Self-Instruction For Students in Gas Engineering:

Advanced.

Gas Engineering

SELF-INSTRUCTION FOR STUDENTS
IN
GAS ENGINEERING:
ADVANCED.

Self-Instruction For Students in Gas Engineering.

BEING

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

By "MENTOR."

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Gas Eng.

PREFACE.

THIS book, which now enters upon a third edition, deals with such subjects as come within the scope of the syllabus for the Honours Grade examination in Gas Engineering held annually by the City and Guilds of London Institute, and is complementary to the "Elementary" book (by the same author)*, which covers the syllabus for the Ordinary Grade examination. In the case of students preparing for the Honours examination, it is, therefore, essential that both books should be studied.

The object of the book is to guide the student and not to "cram" him. Indeed, "cramming" in an examination of this kind is not to be thought of; for the questions set are generally of such a character that the least evidence of mere memory work is almost certainly detected—to the disadvantage of the examinee. The theory upon which the book is based is that if the student has studied sufficiently to enable him to satisfactorily answer the questions set in its pages, he need not much fear the ten which will be set him by the examiner. The reader should therefore attend to the questions first, and

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*"Self-Instruction for Students in Gas Engineering—Elementary."—GAS WORLD Offices. Price 3s. 6d.

test his knowledge by attempting answers without consulting the answers given in the book. When he comes to a question upon which he is obviously weak, he should read up that particular subject until he is satisfied that he has got such a grasp of it as will enable him to give a satisfactory answer. In the answers given there will be found much information not to be found in the general text-books.

The standard works recommended for use with "Self-Instruction" 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"; Calvert's "Manufacture of Sulphate of Ammonia"; Lunge's "Coal Tar and Ammonia"; Arnold's "Ammonia and Ammonium Compounds"; Brackenbury's "Modern Methods of Saving Labour in Gasworks"; Butterfield's "Chemistry of Gas Manufacture"; and Brooke's "Construction and Working of Modern Retort Settings." The prices of the books mentioned will be found in the advertisements on pages 260 and 261. Where expense is an object, the student should be able to give a good account of himself with the aid of "Newbigging" and "Hornby."

CONTENTS.

CHAPTER I.

COALS, AND THE METHODS OF TESTING THEM.

CHAPTER II.

EFFECT OF TEMPERATURE IN CARBONIZATION.

CHAPTER III.

COMPOSITION OF COAL GAS.

CHAPTER IV.

TESTING FOR IMPURITIES.

CHAPTER V.

GAS ANALYSIS.

CHAPTER VI.

HEATING OF RETORT SETTINGS.

CHAPTER VII.

PHOTOMETRY, CALORIMETRY AND PYROMETRY.

CHAPTER VIII.

CARBURETTED WATER GAS.

CHAPTER IX.

SULPHATE OF AMMONIA MANUFACTURE.

CHAPTER X.

LABOUR-SAVING MACHINERY.

CHAPTER XI.

INCLINED AND VERTICAL RETORTS.

CHAPTER XII.

CARBURATION AND NAPHTHALENE.

CHAPTER XIII.

CYANOGEN RECOVERY AND PURIFICATION.

CHAPTER XIV.

GASHOLDER CONSTRUCTION.

CHAPTER XV.

POINTS IN MANAGEMENT.

CHAPTER XVI.

DELIVERY OF GAS THROUGH MAINS.

APPENDIX.

SELF-INSTRUCTION IN GAS ENGINEERING.

HONOURS GRADE QUESTIONS.

CHAPTER I.

COALS, AND THE METHODS OF TESTING THEM.

(1) State the distinguishing features of the principal coals used in gasmaking. Compare their chemical compositions.

The ordinary coals used in gasmaking may be broadly divided into caking and non-caking.

Caking coals possess the property of becoming soft and pasty on heating, and after the expulsion of the volatile matters there is left a cellular mass of coke which bears no resemblance, either in form or shape, to the original coal from which it was derived. The peculiar property possessed by caking coals of thus conglomerating appears to be due not so much to the ultimate composition of the coal as to the particular forms of combination of the elements composing it, since some coals do not cake although they may possess an elementary composition exactly similar to caking coals. Caking coals are usually of a greyish-black, shining, resinous lustre. They yield from 60 to 80 per cent. of coke, and the amount of ash varies from 2 to 12 per cent. Caking coal is found chiefly in Northumberland, Durham, Yorkshire, Nottingham and Wales.

Non-caking coals are found in Lancashire, Yorkshire, South Wales, Staffordshire, Derbyshire and Scotland. The feature that distinguishes non-caking from caking coal lies in the behaviour on heating. The non-caking variety does not undergo any softening or fusing, and yields a coke which either retains the form of the original coal or crumbles into small pieces. The yield of coke from non-caking coal is usually less than that from caking coal.

Caking and non-caking coals are very similar in chemical composition. The following table shows the composition and specific gravities.

Coal.	Specific Gravity.	Composition (Per Cent.) of Coal, Dry and Free from Ash				
		Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.
Caking .	1·25 to 1·35	80 to 90	4·5 to 6	5 to 13	1 to 2·5	0·5 to 2·5
Non-caking.	1·25 to 1·40	70 to 85	4·5 to 6	10 to 18	1 to 2·0	0·5 to 1·5

(2) How do bituminous or caking coals differ from cannel coals?

The distinguishing features of cannels, as compared with bituminous coals, are their homogeneous appearance and the fact that they are harder and apparently non-laminated. The richer descriptions possess a dull brown colour, and the poorer varieties are bright and black. A true cannel does not cake in the retort but yields a species of coke strongly resembling the original cannel, plus some cracks and fissures, indicating the laminated structure of the material, which was invisible in the original cannel. The ash in cannel coal is greater than that in caking coal, being from 5 to 20 per cent., and it frequently shows the laminated structure more prominently than does the coke. It is usually whiter and freer from iron than the ash from caking coal. The yield of tar from cannel coal is, as a rule, greater than that from caking coal, but it possesses a lower specific gravity than the tar derived from caking coal. The amount of gas obtainable per ton, and the illuminating power yielded, are higher in cannel than in caking coals. The amount of the impurity, carbonic acid, is also greater. The specific gravity of cannels varies from about 1·1 to 1·4.

(3) How would you determine the volatile matter and coke in a sample of coal? Give an example.

From 30 to 40 grains of finely powdered coal are weighed out in a thin platinum crucible and spread in an even layer on the bottom thereof, the weighing being effected without the cover. The crucible is now loosely covered with its lid and placed upright on an iron retort ring which has been bound round with platinum wire in order to prevent any contact between the iron and the platinum crucible. A powerful bunsen flame is next applied to the crucible, the length of the flame and the relative position of the crucible thereto being the same in all experiments, in order that the results obtained may be comparable. The crucible should be heated for one minute after gases cease to issue from beneath the lid, and then the gas flame is removed and the crucible and cover placed to cool in a desiccator for about five minutes. As soon as cool the crucible is weighed without the cover, as before. The loss of weight on the quantity of coal taken represents the volatile matter which has been driven off from the coal by the heating; the residue in the crucible represents the coke (including the ash). Example:—

Before heating—

Weight of crucible and coal . .	356·46	grains.
,, ,, . . .	316·46	,,
Weight of coal taken . . .	40	grains.

After heating—

Weight of crucible and coke . .	344·46	grains.
,, ,, . . .	316·46	,,
	28	grains.

Then 40 − 28 = 12 grains volatile matter; and as 40 grains of coal were originally taken, in order to obtain the percenage, we say

As 40 : 100 :: 12 : 30

and for the percentage of coke

As 40 : 100 :: 28 : 70

So the result of the experiment is—

Volatile matter	30 per cent.
Coke	70 ,,
	100

(4) What is the constitution of the ash of coal? What does a reddish coloured ash indicate? Give an example. How is the amount of ash determined and what is the amount of ash you would expect to find in a good class of gas coal? About what percentage of ash would you expect to find in the coke produced from a gas coal containing 3·5 per cent. of ash?

The ash of coal consists of inorganic matter, and usually contains silica, alumina, oxide of iron, lime, magnesia, and potassium oxide. A red or reddish-brown coloured ash indicates that the ash contains a considerable quantity of iron. The following is an analysis of the ash of a Newcastle coal:—

	Per Cent.
Silica, SiO_2	59·56
Alumina, Al_2O_3	12·19
Ferric Oxide, Fe_2O_3	15·96
Lime, CaO	9·99
Magnesia, MgO	1·13
Potash, K_2O	1·17
	100·00

The proportion of ash in good class bituminous coal averages about 2·5 per cent., and in the coke derived from the same coal about 3¾ per cent. Cannel coals yield considerably more ash than caking coals do.

