, of Keighley, and consists of a cast-iron vessel with semi-circular top, built up in segments; the bottom portion of the vessel being divided into internal chambers by cast-iron plates, in which cylinders keyed to a steel shaft running from end to end of the apparatus revolve. The shaft is carried on bearings fixed on each end plate, and by other bearings fixed to the division plates forming the chambers. The outer edges of the cylinders are faced, and run against similar facings inside the case, which prevents slip of gas from one chamber to another, and compels the gas to pass through the cylinders, which are filled with wood balls about $1\frac{1}{4}$ to 2 inches diameter (depending upon the capacity of the machine), bored with a $\frac{1}{2}$-inch hole in the centre.

These balls are continually wetted with liquor, which is picked up from the bottom part of the washer by perforated buckets fixed to the peripheries of the revolving chambers, in one make of washer, while in another type the liquor passes through openings in the side plates of the revolving drums, thus ensuring a constantly wetted washing area being presented to the gas. The weak part about washers of this description is the liability of slip of gas taking place; and the makers of the "Eclipse" got over this difficulty by fitting a tail-pin to keep the facings of the revolving cylinders in contact with the case. The washer may be driven in any ordinary way—belt-driven or direct driven—but in machines of recent make worm gearing enclosed in a cast-iron box is fitted, being direct driven by a specially designed small engine, mounted on the same bed-plate. I am informed that an "Eclipse" machine has been in constant work since the year 1891, and has not cost a penny for repairs; which speaks well for the quality of material and workmanship employed.

I might mention at this point, and to save repetition, that it is usual, in the rotary types of washer-scrubbers, to supply the same with clean water at the gas outlet end, which, after entering the washer, overflows from chamber to chamber, gradually getting stronger and stronger, and overflows at the end where the gas enters the apparatus.



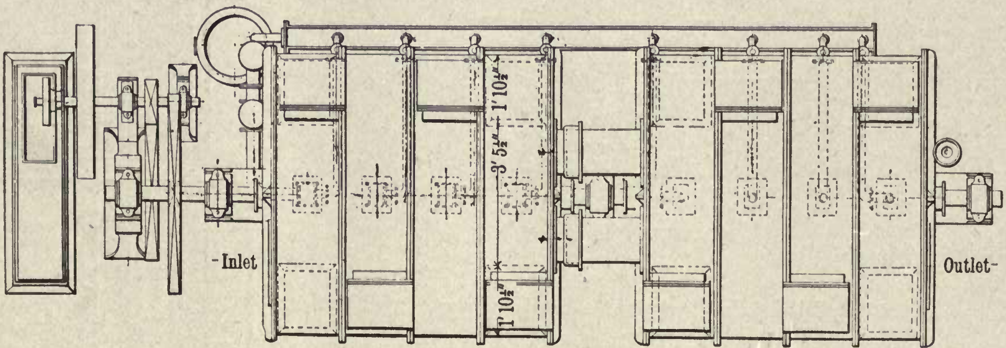
Side Elevation (Part Section).

LAYCOCK AND CLAPHAM'S PATENT "ECLIPSE" WASHER-SCRUBBER.

These washer-scrubbers are also fitted with "draw-off" or sludge cocks, and in some cases with hydrometers under glass cases, to enable the strength of the overflow liquor to be noted.

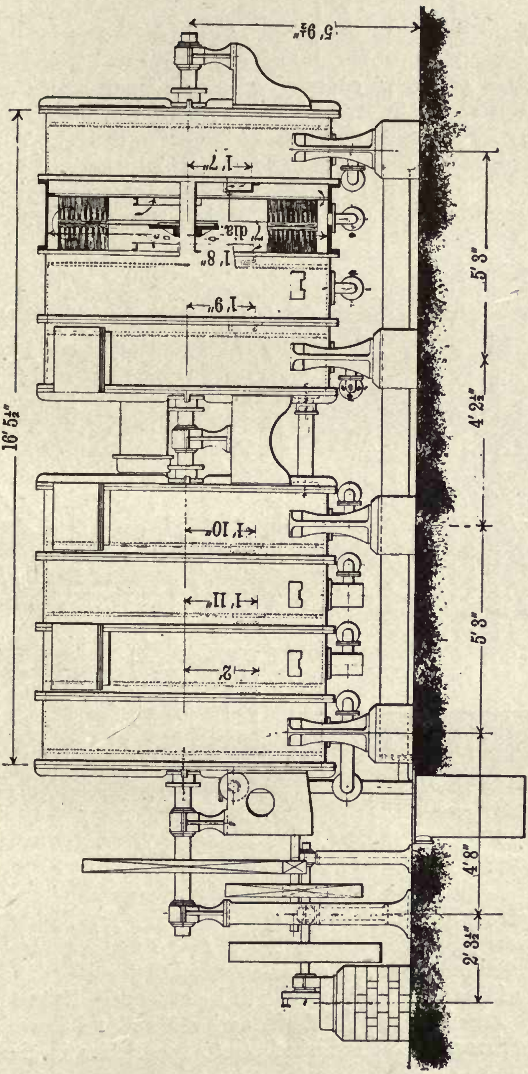
W. C. Holmes and Co.'s Washer-Scrubber.

This is another type of horizontal rotary washer-scrubber, and consists of a cylindrical outer case composed of cast-iron



Plan.

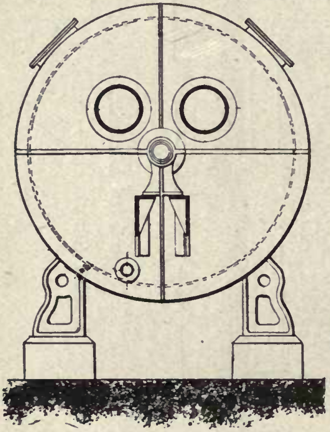
HOLMES' ROTARY SCRUBBER-WASHER.



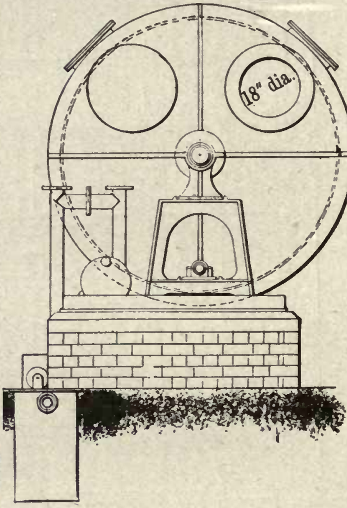
Side Sectional Elevation.

HOLMES' SCRUBBER-WASHER.

plates, divided into separate chambers, as in the "Eclipse" washer-scrubber, by means of vertical cast-iron plates; each chamber containing ammoniacal liquor as before. Inside, a number of $\frac{1}{4}$-inch wrought-iron plates are ranged, fixed alternately between the flanges of the cylinders and to the driving shaft running from end to end of the apparatus. This shaft is supported on brackets carrying bearings outside each end plate, and, in the older types,

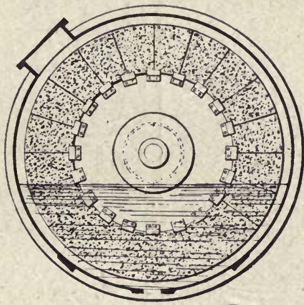


End Elevation.
HOLMES' ROTARY SCRUBBER-WASHER.



End Elevation.
HOLMES' ROTARY SCRUBBER-WASHER.

by another in the centre of the washer-scrubber carried on a cast-iron standard; but in recent machines an outside bearing is arranged, the washer being made in two halves and connected together by a gas-connecting piece. The advantage of the outside bearings will be obvious. To the iron plates attached to the shaft, and referred to above, circular brushes are fixed, which dip into the liquor in the lower portion of the washer and revolve with the shaft, and constantly supply freshly wetted surfaces to the gas, through which brushwood the gas has to pass before reaching the outlet. These brushes contain an enormous area of washing surface, and occupy a very small space. The cost of the brushes for renewal is, however, somewhat heavy; but this is of small account with so efficient an apparatus (99 per cent. efficiency). The method adopted in this washer-scrubber to prevent slip is to set the brushes to give a $\frac{1}{4}$-inch thrust on each of the division plates. Between the washing chambers in some of the designs of this washer-scrubber, annular spaces are arranged, which the makers say enable the liquid to be worked up to a greater strength, these spaces being known as "still" chambers.



Detail of Brushes.

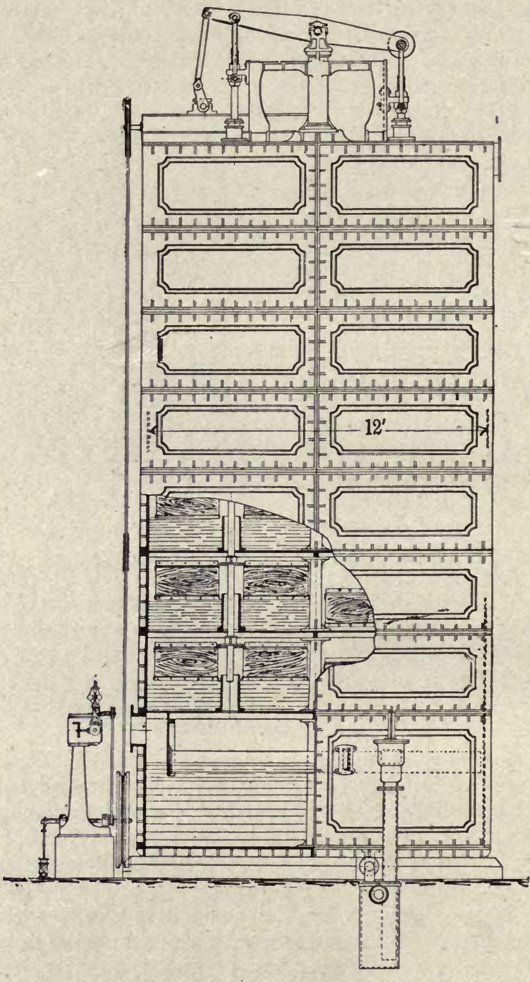
HOLMES' ROTARY SCRUBBER-WASHER.

Messrs. Holmes also make a vertical rotary scrubber-washer for works where ground space is a consideration. This is very similar to the Anderson type, and need not take up any more of our time.

Walker's Purifying Machine.

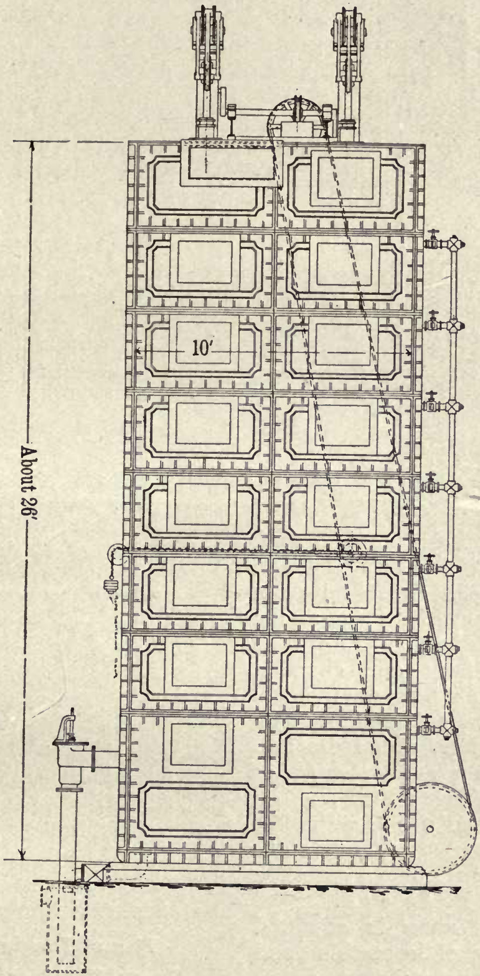
This machine, as made by Messrs. C. and W. Walker, Limited of Donnington, differs entirely from all other ammonia washing plants. It consists of a rectangular cast-iron vessel, and in some cases is fitted with a washer of Walker's design in the lower part. This washer has previously been described.