In determining the amount of ash in coal, a fair sample is taken and roughly powdered. A piece of platinum foil is then taken and its edges turned up so as to form a kind of small boat. Before using, the boat is cleaned and ignited, then cooled in a desiccator, and, when cold, weighed. A portion of the sample of coal is next placed in the boat so as to give a thickness of about ⅛ of an inch of coal at the bottom of the boat. The whole is then weighed. The difference between the two weighings gives the weight of coal taken. A porcelain tube about 2 feet long is next clamped in a retort stand and the platinum boat inserted at one end so that the portion containing the coal projects, and the other end is connected to a water aspirator, which draws a gentle current of air over the boat. The boat is heated by two large bunsen burners with flattened tops, so as to heat the full length of the bottom of the boat without enveloping the contents, since that would impede the free access of air. It will be found, as a rule, that it requires from six to eight hours to completely burn off the carbonaceous matter. As soon as this appears to have been effected the burners are turned off and the boat is transferred as rapidly as possible to the desiccator. As soon as cool it is weighed, replaced in the tube and heated again for thirty minutes, when it is again cooled and weighed. Should the first and second weighings agree, then we can assume that the combustion of the carbonaceous matter is complete, and on deducting from the weight of the boat and of the resulting ash the original weight of the boat, we obtain the weight of the ash yielded by the weight of coal employed, and from this the percentage of ash in the coal can be readily calculated. Example :—

Weight of coal and boat	120·6 grains.
,, boat	89·7 ,,
Weight of coal	30·9 grains.
Weight of ash and boat	91·5 grains.
,, boat	89·7 ,,
Weight of ash	1·8 grains.

Then

As 30·9 : 100 :: 1·8 : 5·82 = per cent. of ash.

In answering the last part of the question we assume that the coke produced equals 70 per cent. of the weight of the original coal. Then, since the whole of the ash is found in the coke, 70 parts of coke contain 3·5 parts of ash. Consequently, in order to arrive at the percentage, we say

As 70 : 100 :: 3·5 : 5 = per cent. of ash.

(5) In what form does the sulphur which is found in gas coal occur? State how you would determine the total amount of sulphur in a sample of coal. In determining the sulphur in a certain coal, 20 grains of coal yielded a precipitate of 2·16 grains of barium sulphate. What was the percentage of sulphur in the coal?

Coal may contain sulphur in three different states of combination, viz., as metallic sulphides (principally iron), as sulphates, and in the organic matter. To determine the amount of sulphur in coal, 20 grains of finely powdered coal are intimately mixed with 500 grains of sodium chloride and potassium nitrate in the proportion of 2 : 1. A platinum crucible is heated by a Berzelius spirit lamp, and the mixture is fed into this in small portions at a time. As soon as the deflagration is completed, the resulting mass is dissolved in water and made up to half a pint. Hydrochloric acid in slight excess is then added, and the solution is heated for twenty minutes. It is then filtered, the filter paper washed free from acid, and to the boiling filtrate a slight excess of barium chloride is added, which throws down a precipitate of barium sulphate. This is filtered, washed, dried, ignited, and weighed. The weight obtained multiplied by 0·13734 and by 5 will give the percentage of sulphur in the coal.

Example :—20 grains of coal yielded 2·16 grains $BaSO_4$. Then $2{\cdot}16 \times 0{\cdot}13734 = 0{\cdot}296$ grains $S \times 5 = 1{\cdot}48$ per cent. S.

(6) State how you would determine the amount of moisture in a sample of coal, and discuss the relative merits of the various methods employed in making such determinations.

The proper method to be adopted and the temperature to be employed in the drying of coal is a question which is rather in dispute. If we dry coal at a temperature of 212° Fahr. we do not drive off all the moisture; but as this is a temperature which is easily maintained and kept constant, it is frequently adopted, although, for the reason mentioned, some analysts recommend a higher temperature.

Thus Lunge recommends 221° Fahr. and Henrichs 239° Fahr. When heated at high temperatures, coal first gives off water, and loses weight correspondingly, but after a time it increases in weight, probably owing to the slow oxidation of the pyrites in the coal, or to the absorption of gaseous matter in the pores of the coal, left vacant by the expelled moisture.

The method which appears to yield the most satisfactory result consists in absorbing the water driven off from the coal in a weighed drying tube. The details of the test are as follows. A stoppered U-tube is first weighed empty, with the exception of some dried cotton-wool, which fills the hollows of the stoppers. A quantity of powdered coal is then placed in the tube, after which it is again weighed, the difference between the first and second weighing giving the amount of coal taken. A similar U-tube is filled with pieces of fused calcium chloride, free from alkalinity, and weighed after the air contained has been displaced by coal gas. The U-tube containing the coal is placed in a beaker of water which is kept boiling, and a current of coal gas, previously dried by passing through a large tube containing calcium chloride, is passed through the coal tube and into the weighed calcium chloride tube, which has a smaller calcium chloride tube on its outlet to guard the larger tube from moisture in the air. The escaping gas may be burned at a small jet on the outlet of the apparatus. The experiment should extend over two or three hours, when the stoppers of the weighed calcium chloride tube should be closed, the tube disconnected from the remainder of the apparatus, placed in the balance case for a short time, and weighed. The increase in weight will give the amount of water in the coal. The tube should then be reconnected and the previous operation resumed for another half-hour, when, after the same precautions, the drying tube should be weighed a second time, in order to ensure that all the moisture was driven off at the time of the second weighing, indicated by there being no further increase shown in the weight.

(7) Explain a method for determining the quantity of nitrogen in coal and coke. What percentage would you expect to find in each?

One method of ascertaining the quantity of nitrogen in coal or coke is that known as the Kjeldahl method, which consists in heating finely-powdered coal or coke with concentrated sulphuric acid in the presence of manganese dioxide. This destroys all the carbonaceous and organic matter, and converts the whole of the nitrogen into ammonium sulphate. To this is added an excess of sodium hydrate solution, which is distilled into a standard solution of sulphuric acid, and the amount of ammonia liberated is calculated from the quantity of sulphuric acid neutralized.

The quantities used may be :—

Coal or coke, 1 gram,
Heated with 25 to 30 c.c. strong sulphuric acid for thirty minutes,
Add 5 grams of manganese dioxide and boil for forty-five minutes,
Then add a further 5 grams, heating finally for forty-five minutes.

Then cool and very carefully add a little distilled water, rinse into a copper flask, add a solution of sodium hydrate, containing about ·25 grams of the solid. Distil into a solution of normal sulphuric acid; about 15 c.c. diluted is usually sufficient.

Each 1 c.c. of acid neutralized represents 0·014 gram of nitrogen.

Coal contains from 1 to 2½ per cent., and coke about 58 to 59 per cent. of nitrogen.

(8) How would you determine the calorific power of coal or coke? Give a sketch of an apparatus which may be used for such purpose.

The calorific or heating value of coal or coke (hence its evaporative power) can be determined in several ways by the combustion of the fuel in oxygen, and measuring the heat thus produced. The calorific value of a fuel may also be calculated from an elementary analysis of the fuel, though the results do not quite agree with those obtained in a practical test.

The best-known apparatus used for this class of experiment is the Lewis Thompson calorimeter, others being the William Thomson and the bomb type of calorimeter. Mahler's calorimeter is the best known of the last-mentioned type, but its use is restricted where cost has to be considered.

The Lewis Thompson calorimeter is shown in Fig. 1. The apparatus is constructed on the following principles:—First, that the latent heat of steam is equal to 967° Fahr.; and, secondly, that any fuel burned in pure oxygen evolves the same amount of heat as when perfectly burned in atmospheric air. The method of making an experiment is as follows. Two grains of finely powdered and sifted coal are intimately mixed with 20 grains of a mixture of one part of nitrate of potash and three parts of potassium chlorate which has been previously well dried in a water oven. The mixed mass is introduced into a copper cylinder, A, and this is placed on a brass base, B. A hole is made in the mixture to receive a fuse consisting of a cotton wick which has been dipped in a solution of nitre and dried. The wick is fixed by pressing the mixture round it. The next portion of the apparatus consists of another copper cylinder, C, which fits over the one containing the coal. This second cylinder is perforated with a number of small holes, to enable the gases produced by the combustion of the coal to pass through the water, and so give up their heat to the latter. It is further provided with a long copper tube, D, fitted with a stopcock; so that when the two cylinders, fitted together, are introduced into water, the water is excluded or admitted to the cylinder containing the coal, according as the stopcock is shut or opened.