After leaving the washer, the gas enters the "purifying machine" proper, which is built up of six or more chambers, in which movable wooden boxes, or what the makers term "devices," are attached to vertical shafts, connected to rocking beams at the top of the machine, which are worked



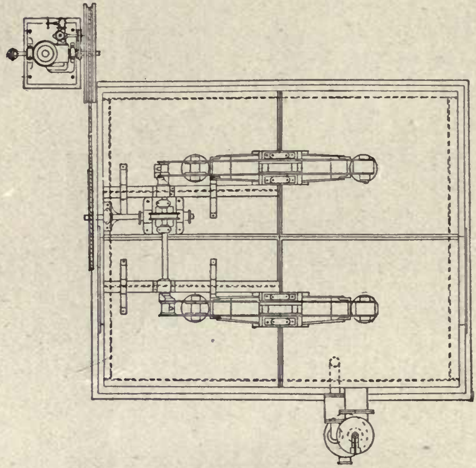
Side Sectional Elevation.

C. AND W. WALKER'S PATENT PURIFYING MACHINE.



End Elevation

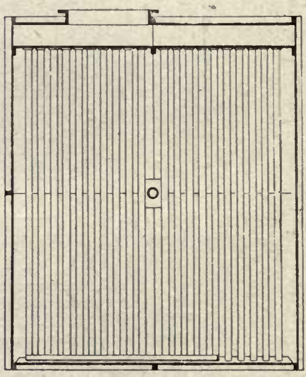
C. and W. Walker's Purifying Machine.



Plan of Machinery.

C. AND W. WALKER'S PURIFYING MACHINE.

by an outside vertical shaft and bevel gearing, and driven by a small horizontal steam engine, usually fixed at the ground level. The gas travels from one chamber to another between the constantly wetted boards forming the devices, which dip into the liquor at one stroke of the rocking beam, and on the return stroke are pulled up from the same to come into contact with the gas.



Plan of Troughs.

C. AND W. WALKER'S PURIFYING MACHINE.

Clean water is admitted at the top of the machine, and flows downward from chamber to chamber, finally overflowing as a strong ammoniacal liquor. This arrangement is adopted when the machine is employed as a finishing washer or scrubber; but when followed by another washing or scrubbing apparatus, liquor should be used in place of water. Such is the arrangement at Saltley, where, in one section of the works, a Walker's purifying machine, dealing with 5,000,000 cubic feet per day, precedes a 20 feet diameter tower scrubber, and deals with gas which has previously been treated in a Young's washer.

The power required for driving the necessary gearing is small. The machine works very efficiently, and requires little attention beyond the daily running off of any tar which may have been arrested, adjusting the seals, and regulating the water or liquor used.

The whole arrangement of washing devices, gearing, etc., is illustrated in the drawings, and calls for no further remarks here, beyond saying that rope-driving arrangements are shown in this case.

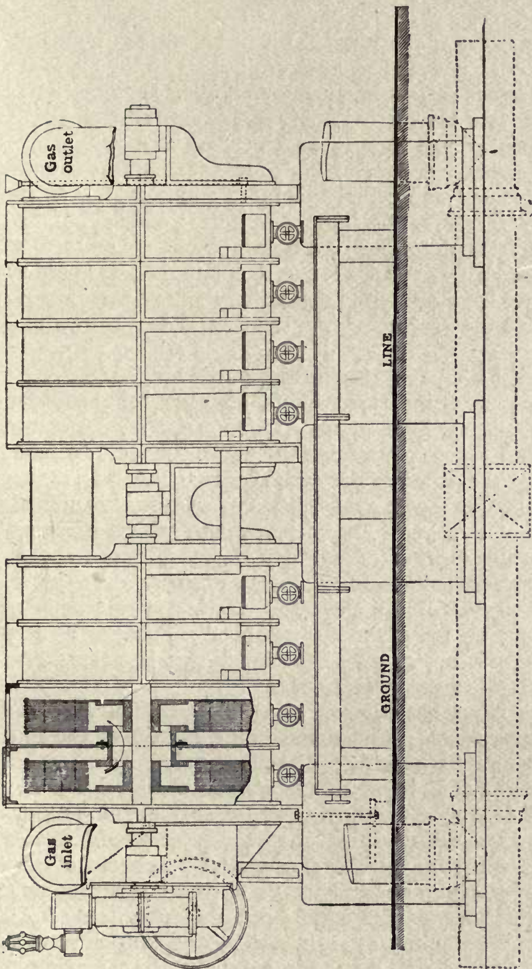
The Whessoe Rotary Washer-Scrubber.

This washer-scrubber consists of a cylindrical outer vessel, divided into separate chambers as described in the other rotary types, fitted with a horizontal shaft carried in suitable end plates and internal bearings; the shaft being fitted with washing devices or bundles built up in segmental clusters of sheet steel (or thin boards if preferred) and the spaces maintained by wooden washers or distance pieces, the bundles held taut and rigid by bolts securing the same to the sheet-iron side plates of the washing drum. In this washer-scrubber, the end plates are made ◠-shaped, and extend the whole length of the pier. This affords great rigidity, and prevents side rock or oscillation, and dispenses with cradles. The provision made for the connections might be specially mentioned, and consists of a cast-iron box bolted to the end plate, through which the driving shaft passes, suitably carried in a stuffing-box. The side, top, and bottom plates of the "universal connection box" referred to are cast with holes, so that the connections may be made in any of these positions; blank flanges being provided for the remaining plates. This is a great convenience, and does away with bends, which are liable to become choked with naphthalene. The connections, may, however, be arranged, if desired, without the universal connection box.

A recent Whessoe improvement consists of a central driving arrangement of spur gearing direct driven; all bearings being in sight, and the washer-scrubber compartments arranged on the twin method—namely, isolated, and connected with gas-way connecting pipes. The advantages claimed for such method of driving are:—(1) Reduced cost of shaft (being central driven, is subjected to less tension, and therefore can be of smaller diameter). (2) Central instead of end strain. (3) Liability of breakdown reduced by 50 per cent. (4) Cost of repairs reduced by 50 per cent. (5) One-half of the machine available for work while the other half is under repair, if connections are so arranged. (6) Exposed bearings.

Kirkham, Hulett, and Chandler's "Standard" Washer-Scrubber.

The earlier make of this type of machine consisted of a ◠-shaped cast-iron tank containing several water compartments, in each of which metal discs were caused to revolve. The discs were made up to about 60 in number in each compartment, fitted together in the form of a sheaf. The surfaces of the discs were indented to a depth of an eighth of an inch, in order to present roughened surfaces to the gas and to keep the discs apart, or, in other words, to act as distance pieces. Each sheaf of discs was suspended from a central shaft supported in the usual manner, the lower portion being immersed in the liquor. The remainder of the apparatus was practically as it is known at the present time. After some little time, the metal discs were discarded, and wooden bundles substituted, the efficiency of the machine being considerably increased. The chief advantages claimed for the new arrangement are: (1) The driving shaft of the washer-scrubber greatly relieved of weight. (2) Less wear and tear. (3) Smaller driving



Side Sectional Elevation.

"STANDARD" WASHER-SCRUBBER.

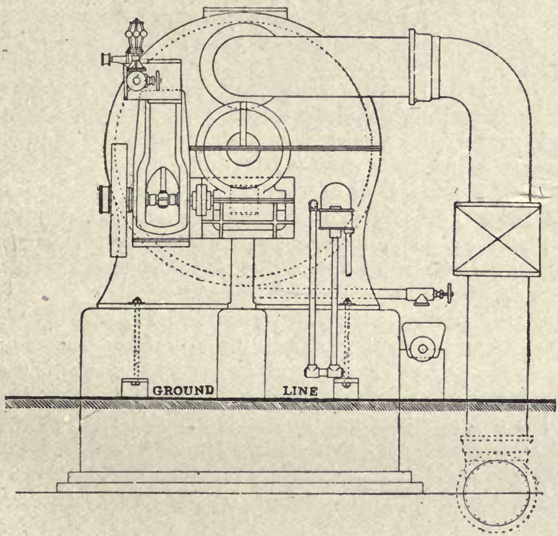
power required. (4) Washing surfaces kept cleaner and free from deposit.

The improved "Standard" washer-scrubber as manufactured to-day is much in advance of the older machine; many important improvements having recently been introduced. It now consists of a horizontal cylindrical vessel divided into compartments by vertical division plates, having circular openings in the centre through which the gas passes from one compartment to another, after being washed or scrubbed by the revolving wooden bundles referred to above. The scrubbing bundles consist of wooden boards $\frac{1}{8}$-inch thick, spaced about $\frac{3}{16}$-inch apart by distance pieces, attached to a light wrought-iron frame; the whole being secured to the shaft by a key driven in a cast-iron collar.

The effectiveness of this washer-scrubber depends to a great extent upon the faced joints between the revolving collars and the division plates. The recent machines are made in two halves, connected by a gas connecting main. All bearings are arranged for easy access; and the washing bundles may be obtained in different patterns to suit all conditions of working. One arrangement which is recommended is in the form of corrugated wrought-iron sheets, the corrugations of alternate sheets crossing each other. This arrangement provides the maximum amount of washing surface for "bundle" washers. The gas is very thoroughly split up, zig-zags between the corrugations, and the water is thoroughly distributed.

Another important improvement is to be found in the driving arrangement; the engine being bolted to the end plate of the washer-scrubber, directly coupled by means of a worm and worm-wheel to the washer shaft. With this method of driving, ground space and cost of engine foundations are saved; also silent running is ensured. I had experience with one of the first washer-scrubbers of this new design, which was erected at Bath, where it is used as a finishing scrubber, dealing with 3,000,000 cubic feet of gas per twenty-four hours, after it has passed through three vertical or tower scrubbers. It is worked at the "maximum make" period; the connections being so arranged to enable the gas to be put through a Cockey washer during the "minimum make" period, and so allows first one and then the other to be let down for cleaning, which process enables all washers, scrubbers, or washer-scrubbers to be maintained in a thoroughly efficient manner. This is of the very utmost importance, if every advantage is to be taken in the recovery of ammonia, to swell the revenue account by this by-product.

A study of the workings of the various gas undertakings shows a very considerable difference in the returns for ammonia in the form of ammoniacal liquor, concentrated ammoniacal liquor, or sulphate of ammonia—the three



End Elevation.

"STANDARD" WASHER-SCRUBBER.

principal forms into which the ammonia is converted in gas-works. Some undertakings only receive ¾d. and even less for ammonia products per thousand cubic feet of gas sold, while others obtain nearly 4d., showing the necessity for some levelling up. There are, of course, matters which enter into the great difference in the returns shown, such as the amount of ammonia evolved from the various kinds of coal carbonized, the wages paid for labour in the different districts (which varies considerably), and also the strength to which the liquor is worked up. It should here be stated that the receipts from ammonia products, as well as those for other residuals, in undertakings manufacturing water gas must be lower per thousand cubic feet of gas sold than in those who manufacture coal gas only, and are therefore not comparable; but the figures quoted above apply to works manufacturing coal gas only.

S. B. Chandler's Double Action Rotary Washer-Scrubber.

Another, and recently patented, apparatus is that known as S. B. Chandler's double action rotary washer-scrubber. This is very similar to other rotary machines. The principal difference is in the washing bundles, which, in this case, consist of several thin iron plates punched all over with small holes, the edges being left in a ragged condition. The plates are bolted together, with distance pieces between them, in the usual manner. The holes are punched in the plates on the "hit-and-miss" principle; alternate plates having the perforations in the same position. By this means, the gas is made to pass through the bundles in a more or less zig-zag course, and is brought in contact with a very great area of wetted surface. The idea is a good one; but I am under the impression that such bundles would quickly make up with naphthalene, and be rather difficult to clear, except by excessive steaming. This is to be avoided, since ammonia would be liberated and driven forward.

I have now dealt with all the well-known and tried types of washers, scrubbers, and washer-scrubbers; but this paper would not be complete if reference were not made to those new appliances from which much is expected in the future, both as regards first cost and working efficiency.

There yet remain three other washers or scrubbers to which reference must be made—namely, the Feld vertical centrifugal, the Kirkham vertical centrifugal, and Burstall's gas washer; which will be taken in the order named.

Feld's Centrifugal Washer.