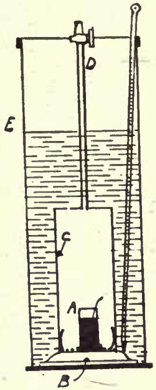


Fig. 1.

A glass cylinder, E, is provided, which, when filled with water up to a certain mark, holds 1,934 grains. The temperature of the water is taken by a very delicate thermometer, and should be about 60° Fahr. The temperature of the water having been determined, the fuse is lighted, and the larger copper cylinder fixed, with its stop-cock closed, over the smaller one. The whole apparatus is then submerged in the water contained in the glass cylinder. A minute or so after the immersion the fuse burns down to the coal. Combustion then commences, and when it ceases the stop-cock is opened and the apparatus is gently moved up and down in the water, which causes the whole of the water contained in the cylinder to acquire the same temperature. The temperature of the water is again determined by the thermometer. The number of degrees to which the water has been heated, increased by one-tenth (the amount of heat absorbed by the apparatus) will then represent the number of pounds of water which the burning of 1 lb. of coal will convert into steam. The calculation is based on the assumption that $\frac{1,934}{2} = 967$ Fahrenheit units of heat are required to convert the unit weight of water into steam.

(9) How would you determine the specific gravity of a sample of coal, and what is the average specific gravity usually found? A piece of coal weighs 462·4 grains in air and when immersed in water it weighs 100·2 grains, what is the specific gravity of the coal?

The specific gravity of coal is determined by first weighing the coal in air and then immersing it in a vessel of water and noting the loss in weight. The weight in air divided by the loss of weight in water represents the specific gravity. The specific gravity of a body is the relationship existing between equal bulks of the substance compared with some other as the standard, which, in the case of liquids and solids, is distilled water at a temperature of 60° Fahr. When the coal is weighed in water it loses weight equal to the weight of its own bulk of water. The coal is suspended from the pan of the balance by means of a horse-hair or piece of fine silk, and before the weight in water is noted it is necessary to remove any adhering air bubbles. In the example given 462·4 – 100·2

= 362·2 = loss of weight in water, and 462·4 ÷ 362·2 = 1·276, the specific gravity of the coal.

(10) What do you understand by the term unoxidised hydrogen as applied to coal? How is it arrived at, and what bearing has it on the suitability of a coal for gasmaking purposes? What is the minimum amount of unoxidised hydrogen a good gas coal should contain? The following is an elementary analysis of a gas coal; give the necessary calculations for arriving at the amount of unoxidised hydrogen:—

	Per Cent.
Carbon	81·26
Hydrogen	5·11
Oxygen	7·30
Nitrogen	0·62
Sulphur	1·28
Ash	3·08
Water	1·33

By percentage of unoxidised hydrogen is meant hydrogen unaccompanied by an equivalent of oxygen, and it is obtained by deducting one-eighth of the percentage of oxygen from the percentage of hydrogen (being the ratio in which hydrogen combines with oxygen). Coal should not contain less than 4 per cent. of unoxidized hydrogen. The reason why the unoxidized hydrogen plays such an important part in the choice of a coal is that in the process of carbonization every 16 parts of oxygen present unite with 2 parts of hydrogen, producing 18 parts of water, leaving only the amount of hydrogen in excess of that capable of entering into combination with the oxygen available for the production of hydrocarbons. In the example given, the percentage of oxygen equals 7·30. One-eighth of this is 0·91, and this deducted from the percentage of hydrogen (5·11) gives 4·20 as the percentage of unoxidized hydrogen.

(11) Show that the total quantity of hydrogen present in a sample of gas coal is not realizable in gasmaking. Calculate the quantity so available in the case of a

coal having the following percentage composition:— C, 85·58; H, 5·31; O, 4·39; and N, S and ash, 4·72. What percentage of available hydrogen should a good gas coal contain?

When coal is carbonized, a portion of the hydrogen unites with the oxygen in the proportion of two parts of hydrogen with sixteen of oxygen, forming eighteen parts of water. Consequently, it is only the hydrogen in excess of that required by the oxygen which is realizable. In the example given, since there is 4·39 per cent. of oxygen, this will combine with 0·55 per cent. of hydrogen, which, being deducted from the total percentage of hydrogen (5·31), leaves 4·76 per cent. of hydrogen which will be realizable in gasmaking. A good gas coal should not contain less than 4 per cent. of available hydrogen.

(12) Describe a method of washing coal and state why it is necessary to wash certain coals before supplying them for gasmaking purposes. Of what do the impurities chiefly consist?

Coal, when mined, always contains more or less impurities of various kinds, which reduce its market value in proportion to the amount present. These impurities consist chiefly of pyrites and siliceous and calcareous shaly matter in association with the coal, whilst other impurities, such as fireclay, sandstone, etc., get mixed with the coal during the process of mining. It is obviously beneficial to buyer and seller that such impurities should be removed, and this is usually done by washing the coal, in which process advantage is taken of the different specific gravities of the coal and the foreign matters. Usually the smaller sizes of coal, such as nuts, beans and peas, only are washed, the separation of impurities from large coals being a comparatively easy matter on the belts and screens.

There are several types of coal-washing plants. In all the coal is agitated in a good supply of water, the agitation being brought about in many different ways, a few being:—

(1) By the flow of water itself,
(2) By travelling belts and scrapers,
(3) By revolving arms,
(4) With the pulsation of the water by pistons or compressed air.

The simplest system is what is known as the trough washer. A trough, varying in length from 50 to 100 feet, and about 3 feet wide and 15 inches deep, is provided at intervals with removable dams. The trough is set at an angle sufficient to ensure the agitation by the water of the coal (which is fed into it by any suitable method), and also to settle out the heavier matters—shale and other impurities—which are arrested by the dams, and which are run off at intervals through sluices at the side of the trough. The washed coal passes over a screen, and the surplus water is collected in an overflow tank, where it is allowed to settle, when it can be used again. The Elliot washer is similar to the one described, but is more efficient, as the coal is agitated in a trough by employing a scraper chain, working in conjunction with the water and against the water flow.

Other well-known coal washers are the jig washer, the Blackett washer, Baum's compressed air washer and Robinson's revolving arm washer.

CHAPTER II.

EFFECT OF TEMPERATURE IN CARBONIZATION.

(13) State the factors which influence the production of the various residuals obtained in the destructive distillation of coal.

The quantity and quality of the residual products yielded in the destructive distillation of coal are influenced by various causes, amongst which may be mentioned the temperature of distillation, the weight of the charges and the manner of their disposal in the retorts, and the period allowed for distillation.

(14) State the effects of temperature on the production of tar, and illustrate your answer by an example. What effect have heavy and long-period charges upon the production of tar?

The quantity and quality of the tar yielded on distillation of coal largely depend upon the temperature of distillation. Low temperatures produce more tar than high temperatures do, but the specific gravity of the low-temperature tar is lower. With a distillation temperature of about 800° Fahr., the tar produced is lighter than water, and is of a thinnish character. It consists principally of hydrocarbons of the paraffin and olefiant series, and contains hardly any free carbon. If the temperature is increased to about 1,700° Fahr., the character of the tar undergoes a change. The tar will be found to be much thicker, and to contain hardly any paraffin or olefiant hydrocarbons (these having been largely replaced by hydrocarbons of the benzene series) and a large proportion of free carbon.

Speaking generally, as the temperature gradually increases the paraffin hydrocarbons are destroyed and hydrocarbons of the benzene series are formed; resulting in an increase in the volume of gas, together with free carbon in the tar. With similar distillation temperatures, cannel coals yield lighter tars, containing more paraffins than caking coal tar does.

This is due, to some extent, to the fact that the volatile matter in cannel coal comes away more easily than does that in common coal, and, consequently, it has not so prolonged a contact with the hot walls of the retort. Further, coals yielding much water in distillation yield thinner tars than similar coals of a drier nature.

As before stated, cannel coals, as a general rule, yield thinner tars than do common coals; but even cannel coals are capable of producing thick tars, if the distillation temperature is sufficiently high. The quality of the coal has an important bearing on the quantity and quality of the tar produced therefrom. Thus the coals of Northumberland and Durham produce tar rich in naphthalene and anthracene, while coals from the Wigan district yield tars containing much benzol and phenol.

The following table, giving the results of experiments by Mr. Lewis T. Wright, shows the effect of temperature on the production of tar:—

Temperature of Distillation.	Production of Gas Per Ton.	Specific Gravity of Tar.	Percentage of 50 Per Cent. Benzol in Tar.	Percentage of Tar Acids in Creosote.
Extremely low .	6,600	1·086	1·1	34·0
Very low . .	7,200	1·102	1·9	30·7
Low . .	8,900	1·140	1·6	28·5
Moderate . .	10,162	1·154	1·2	27·0
High . .	11,700	1·206	0·6	21·0

The tar produced from ordinary bituminous coal has a specific gravity varying from 1·1 to 1·2. The total yield is about 5 per cent. of the weight of the coal from which it is produced, and the quantity from Durham coal, carbonized at ordinary working temperatures, about 10 gallons per ton.

According to Mr. J. Ferguson Bell's experiments, the quantity of tar produced per ton of coal carbonized is increased when working with long-period and heavy charges in horizontal retorts. The specific gravity, also, is found to be lower than that of tar produced from coal in a light charge. The following table is extracted from Mr. Bell's paper, read before the Institution of Gas Engineers in 1909:—

TAR MADE PER TON OF COAL CARBONIZED.

Duration of Charge. Hours.	Gallons.	Specific Gravity.	
		At Hydraulic Main and Condensers.	At Tar Extractor and Drain Boxes.
6	10·64	1·192	1·126
8	11·71	1·173	1·118
10	12·35	1·168	1·110
12	12·84	1·160	1·108

(15) State the effects of temperature on the production of ammonia, and give figures in support of your conclusions. Give figures showing the effect upon the ammonia produced by varying the weight of the charge of coal and the period of carbonization.

Ammonia is produced from the nitrogen in the coal, which occurs to the extent of about 1·5 per cent. by weight The following table, by the late Professor Foster, shows how the nitrogen is distributed amongst the products resulting from the distillation of coal:—

Nitrogen as ammonia	14·5	per cent.
,, as cyanogen	1·56	,,
,, in the coke	49·90	,,
,, unaccounted for	34·04	,,
	100·00	

The quantity of ammonia yielded by any particular coal depends upon the temperature, the quantity increasing with the temperature up to a certain point. When the temperature is a very dull red, little or no ammonia is formed, the nitrogen driven off from the coal being found in the form of various organic bases in the tar; but as the temperature is increased ammonia is formed in increasing quantities, until a temperature is reached at which the production is at its maximum. If this temperature is exceeded the ammonia begins to suffer decomposition, being partly resolved into its constituent elements, hydrogen and nitrogen, and, partly, by the red-hot coke, into cyanogen, in the form of hydrocyanic acid: $NH_3 + C = HCN + H_2$.

The following example by Mr. Lewis T. Wright bears out the above remarks:—

Make per Ton. Cubic Feet.	Yield of NH_3 per Ton. Lbs.	Percentage by Weight of Coal as NH_3.
7,512	6·391	0·285
9,431	7·504	0·335
10,162	7·894	0·352
11,620	7·411	0·331

It will be noticed that the highest yield of ammonia is obtained with the make of 10,162 cubic feet per ton, and that at the higher make of 11,620 cubic feet the yield of ammonia drops off.

The above remarks apply to ordinary six-hour work and 6 to 6½-cwt. charges; but the modern practice being to fill the retorts, the results now obtained under the new conditions have been found to differ very considerably from those given above. It should always be borne in mind that the results will vary according to the amount of nitrogen present in the coal and the temperature employed in carbonizing.

The following results were obtained by Mr. J. Ferguson Bell, from which it will be seen that slow carbonization tends towards an increase in the production of ammonia, there being no less an increase than, roughly, 17 per cent. between charges of six and twelve hours duration.

AMMONIA OBTAINED PER TON OF COAL CARBONIZED.

Duration of Charges.	In Virgin Liquor.	Condensed From Drain Boxes and From Tar.	From the Gas.	Total Ammonia.	Nitrogen in the Coal Recovered.
Hours.	Lbs.	Lbs.	Lbs.	Lbs.	Per Cent.
6	4·03	0·35	2·88	7·26	0·216
8	4·26	0·39	3·61	8·26	0·245
10	4·40	0·50	3·55	8·45	0·248
12	4·30	0·42	3·68	8·50	0·253

(16) State the effects of temperature on the production of cyanogen and coke.

The production of cyanogen is largely, if not entirely, dependent upon the temperature of carbonization. The higher the temperature the greater the yield of cyanogen. In an experiment by Mr. Lewis T. Wright, with a low temperature which gave a production of gas of 7,500 cubic feet per ton, the yield of cyanogen was 0·0035 lb. per 100 lbs. of coal carbonized, whilst the same coal distilled at a high temperature, which produced 11,187 cubic feet per ton, yielded 0·022 lb. of cyanogen per 100 lbs. of coal.

The carbon in coal amounts to about 80 per cent., and in cannel to rather less, and this carbon is found to the amount of about two-thirds of the original coal in the form of coke, one ton of coal producing about 1,500 lbs. of coke, or 85 per cent. of the original carbon. A high temperature generally produces a hard coke, but the same coal may produce coke of greatly varying character, according to the temperature of distillation and the description of retort employed.

(17) State the effects of temperature on the impurities CO_2, SH_2 and CS_2, giving examples. In what quantities do these impurities exist in a gas made from a heavy charge and over an extended period of carbonization?

Speaking generally, the amounts of the impurities CO_2, SH_2 and CS_2 are greatly increased by high temperatures. Experiments by Mr. Lewis T. Wright prove this. At a temperature which produced 7,500 cubic feet per ton, the following were the amounts of impurities:—

	CO_2	SH_2	CS_2
Grains per 100 cubic feet of gas .	1,594	840	27

The same coal carbonized at a temperature which produced 11,187 cubic feet per ton gave off the following impurities:—

	CO_2	SH_2	CS_2
Grains per 100 cubic feet of gas .	1,799	1,057	40·5

The following table shows the effect of gradually increasing temperatures on the production of sulphur compounds other than SH_2:—

Gas Made per Ton. Cubic Feet.	Sulphur other than SH_2 Grains per 100 Cubic Feet.
6,896	13·91
8,370	19·16
9,431	26·75
10,772	36·93
11,620	44·17

As a general rule, cannel coals yield less sulphur compounds and sulphuretted hydrogen, but considerably more carbonic acid, than common coals.

With regard to the last part of the question, we cannot do better than quote figures from Mr. J. Ferguson Bell's 1909 Institution paper. The following table shows that the new method of carbonization, namely, heavy charges worked off in 8, 10 or 12 hours, have very little effect upon percentage of CO_2 in th gas, but in a 12-hour charge the number of grains of SH_2 present is considerably less than that found when working 6-hour charges. This will, therefore, tend to reduce purification costs. The CS_2 is increased for 8 and 10-hour charges, but drops when working 12-hour charges to practically the same as for 6-hour work.

IMPURITIES IN CRUDE GAS.

Duration of Charges.	CO_2 Per Cent. by Volume.	SH_2 Per 100 Cubic Feet.	CS_2 Per 100 Cubic Feet.
Hours.		Grains.	Grains.
6	3·20	736	43·40
8	3·19	996	60·20
10	3·10	814	56·10
12	3·25	620	47·40

(18) A ton of a certain coal yields 10,500 cubic feet of 16-candle gas, having a specific gravity of 0·461; 10 gallons of tar, specific gravity 1·12; and $10\frac{1}{2}$ gallons of virgin ammoniacal liquor, specific gravity 1·02; $\frac{3}{4}$ per cent. SH_2; $2\frac{1}{2}$ per cent. CO_2; ammonia removed in scrubbers, 12 gallons of 10-ounce strength;

and 70 per cent. of the weight of the coal is obtained as coke. Calculate from the above data what proportion of the original weight of the coal is accounted for in the process of carbonization.