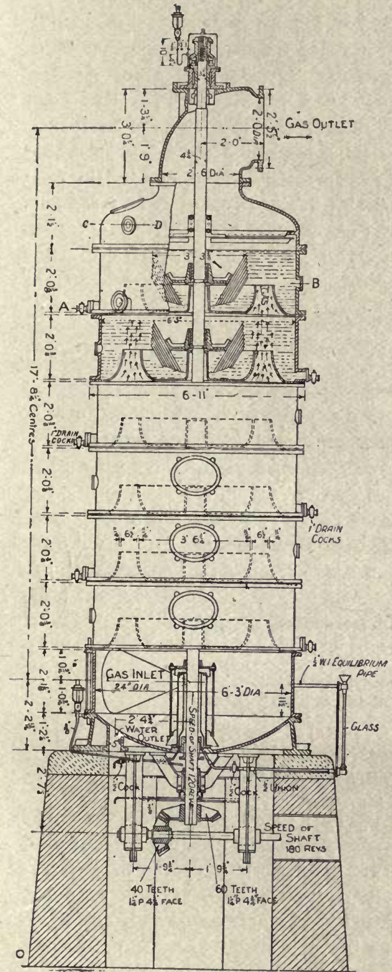
This washer is different in every respect from those previously described, and is the invention of a German chemist—Dr. Feld. It is manufactured by Messrs. R. and J. Dempster, Limited, of Manchester, who have secured the rights of sole manufacturers for Great Britain and the Colonies.

The details of the design and arrangement of the apparatus are shown in the drawings, from which it will be seen that it is of the vertical type, made up of a number of cast-iron chambers or sections of similar construction, cylindrical in form, fixed one above the other, the number of chambers varying according to the required washing capacity. A central shaft is fitted vertically, working in roller bearings, and supported at the bottom of the washer by suitable cast-iron brackets. It is driven by bevel wheels keyed to the lower end and to a horizontal driving shaft, as shown, or by fast-and-loose pulleys. In fact, any ordinary arrangement of drive may be employed. The power required for driving is very small—a washer capable of dealing with 1,000,000 cubic feet of gas per twenty-four hours only requiring a two horse-power engine. To the central shaft, sets of cones are keyed, each set consisting of six to twelve plates placed one inside the other, one set to each chamber or section. The lower ends of the cones dip into the dish-shaped casting containing the washing fluid —water or ammoniacal liquor. In the latest design, only four cones make up a set; the outer one being slotted and somewhat deeper than the others, by which a better spray is obtained. Four or more openings are arranged in the dish-shaped liquor containers, through which the gas may pass upward from chamber to chamber against the downward flow of excess liquor on its way to the outlet.

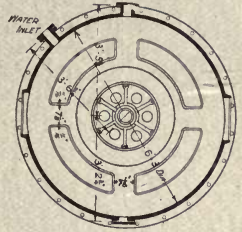
When the washer is in action, the central shaft with the attached sets of cones, driven at the rate of 120 revolutions per minute, causes the liquor to be drawn up on the inside of the cones from the liquor containers, and thrown off at a tangent at the upper edges with great velocity across the gas-ways, and against the chamber walls, in the form of a thin spray or sheet of liquor; and it is through this that the gas has to pass, and by this it is washed. It will be seen that the gas and water are brought into contact with each other in such a way that very thorough washing is ensured—not merely by bringing the gas in contact with wetted areas, as in the horizontal rotary type of washer, but by actually passing the gas through a thin sheet of water or liquor; and this is done without an increase of back pressure—certainly not more than half an inch. A baffle or screening plate is fixed in the top of the washer, to prevent the spray being carried over; thus allowing the gas to pass away in a dry state.

The advantages claimed for this new washer are set out by the patentee as follows:—(1) Most intimate mixture of gas and washing liquid. (2) Highest possible efficiency, owing to exceedingly fine diffusion of washing liquid due to centrifugal force. (3) Throws practically no back pressure. (4) Lowest volume of washing medium required. (5) Concentrated liquors are obtained. (6) No clogging, even when working with muddy solutions. (7) Simple operation. (8) Small power required for driving. (9) Small space required. (10) Can be constructed in practically any capacity. It is very compact. Therefore, its first cost is low compared with other forms of scrubbers.

The dimensions of a washer designed to deal with 7,000,000 cubic feet of gas per twenty-four hours in six chambers are only 26 feet 1½ inches high by 6 feet 3 inches diameter. Such a washer is in use at Saltley, and has been running for two years; the cost of repairs being nil. This washer is employed for the extraction of cyanogen, but tests have been made to obtain its efficiency for ammonia extraction, which comes out at 99 per cent., making a 6 oz. liquor. No doubt better results could be obtained if arrangements had existed for pumping the liquor over and over, or if two washers had been worked in series to produce a stronger liquor. This, however, was not possible; but I think the tests will prove the efficiency of the washer,

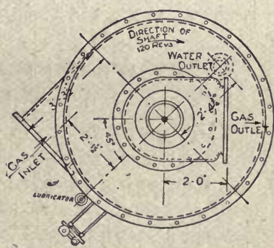


Sectional Elevation.



Section on Line A—B.

Section on Line C—D.



Plan.

FELD'S CENTRIFUGAL WASHER.

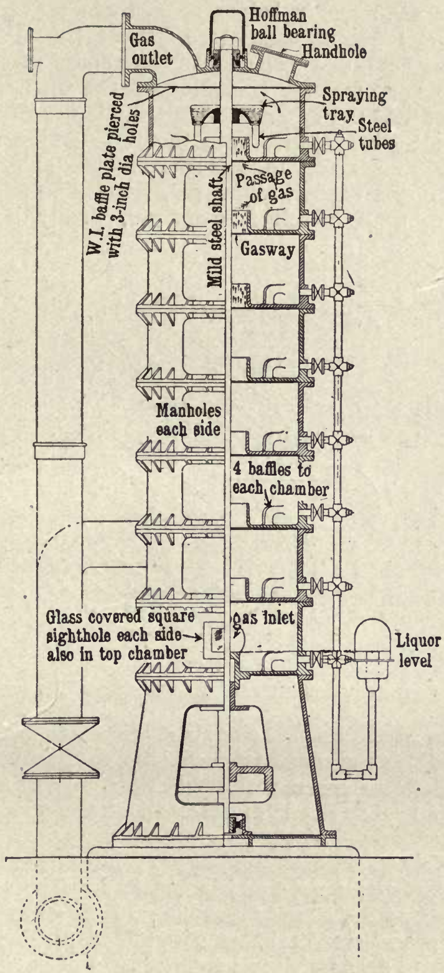
which no doubt has a great future before it, and may possibly revolutionize the existing methods of gas purification and by-products recovery. In fact, a plant on the Feld principle has already been put to work at the East Hull gasworks for the extraction of sulphuretted hydrogen from coal gas ; the active agent employed in the washers being zinc thiosulphate solution, which is made in the first instance by the action of sulphur dioxide on zinc sulphide, formed from zinc oxide and sulphuretted hydrogen. Two Feld washers are used in this system, and the reactions which take place are as follows :—

$$2ZnS + 3SO_2 = 2ZnS_2O_3 + S$$
$$2ZnS_2O_3 + 6H_2S = 2ZnS + 6H_2O + 8S.$$

Even further advance is proposed ; Dr. Feld being at present engaged in perfecting a process by which ammonia is to be removed from gases and converted into ammonium sulphate simultaneously with the removal of sulphuretted hydrogen. If this is found to be an efficient system, the days of the dry purifier will be short. Ammonia and sulphuretted hydrogen, the only impurities (not including naphthalene) which have to be eliminated (since the disappearance of the sulphur clauses), will then be dealt with in the same plant, the advantages of which will be obvious. These matters have been mentioned to show the possibilities of the Feld washer ; but further cannot be said at present, as no working results are available.

Kirkham, Hulett and Chandler's "Standard" Centrifugal Washer.

This machine is very similar in its action to the Feld washer described above. It consists of a vertical cylindrical cast-iron vessel, divided into a number of chambers, fitted with a central vertical shaft, to which are attached spraying devices for lifting and spraying the ammoniacal liquor or water used as a washing medium ; bringing it into intimate contact with the gas. The devices consist of specially-designed trays, having perforated rims and bent tubes (usually four in number) depending from their under sides.

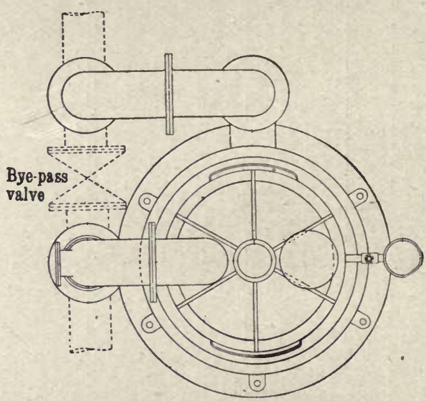


Sectional Elevation.

PATENT "STANDARD" CENTRIFUGAL WASHER.

The trays are made in halves, to facilitate taking apart for cleaning, if found necessary (see drawings).

The shaft and trays are revolved at a speed of 100 to 150 revolutions per minute, according to the diameter of the apparatus. As the devices revolve, the liquor is picked up by the bent tubes, carried into the trays and through the perforated rims, across the gas space to the plates forming the shell of the washer, rebounding and falling to the liquor container, from which it overflows, finally leaving the



Plan.

PATENT "STANDARD" CENTRIFUGAL WASHER.

apparatus at the bottom chamber. The gas enters at the base, and flows upwards from chamber to chamber, through the central openings and through the spray, finally leaving at the top. The liquor is admitted at the top, and flows downward through the central openings.

It is a very simple washer, requires little or no attention, the driving power necessary is small, its first cost is low compared with ordinary scrubbers, and great saving in ground space can be effected by its adoption; a washer designed to deal with 500,000 cubic feet of gas per twenty-four hours, working at the Hitchin gasworks, being only 3 feet in diameter by 17 feet high, over all.

Burstall's Washer.

This apparatus, which is a recent invention of Professor Burstall, of the Birmingham University, and which I was recently kindly allowed to inspect, is of very simple construction, very compact, and surprisingly small for dealing with any given quantity of gas per hour. The washer is mechanical, and consists of a cylindrical outer case, fitted with a horizontal central driving shaft, to which perforated plates are attached, and which are revolved at about fifty revolutions per minute. The end plates are fitted with the usual inlet and outlet pipes for gas and liquor. The perforations in alternate plates are arranged at the centre and at the periphery, respectively, and about $\frac{1}{8}$th inch clearance allowed between the edges of the plates and the casing of the washer; the seal being secured by the centrifugal action of the revolving plates on the liquor contained in the washer, and slip of gas rendered impossible. From the inlet the gas is made to pass through the washer, in a zig-zag fashion, flowing through a central perforation in one plate, then rising to the top portion to pass through another opening in the next plate, to again descend and rise between the plates until the outlet is reached, being brought into contact with wetted surfaces, and, consequently, cooled and washed.

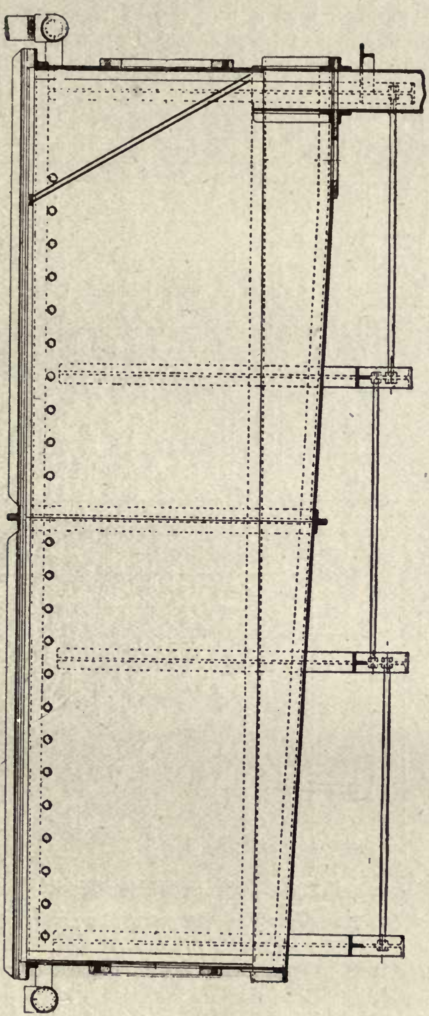
Professor Burstall explains that when washing ammonia from coal gas, it would be advisable to employ two such washers in series, and utilize them, not only for washing, but also for condensing purposes. The gas at the outlet of the first washer would probably be reduced to about 80° Fahr., and to 60° Fahr. in the second one. The liquor leaving No. 2 washer would flow into a bosh, from which it would be pumped and circulated through No. 1 washer, and the hot liquor from No. 1 pumped into an atmospheric condenser, from which it would flow to No. 2 washer, until it attained any predetermined strength, when it would be run off to the storage well, and a supply of clean water admitted, to take its place.