	Lbs.
10,500 cubic feet of gas, s.g. 0·461 weigh $\frac{10{,}500 \times 1{,}728 \times (31{\cdot}012 \times 0{\cdot}461)}{7{,}000 \times 100}$	370·56
10 gallons of tar, s.g. 1·12	112·00
10½ ,, virgin ammoniacal liquor, s.g. 1·02	107·10
Impurities—	
SH_2 taken out, say, ¾ per cent. $\frac{78{\cdot}75 \times 1{,}728 \times 36{\cdot}33}{7{,}000 \times 100}$	7·06
CO_2 taken out, say, 2½ per cent., $\frac{262{\cdot}5 \times 1{,}728 \times 47{\cdot}26}{7{,}000 \times 100}$	30·62
Ammonia removed after condensation, say, 12 gallons 10-ounce $\frac{12 \times 10 \times 17}{49}$ ozs. .	2·60
Total volatile products . . .	629·94
Coke, say, ...	1560·00
Total	2189·94
Leaving a deficiency of	50·06
	2240·00

Or $\frac{2189{\cdot}94 \times 100}{2240} = 97{\cdot}76$ per cent. of the original weight of the coal accounted for.

The following hints will help to make the foregoing calculations clear. 31·012 is the weight of 100 cubic inches of air, and on multiplying by 0·461 we obtain the weight of 100 cubic inches of coal gas. 7,000 are the number of grains in a pound. A gallon of water weighs 10 lbs., and the weight of any other liquid varies with the specific gravity. In the example dealing with the weight of tar, as the specific gravity is 1·12 the weight of a gallon would be

11·2 lbs. In calculating the weight of the sulphuretted hydrogen, ¾ per cent. of 10,500 cubic feet = 78·75 feet, and the weight of 100 cubic inches of sulphuretted hydrogen is 36·33 grains. Similarly, in calculating the weight of the carbonic acid, 2½ per cent. of CO_2 = 262·5 cubic feet, and 47·26 is the weight of 100 cubic inches of CO_2. In calculating the weight of ammonia it is necessary to note that 10-ounce liquor means that a gallon of such liquor would require 10 ounces of sulphuric acid to neutralise the ammonia contained therein, and that 49 parts of sulphuric acid combine with 17 of ammonia, thus: $2NH_3 + H_2SO_4 = (NH_4)_2SO_4$.

(19) Give the elementary composition of coal and show how the various elements are distributed in the process of carbonization.

Coal consists of the elements carbon, hydrogen, oxygen, nitrogen and sulphur, together with varying proportions of mineral matter. In the process of carbonization the carbon combines with the hydrogen to form the various hydrocarbons on which the luminosity of the gas depends. The principal of these are:—

Marsh gas or methane . . .	CH_4
Olefiant gas or ethylene . . .	C_2H_4
Acetylene	C_2H_2
Benzene	C_6H_6
Naphthalene	$C_{10}H_8$

Carbon also combines with oxygen to form carbon monoxide (CO) and carbon dioxide (CO_2). It also combines with nitrogen, forming cyanogen (CN), and with sulphur, to form carbon bisulphide (CS_2). It is also found as free carbon in the form of scurf, and in the coke. Hydrogen unites with carbon to form the hydrocarbons previously enumerated; with oxygen to form water (H_2O); with nitrogen to form ammonia (NH_3); and with sulphur to form sulphuretted hydrogen (SH_2). It also exists as free hydrogen in the gas.

Oxygen combines with carbon and hydrogen as shown above; nitrogen combines with hydrogen to form ammonia, with carbon to form cyanogen (CN), and with both elements to form hydrocyanic acid (HCN). Sulphur combines with hydrogen to form sulphuretted hydrogen (SH_2) and with carbon to form carbon bisulphide (CS_2). These are the principal combinations, but, in addition, there are a great number of complex bodies in the tar and ammoniacal liquor which are made up of the same elements.

CHAPTER III.

COMPOSITION OF COAL GAS.

(20) State in general terms the composition of coal gas.

Purified coal gas consists of a mechanical mixture of marsh gas (CH_4) and other members of the paraffin series of hydrocarbons, hydrogen, carbonic oxide, ethylene (C_2H_4), acetylene, crotonylene and the benzenoid hydrocarbons (benzene, toluene, xylene and naphthalene), together with nitrogen and sometimes small amounts of oxygen.

(21) How may the various constituents of coal gas be classified?

The substances which enter into the composition of coal gas may be conveniently classified as follows:—

Light-yielding bodies, which, on being burned, deposit free carbon in the flame of a flat-flame or argand burner and so produce a luminous effect. This group embraces the various descriptions of hydrocarbons.

Bodies which, on combustion, do not yield light but produce a considerable heating effect. Hydrogen and carbonic oxide come under this heading.

Diluents, which reduce the luminous effect by diluting and cooling the flame. These include nitrogen and carbonic acid and oxygen, which only dilute the flame.

(22) How may the various hydrocarbons which occur in coal gas be grouped?

The hydrocarbons entering into the composition of coal gas are divided into two groups, known as the saturated and the unsaturated series of hydrocarbons. These are recognisable, on analysing the gas, by their respective behaviours with a solution of bromine in bromide of potassium or with strong sulphuric acid. The unsaturated hydrocarbons are absorbed by the solutions mentioned, leaving the saturated hydrocarbons unaffected. The saturated hydrocarbons consist of the paraffin series, of which marsh gas (CH_4) is the most important member. Minute traces of other members of the same series, viz., ethane, propane and butane are also present. The unsaturated series of hydrocarbons consist principally of ethylene (C_2H_4) and benzene (C_6H_6), together with traces of propylene, butylene, acetylene, crotonylene and naphthalene.

(23) What do you understand by the terms "homologous series" and "homologue" as applied to hydrocarbons? Give illustrations showing the bearing of these on the hydrocarbons contained in coal gas.

When the hydrocarbons of the methane, or paraffin, group are arranged in the order of their molecular weights they form a series, each member of which contains 1 atom of carbon and 2 atoms of hydrogen more than the preceding member. Thus we have :—

Methane (CH_4).
Ethane (C_2H_6).
Propane (C_3H_8).
Butane (C_4H_{10}).

Such a series is termed homologous and the several members are spoken of as homologues of one another. The molecular composition of all the members of a homologous series can be expressed by a general formula. In the case of the paraffin series the general formula is C_nH_{2n+2}, which means that in any member of the series containing n atoms of carbon in the molecule, there are $2n+2$ atoms of hydrogen. In butane (C_4H_{10}), for example, $n=4$ and $2n+2=10$.

In the olefine, or ethylene, series the general formula is C_nH_{2n}. The following are the more important members of the series :—

Ethylene (C_2H_4).
Propylene (C_3H_6).
Butylene (C_4H_8).

There are also present in coal gas hydrocarbons of the acetylene series, having the general formula C_nH_{2n-2}; the benzenes, C_nH_{2n-6}; and naphthalene, having the general formula C_nH_{2n-12}.

(24) Give a brief statement of the light values of the various combustible constituents found in coal gas.

The following are the light-giving values of the principal constituents of coal gas :—

Methane	5 cubic feet per hour	= 5·2	candles.
Ethane	,, ,, ,,	= 35·7	,,
Propane	,, ,, ,,	= 56·7	,,
Ethylene	,, ,, ,,	= 70·0	,,
Benzene (as vapour)	,, ,, ,,	=820·0	,,
Toluene	one pound	= 12·8	lbs. sperm.
Naphthalene	,,	= 17·1	,,

It is necessary to note that although the particulars given above are the results of careful research, it is not possible to draw any definite conclusions therefrom as to the effect of composition on the illuminating power. The figures show that as the carbon density increases so does the capability for developing light, but this is not dependent upon any general principle such as atomic density of carbon, specific gravity, or proportion of carbon. For example, the specific gravities of ethane and ethylene are nearly the same and the carbon densities are equal, yet the one develops nearly twice as much light as the other.

(25) State the effects of the various diluents present in coal gas.

The effect of the various diluents present in coal gas on its illuminating power has been studied by experimenting on ethylene, which has an illuminating power of 70 candles per 5 cubic feet, with various percentages of the different diluents.

Mixtures of hydrogen with ethylene showed a regular fall in illuminating power from the original value to zero as the quantity of hydrogen was increased, this result being obtained with 90 per cent. hydrogen and 10 per cent. ethylene. In experiments with mixtures of carbonic oxide and ethylene it was found that so long as the former remained under 60 per cent. of the whole the illuminating value was only slightly less than that shown by a corresponding percentage of hydrogen; but above this point a rapid falling-off occurs, until the non-luminous point is reached at 20 per cent. of ethylene to 80 of carbonic oxide. The intrinsic value of the ethylene is not materially reduced until the limit of 60 to 40 is reached; but after this it rapidly falls.

The action of the incombustible diluents was as follows :—In the case of carbon dioxide, 10·97 per cent. of the diluent reduced the original illuminating power of 70 candles to 50 candles, 54 per cent. to 7½ candles, and 60 per cent. to *nil.* In the case of nitrogen, 15 per cent. of the diluent reduced the illuminating power to 52 candles, 60 per cent. to 21 candles, and 71 per cent. to 7 candles. The addition of oxygen to gas rich in hydrocarbons caused an increase in the illuminating power up to a certain point: 31½ per cent. of oxygen gave an illuminating power of 71 candles against the original 70; but 39 per cent. resulted in explosion.

(26) Give an analysis of a gas made from common and cannel coal, respectively.

Composition of gas (24·2 candle-power) from cannel coal :—

	Per Cent. by Volume.
Hydrogen	41·60
Marsh gas	42·00
Illuminants	8·73
Carbon monoxide	4·67
Nitrogen	3·00
	100·00

Composition of gas (16·3 candle-power) from common coal :—

Hydrogen	53·70
Saturated hydrocarbons	34·00
Unsaturated ,,	4·38
Carbon monoxide	4·00
Carbon dioxide	0·50
Nitrogen	3·00
Oxygen	0·42
	100·00

(27) How does the composition of the gas affect the length of the flame yielded thereby, and why?

The reason why gases of varying composition yield different lengths of flame when burned at the same rate per hour is that they require different quantities of oxygen for their complete combustion. Hydrogen and carbon monoxide burn with exceedingly short flames, since they only require one-half their own volume of oxygen for complete combustion, and they are able to obtain the necessary oxygen a short distance from the point of ignition. Marsh gas requires twice its own volume of oxygen, and thus burns with a flame nearly four times the height of hydrogen and carbon monoxide when burned at the same rate. The remaining combustible bodies, ethylene, ethane and benzene, exist in such small proportions as to make their influence on the length of flame almost a negligible quantity. We, consequently, find that a 16-candle gas, made in the ordinary way from bituminous coals, will give a flame in the No. 1 argand burner about 3 inches in height, the height of the flame being mainly due to the methane present, as such gas will contain from 35 to 40 per cent. of that hydrocarbon. But in the case of a gas like carburetted water gas, which contains, say, from 16 to 20 per cent. of methane and large quantities of H and CO, it will be found that a much shorter flame will give the same illuminating power.

(28) What is the effect of air and moisture on the illuminating power of gas?

The effect of air on the illuminating power of coal gas has been studied by Wurtz, who obtained the following results :—

Percentage of Air added.	Percentage Loss of Light.
3·0	15·69
4·96	20·83
11·71	41·46
16·18	57·53
25·00	84·00

The effect of moisture on ethylene when present in the proportion found in coal gas when saturated at a temperature of 60° Fahr. and 30 inches Bar. reduces the illuminating power 3·6 per cent., or coal gas 3·3 per cent.

(29) What is the standard on which the heating value of gas is based? Show the connection between the standard employed in scientific work and in ordinary gasworks practice.

The standard of heat in the metric system of weights and measures, which is adopted in all scientific work, is the calorie, which represents the amount of heat required to raise 1 litre (1,000 grammes or 1 kilogramme) of water 1° C. So that when it is stated that a gas has a calorific value of so many calories per cubic foot we understand that the gas is capable of yielding, on complete combustion, sufficient heat to raise the same number of litres, or kilogrammes, of water as the gas has calories through 1° C. In ordinary everyday work, however, the unit employed is the British thermal unit, which is the quantity of heat required to raise 1 lb. of distilled water through 1° Fahr. Now, the kilogramme is equal to 2·2 lbs. and 1° Fahr. is equal to five-ninths of 1° C.; consequently 1 calorie $= \frac{2{\cdot}2 \times 9}{5} = 3{\cdot}96$ British thermal units, commonly designated B.Th.U. In order, therefore, to convert calories into British thermal units we multiply by 3·96, or, dividing British thermal units by the same factor, we obtain calories.

(30) Give the calorific values of the combustible constituents of coal gas.

Calorific values of combustible constituents of coal gas:—

	Calories per Cubic Foot.		British Thermal Units per Cubic Foot.	
	Gross.	Net.	Gross.	Net.
Benzene vapour	938·9	902·5	3,718	3,574
Ethylene	404·8	381·3	1,603	1,510
Methane	258·6	232·0	1,024	919
Carbon monoxide	83·3	83·3	330	330
Hydrogen	82·0	68·7	325	272

(31) State how you would obtain the calorific value of a gas from its analysis. A gas has the following composition:—

	Per Cent.
Hydrogen	**54·1**
Methane	**34·2**

Ethylene	**3·0**
Benzene	**1·0**
Carbon monoxide	**5·9**

From the data given above calculate the calorific value of the gas.

In obtaining the calorific value of a sample of coal gas by calculation we first obtain the calorific values of the combustible constituents of which the gas is composed. These are worked out per cubic foot. The various combustible constituents per cent. are then separately multiplied by their respective calorific values; and the total of these, divided by 100, will give the calorific value of the gas per cubic foot. The following is an example worked out, to show the bearing of the various constituents on the total calorific value of the gas:—

	Per Cent.		Calorific Value per Cub. Ft.	B.Th.U.
Hydrogen	54·1	×	325	17,582·5
Methane	34·2	×	1,024	35,020·8
Ethylene	3·0	×	1,603	4,809·0
Benzene	1·0	×	3,718	3,718·0
Carbon monoxide	5·9	×	330	1,947·0
				63,077·3

=630·7 B.Th.U. per cubic foot.

(32) State the general effects of temperature in modifying the composition of gas and show in tabular form the changes in the composition of the gas at various distillation temperatures. What do you understand by polymerisation?

The effect of distillation temperatures on the quality of the gas may be briefly stated as follows. With an extremely low temperature the quantity of gas produced is small but its quality is high, and on gradually increasing the temperature the amount of gas yielded is increased but its quality is lowered, marsh gas being abundantly formed, while at the last stage of the distillation process the gas coming off consists almost entirely of free hydrogen. In order to understand the effects of temperature on the composition of the gas, it is necessary to note the conditions under which the gas is given off from coal. The first portion of the coal which comes under the influence of the heat is its exterior surface, which, coming into contact with the hot walls of the retort, is at once decomposed and yields hydrocarbons, such as ethylene (C_2H_4), which at the prevailing high temperature are partly decomposed and converted into methane (CH_4) and free hydrogen, these gaseous bodies accompanied by some unaltered ethylene and volatile hydrocarbons escaping from the retort. The interior of the charge of coal is, however, under a different set of conditions, by reason of its being exposed to only a very moderate degree of heat, which results in the formation of those compounds which are produced at comparatively low temperature, viz., the heavy hydrocarbons. These as they pass away come into contact with the red-hot surface of the exterior mass of coal and also with the hot sides of the retort. This results in the deposition of a portion of the carbon of the hydrocarbons and the resolution of the latter into simpler compounds such as ethylene and volatile hydrocarbons; and these, in turn, suffer a partial decomposition. At a later stage of the distillation process, as the heat penetrates to the centre of the coal and causes a red-hot mass of coke of considerable thickness to surround the decomposing coal in the interior, which are the conditions which prevail at the end of the charge, the whole of the hydrocarbons which are then formed are at once decomposed, owing to their having to pass over such a large extent of heated surface, and this results in free hydrogen being given off in great abundance. In addition to the above phenomena, the hydrocarbons of the paraffin series are decomposed by heat into lower members of the same series and olefines, which, being acted upon by coming into contact with the hot sides of the retort, and by the radiant heat from the latter, causes numerous changes and decompositions. Thus, ethane is decomposed into ethylene and hydrogen, while ethylene is split up into methane and acetylene. The latter immediately polymerises to benzene, etc.