A washer to deal with 30,000 cubic feet of gas per hour would have the following dimensions:—3 feet 6 inches diameter by 3 feet 6 inches long, or about 5 feet long, including bearings and supporting standards.

Burstall's "*Static*" Washer (Non-*Mechanical*).

Professor Burstall has now invented a non-mechanical washer, designed to cool the gas and to recover the tar. But with some slight modification this has been recently installed in a gasworks to recover ammonia. This washer consists of a rectangular steel tank, fitted with a dished bottom, and supported upon a light framework, as shown in the drawings. The gas inlet and outlet connections are arranged in the end plates, and the overflow liquor taken from the deeper end of the washer. The "Static" washer is 3 feet 4 inches deep at one end and 3 feet 7 inches deep at the other, to which end the tar flows, and from which it is drawn off. Under the top cover plate, and spanning across the washer, a number of $\frac{13}{16}$ inch by $\frac{13}{16}$-inch inverted steel channels are arranged, and supported by the side plates, as shown in the enlarged cross section. Into the channels wires are cast (the wires are placed into position in the channels before the latter are fixed, and molten lead run in) and the channels closed in between the wires, as shown on the drawings. The number of wires in each channel or section number fifty-eight and fifty-nine alternately, and are arranged in the sections so that those in one section come opposite spaces in the next section (see detail drawing). The number of sections in the washer shown, which has been designed to deal with 50,000 cubic feet per hour, is 117.

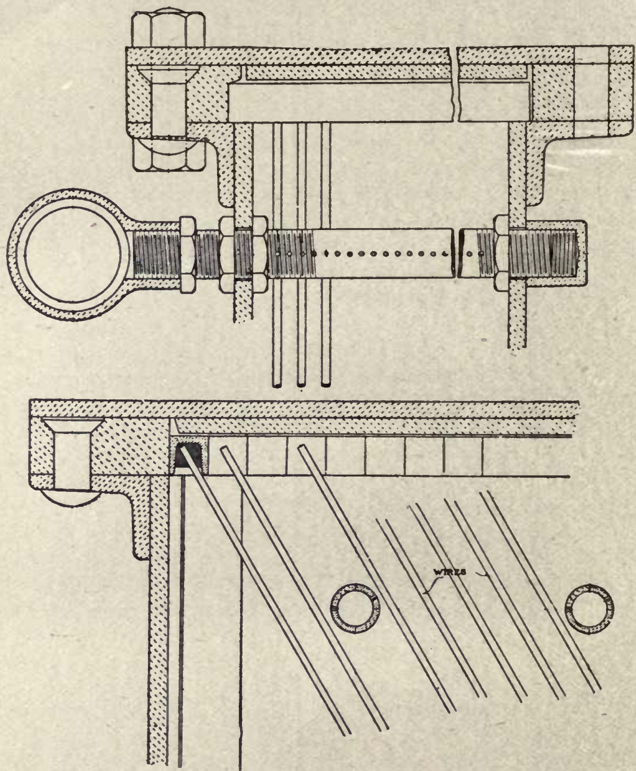
Around the top of the washer, water-supply pipes are fitted, from which several branches are taken and carried internally across the washer. Holes, $\frac{1}{16}$-inch in diameter by $\frac{1}{4}$-inch pitch, are pierced in the cross water tubes, in the positions shown; and as the water is supplied at a fair pressure, jets of water are caused to impinge upon the wires, and to form thin sheets, through which the gas is made to pass, and it is also brought into contact with the large number of wetted wires (about 6,780) contained in the washer. When used for ammonia recovery, the



Side Elevation.

"Static" Gas Washer and Cooler.

apparatus is divided into a number of separate compartments, connected by gas passages, and the liquor caused to pass from one to the other, by means of a small pump,



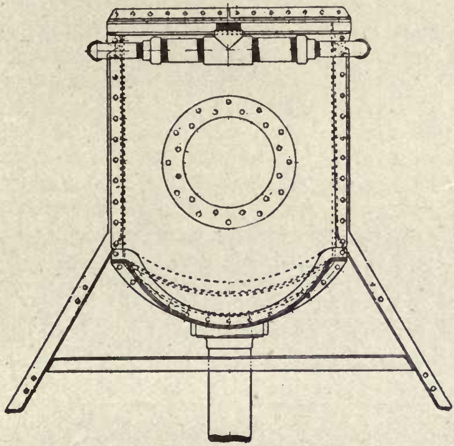
Details of Wire Holder and Water Pipes.

"STATIC" GAS WASHER AND COOLER.

becoming stronger in ammonia as it passes through the washer.

The advantages claimed for this washer are :—(1) It has no moving parts. (2) It is very compact. (3) It does not clog with tar.

The illustrations show a washer designed to extract tar;



End Elevation.

"STATIC" GAS WASHER AND COOLER.

but it will serve to show the general arrangement of the ammonia washer.

Burkheiser's Washing Process.

I would like to draw your attention to a recently patented process which appears to me to have a great future before it. I refer to Burkheiser's process for washing and purifying gases, in which it is intended to (1) absorb sulphuretted hydrogen by means of ferric hydrate; (2) revivify the fouled material and form sulphur dioxide; (3) form ammonium bisulphite from the sulphur dioxide and a solution of ammonium sulphite; (4) form ammonium sulphite by the taking up of ammonia by the solution of ammonium bisulphite; and (5) to effect the oxidation of the ammonium sulphite to ammonium sulphate. Further particulars cannot be given here, but a full description may be found in the "Journal of Gas Lighting" for 4th October 1910, to which I would draw your attention.

Weekly Tests on Plant.

Weekly tests on the outlet of the finishing scrubbers should be taken for the amount of ammonia passing in grains per 100 cubic feet of gas, and the amount calculated as so much 10-oz. liquor lost, to enable comparisons to be made of the working over any extended period. This method is to be preferred to that which simply shows the ammonia which is not eliminated, for this does not take into account the quantity of gas dealt with, and, therefore, the quantity of ammonia lost for comparative purposes.

The calculation is made as follows:—

$$\frac{\text{Make of gas for week}}{100} \times \text{loss of } NH_3 \text{ in grains} = \text{total}$$

grains of NH_3 lost.