Some of the reactions last mentioned may be represented by equations, thus :—

$$\underset{\text{Methane}}{2CH_4} = \underset{\text{Acetylene}}{C_2H_2} + \underset{\text{Hydrogen}}{3H_2}$$

$$\underset{\text{Acetylene}}{3C_2H_2} = \underset{\text{Benzene}}{C_6H_6}$$

$$\underset{\text{Ethylene}}{3C_2H_4} = \underset{\text{Acetylene}}{2C_2H_2} + \underset{\text{Methane.}}{2CH_4}$$

The effect of temperature on the composition of gas is shown in the following table :—

Temperature of Distillation	Composition of Gas.					
	Hydrogen.	Methane.	Olefines.	Carbonic Oxide.	Nitrogen.	Total.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	
Dull red . .	38·09	42·72	7·55	8·72	2·92	100·00
Hotter . .	43·77	34·50	5·83	12·50	3·40	100·00
Bright orange	48·02	30·70	4·51	13·96	2·81	100·00

The different forms in which a definite compound may exist are termed polymeric forms or modifications, and are analogous to the allotropic forms of the elements—that is to say, a polymeric form is simply an aggregate of the molecules of the original substance, and the change of the simple into the complex form is spoken of as polymerisation. Thus in the equation given, the aggregate of the molecules of acetylene $3(C_2H_2) = 3 \times 2 = 6C$ and $3 \times 2 = 6H$, or C_6H_6.

(33) What is the effect upon the calorific and illuminating values of a gas when 1 per cent. of air, carbon dioxide and nitrogen are added, respectively?

The admission of any of the three mentioned gases has the effect of lowering both the calorific value and the illuminating power of coal gas. According to tests carried out by Dr. W. B. Davidson, of Birmingham, working on a 16-candle gas of 540 B.Th.U., the following results were arrived at :—

Constituent Added.	Calorific Value. Per Cent.	Candle-Power. Per Cent.
1 per cent. of air	−1·0	−3·5
1 ,, CO_2	−1·0	−3·0
1 ,, N_2	−1·0	−2·6

CHAPTER IV.

TESTING FOR IMPURITIES.

(34) State how you would determine the amount of ammonia in crude gas.

In the estimation of the amount of ammonia in crude gas we require a standard solution of sulphuric acid and a standard solution of an alkali, either ammonia or caustic soda. The solutions employed may conveniently be the ordinary normal solutions of the laboratory, viz., a sulphuric acid solution containing 49 grammes of sulphuric acid per litre and a soda solution containing 40 grammes of soda per litre. Twenty-five cubic centimetres of normal acid are placed in a Referees' ammonia cylinder, and about 1 foot of gas passed slowly through, the gas being filtered from tarry matters before entering the cylinder by passing through a glass tube containing cotton wool. At the expiration of the experiment the glass cylinder is well washed out with distilled water into a porcelain dish, and the solution coloured with methyl-orange solution and titrated with normal caustic soda solution. The original 25 c.c. of acid would require 25 of the alkali for neutralisation, but the amount required after the experiment will be found to be less, owing to the ammonia in the gas having neutralised a portion of the acid. Each c.c. of the normal acid neutralised will represent 0·017 gramme of ammonia in the quantity of gas passed, and as there are 15·43 grains in a gramme, on multiplying 0·017 by 15·43 we get the quantity in grains, the quantity per 100 cubic feet being obtained by proportion. The gas can be measured by an aspirator or a meter, as is most convenient. If an aspirator is employed it will be found convenient to measure the water in ounces, since each ounce represents the one-thousandth part of a cubic foot.

(35) In determining the amount of ammonia in a sample of crude gas, 25 c.c. of normal sulphuric acid were employed. After passing 1·3 cubic feet of gas through the solution, it was found that it required 15·4 c.c. of normal alkali for neutralisation. From these data calculate the amount of ammonia in the gas per 100 cubic feet, in grains.

25 − 15·4 = 9·6 c.c. of acid neutralised by the NH_3 in the gas. 9·6 × 0·017 × 15·43 = 2·518 grains in 1·3 cubic feet. Consequently,

As 1·3 : 100 :: 2·518 : 193·7 grains per 100 cubic feet.

(36) How would you prepare the necessary solutions for quantitatively testing purified gas for ammonia?

The amount of ammonia in purified gas is usually stated in grains per 100 cubic feet, and the solutions and apparatus employed are those devised by the London Gas Referees. In making the test two solutions are required—a standard acid and a standard alkali solution. The standard acid solution is of such a strength that 25 measures will exactly combine with 100 measures of the alkali solution which contains one grain of alkali (usually ammonia). It is first necessary to prepare the standard acid solution by adding to a decigallon of distilled water 9·4 septems of pure sulphuric acid and well mixing. After cooling, 50 septems are taken out by a pipette, transferred to a beaker, diluted with distilled water, neutralized with ammonia, acidified with hydrochloric acid raised to the boiling point, and the sulphuric acid precipitated by barium chloride. The resulting precipitate of barium sulphate is treated in the usual manner, and if the solution is of the correct strength should weigh exactly 13·8 grains; if not, and the weight differs by more than 0·1 grain either way, it will be necessary to add water or sulphuric acid as the case may be, in order to bring it up to the correct strength. It will usually be found that the solution is too strong, necessitating the adding of more water in order to reduce the strength. In order to find out how much water is necessary to be added, the number of septems contained in the mixing vessel are divided by 13·8 and the quotient multiplied by the difference between 13·8 grains and the number of grains of sulphate of barium obtained. This will give the number of septems of water required to be added. On re-testing the solution it should now be found of the correct strength. The next operation is to prepare the ammonia solution to match the acid solution, by adding 5 septems of pure strong ammonia solution, specific gravity 0·88, to a decigallon of distilled water and well shaking the mixture. This must now be compared with the acid solution, by running 25 septems of the latter solution into a beaker, which is placed on a white tile underneath a septem burette divided into 100 parts. The solution is diluted with distilled water and coloured with a few drops of cochineal solution. The contents of the burette are then gradually run into the acid solution, which is kept well stirred during the process. As soon as the acid solution is neutralized the colour will change to purple, and if it takes exactly 100 septems of the alkaline solution to effect this, the solution is of the correct strength; if not, more water or ammonia must be added and fresh trials made until the correct strength is attained.

(37) Describe Wright's method for the determination of carbonic acid and sulphuretted hydrogen in gas.

This method consists in absorbing, in U-tubes, the SH_2 by a specially prepared cupric phosphate and the CO_2 by soda-lime; the amounts of the impurities absorbed being directly arrived at by the gain in weight of the tubes employed. The U-tubes recommended are those having hollow-ground stoppers, the hollow of the stopper being loosely filled with a plug of cotton wool. One limb of such a tube is filled with dried cupric phosphate and the other limb with pieces of calcium chloride free from alkalinity. After charging, a current of clean, dry coal gas is passed through the tube for three or four hours at the rate of about a foot an hour. The tube is then wiped with a clean, dry cloth, placed in the balance case for half an hour, and then weighed, when it is ready for use. The tube for the estimation of the CO_2 is similarly prepared, but substituting soda-lime for the cupric phosphate. A large drying cylinder filled with calcium chloride, and a 12-inch U-tube filled with pumice saturated with syrupy phosphoric acid, are also required. The apparatus is arranged as follows:—First, the tube containing the phosphoric acid, in order to remove the ammonia, then the drying cylinder, and next a T piece with cock for blowing gas through before starting the experiment. Connected to the T-piece is the phosphate tube, and following this the soda-lime tube, which is connected to a meter or aspirator. Gas is passed through the tubes at the rate of half a cubic foot per hour, for an hour, and at the expiration of the test the quantity of gas registered is noted, together with the temperature and the height of the barometer at the time of making the experiment. About half a cubic foot of clean coal gas is then passed through the apparatus, letting it pass in train through a wash bottle containing caustic potash before the phosphate and soda tubes. The tubes are then disconnected and weighed with the same precautions as before the experiment. The gain in weight of the tubes will represent the weight of the impurities absorbed.

(38) **The following are the results obtained in determining the quantities of CO_2 and SH_2 in crude gas by Wright's method. From the data given show how you can obtain the percentage by volume without referring to tables.**

For SH_2.	Grains.
Weight of copper phosphate tube after experiment	1626·2
,, ,, ,, ,, before ,, .	1622·1
Weight of SH_2 absorbed	4·1

For CO_2	Grains.
Weight of soda-lime tube after experiment . .	1875·4
,, ,, ,, before ,, . .	1866·2
Weight of CO_2 absorbed	9·2

Volume of gas passed, corrected to 60° and 30″ Bar. = 0·58 cubic foot.