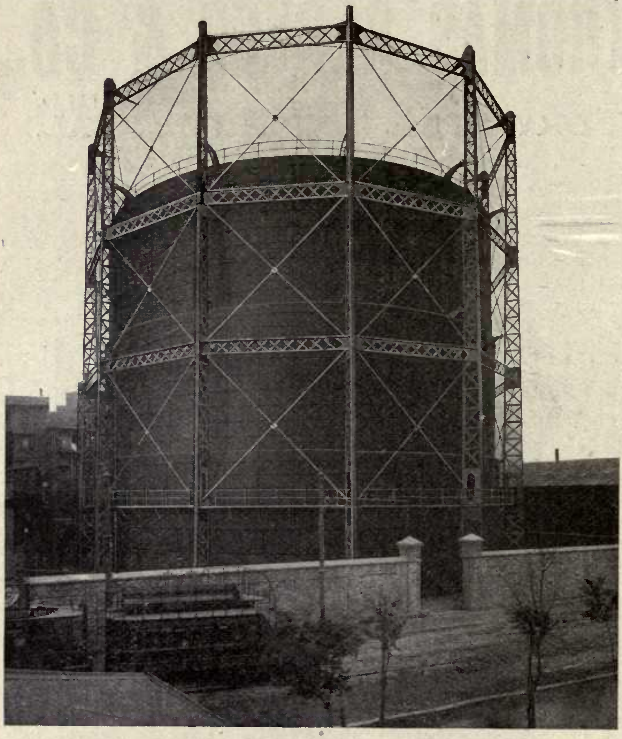
$$\therefore \frac{\text{Total grains } NH_3 \text{ lost}}{1522 \text{ (grains } NH_3 \text{ in 1 gallon 10-oz. liquor)}} = \text{Quantity}$$

of 10-oz. liquor lost, in gallons.

The recovery of ammonia and its conversion into ammonium sulphate in the same apparatus appears to me to be the next advance in gasworks economies, by which a saving of as much as £2 per ton of sulphate made should be obtained, thus:—

	£	s.	d.
Fuel	0	10	0
Manufacturing wages	0	6	0
Stores (manufacture)	0	0	3
Stores (repairs)	0	12	0
Wages (repairs)	0	7	0
	£1	15	3

To this must be added the saving in interest and redemption on lower capital expenditure on plant; making, roughly, a saving of £2 per ton of sulphate produced.



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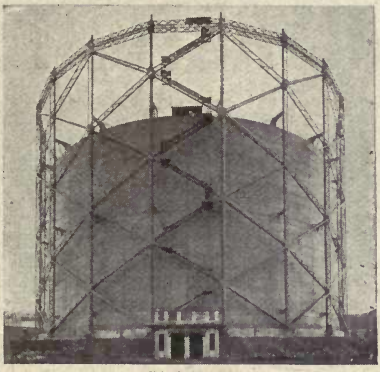

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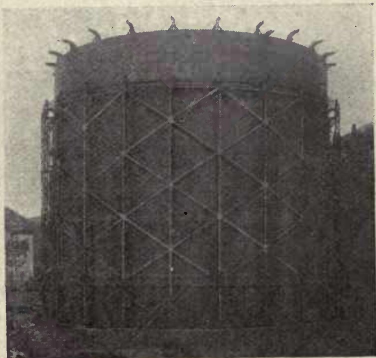

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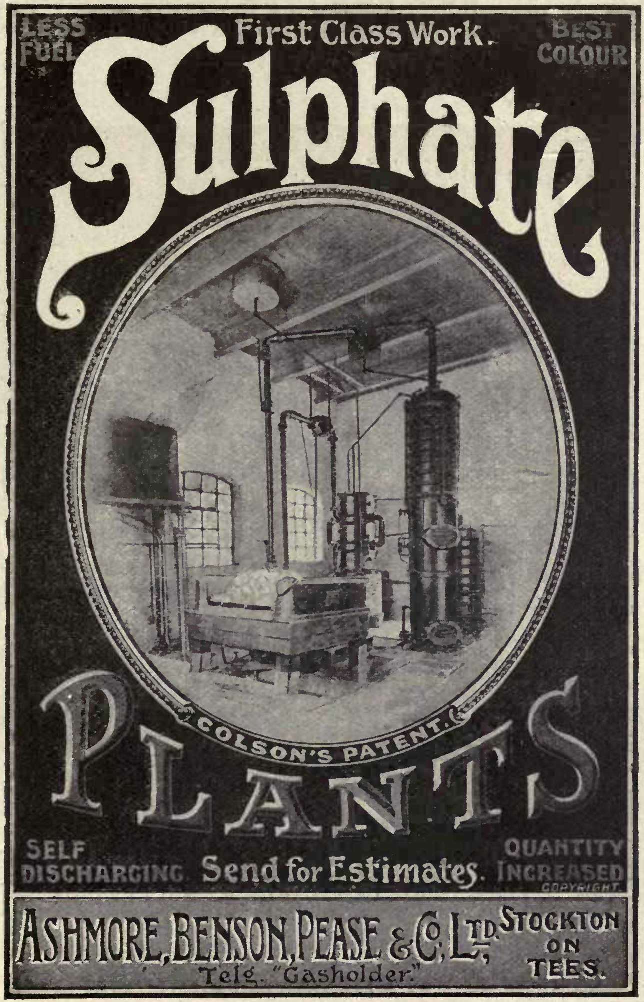
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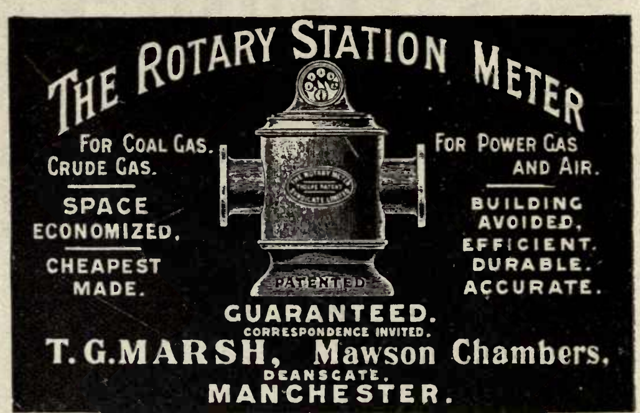

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