The first operation is to obtain the weight of 1 cubic foot of SH_2, and this is arrived at by multiplying the weight of 1 cubic foot of hydrogen, which is 37·15 grains, by half the molecular weight of SH_2 (this rule applying to all compound gases, with a few exceptions). Since half the molecular weight of SH_2 is 17 (S=32, H=1), $17 \times 37 \cdot 15 = 631 \cdot 55$ grains as the weight of 1 cubic foot of SH_2. Now, since the gas contained 4·1 grains of SH_2 in 0·58 cubic foot, it contains 706·9 grains in 100 cubic feet, and as 1 cubic foot = 631·55 grains, 706·9 grains will be equal to 1·12 cubic foot, or 1·12 cubic feet in 100 cubic feet, or 1·12 per cent. by volume.

Similarly, in the case of the CO_2, the weight of a cubic foot of CO_2 is obtained by multiplying half the molecular weight of $CO_2 = 44 \div 2 = 22$ by $37 \cdot 15 = 817 \cdot 3$ grains. Then, since 0·58 cubic foot of the gas contained 9·2 grains of CO_2, 100 cubic feet will contain 1,586 grains, and as 1 cubic foot = 817·3 grains, 1,586 grains will equal 1·94 cubic feet, or 1·94 cubic feet in 100 cubic feet, or 1·94 per cent. by volume.

It is necessary to make a further calculation in order to get absolutely accurate results, due to the fact that the gas is measured after the abstraction of the impurities, making the original volume greater than that recorded by the meter. This is effected by adding to 100 the volume of the impurities taken out, thus: $1 \cdot 12 + 1 \cdot 94 = 3 \cdot 06 + 100 = 103 \cdot 06$ cubic feet. Then, in order to get the true percentage, we say

$$\text{As } 103 \cdot 06 : 100 :: 1 \cdot 12 : x \text{ for } SH_2,$$
$$\text{and As } 103 \cdot 06 : 100 :: 1 \cdot 94 : x \text{ for } CO_2.$$

(39) Describe, with sketch, Sheard's method for the estimation of CO_2 in crude gas.

Sheard's method for the estimation of CO_2 in gas consists in absorbing the CO_2 in a solution of barium hydrate of known strength, the resultant liquid being afterwards titrated with standard acid in order to ascertain the amount of free hydrate remaining in solution, from which the amount of carbonic acid absorbed can be deduced. The solution of barium hydrate employed is obtained by dissolving ordinary crystallised hydrate of baryta in water to saturation and syphoning off the clear liquid into a tightly stoppered bottle.

The strength of the clear liquid is then accurately determined by titrating it with decinormal hydrochloric acid. It should be approximately equal in strength to the acid. It is necessary to check the strength of the barium solution from time to time, since it is liable to absorb CO_2 from the atmosphere, and thus alter in strength. The apparatus employed is shown in Fig. 2. In addition to what is shown in the figure, two 50 c.c. burettes graduated into tenths, a supply of soft water free from carbonic acid, and a decinormal solution of hydrochloric acid (each c.c. of which is equal to 0·0022 gramme of CO_2) are required. In order to make a test with the apparatus, the gas must first be freed from sulphuretted hydrogen. A measured quantity of the barium hydrate solution, varying from 15 to 30 c.c. according to the quantity of CO_2 in the gas, is run from a burette into one of the absorption tubes, and from 10 to 20 c.c. into the other. If the smaller quantities mentioned are employed, an amount of water must be added to make the bulk of liquid about 30 c.c. in each tube. The tubes are then placed in the stand and the apparatus connected up as shown. In connecting the gas-supply tube to the inlet of the first absorption tube, gas must first be allowed to blow away and the indiarubber tube pushed over the bent glass tube while the gas is issuing, care being taken that the pressure of the gas supply is not so great as to force the gas through the liquid in the bulbs without the aspirator being in operation. In starting the experiment the measuring flask is brought under the tap of the aspirator and water allowed to flow so as to draw the gas in bubbles through

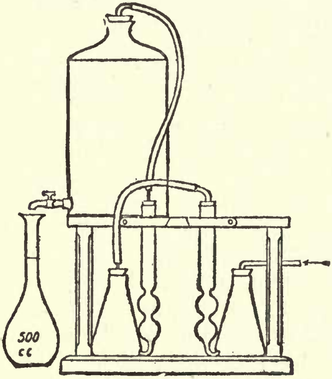


Fig. 2.

the liquid in the bulbs. The connections are then tried for tightness, by turning off the gas supply and the tap of the aspirator and observing whether the level of the liquid in the bulbs remains stationary or not. If everything is tight, the current of gas is continued until 500 c.c. have been drawn through the tubes, as shown by the water which has run out of the aspirator. The speed at which the gas passes is controlled so as to make the water coming from the aspirator to flow in not quite a continuous stream. The gas supply is disconnected from the inlet to the first tube, without stopping the flow of water, by slipping off the indiarubber tube as the water in the flask reaches the mark engraved on the flask. At the same time a fresh flask is brought under the aspirator, and 500 c.c. of air is drawn through the apparatus in order to drive forward the gas remaining in the reservoirs of the two absorption tubes at the end of the first aspiration. The tubes are afterwards disconnected, and a little water, free from carbonic acid, run through them. A few drops of phenol-phthalein solution are added, and the liquid is titrated with decinormal hydrochloric acid solution, the point of saturation being shown by the disappearance of the purple colour imparted to the liquid by the phenol-phthalein. The difference between the quantity of free barium hydrate found at the close of the experiment and the quantity originally placed in the tubes shows the amount of carbonic acid absorbed, and from this the amount of CO_2 in the gas may be calculated into grains per cubic foot or percentage by volume.

(40) **In a determination of the amount of CO_2 in a sample of gas by means of Sheard's apparatus, two gas-absorption tubes were charged, the first with 30 c.c. and the second with 20 c.c. of barium hydrate solution. After passing 500 c.c. of gas through the tubes, and performing the necessary operations, it was found that the first tube required 20·6 c.c. and the second tube 19·4 c.c. of decinormal hydrochloric acid for neutralisation, the solution of barium hydrate and the acid being of equal strength. From the data given calculate the amount of CO_2 in the gas as a percentage by volume and in grains per 100 cubic feet.**

In order to obtain the percentage by volume :—

	First Tube.	Second Tube.
Barium hydrate employed	30·0 c.c.	20·0 c.c.
$\frac{N}{10}$ acid required to neutralise the resultant liquid	20·6 c.c.	19·4 c.c.
Equivalent of barium hydrate neutralised .	9·4 c.c.	0·6 c.c.

The total equivalent of BaO,H_2O neutralised is 9·4 + 0·6 = 10 c.c., and as each c.c. is equal to 0·0022 gramme CO_2, 10 × 0·0022 = 0·022 gramme CO_2 in 500 c.c. of gas.

500 c.c. of CO_2 measured moist weigh 0·914 gramme, consequently

As 0·914 : 0·022 : : 500 : 12·03.

That is, there were 12·03 c.c. in 500 c.c. of gas. So to obtain the percentage, we say,

As 500 : 100 : : 12·03 : 2·40 = 2·40 per cent. by volume.

In order to obtain the weight in grains of CO_2 per cubic foot of gas, we proceed as follows :—

10 × 0·0022 = 0·022 gramme CO_2, and this multiplied by 15·432 will give grains per 500 c.c. = 0·339504.

A cubic foot = 28,315 c.c. ; consequently,

As 500 : 28315 : : 0·339504 : 19·22 = 19·22 grains per cubic foot of gas. 19·22 × 100 = 1922 grains CO_2 per 100 cubic feet of gas.

(41) Describe methods for approximately arriving at the amounts of CO_2 and SH_2 in crude gas.

The amount of CO_2 in crude gas may be determined by a method devised by Folkard. The scrubbed gas is first passed through a small oxide purifier, and is then collected in an inverted bottle having a capacity of about 24 ounces. When all the air has been expelled, a measured quantity of baryta water, contained in a glass tube passing through a cork, is placed in the bottle and the latter turned upside down. The baryta water is caused to run over the sides and bottom of the bottle, and after three or four minutes contact it will have absorbed all the CO_2 in the gas. The cork and tube are then removed, a few drops of 1-20th per cent. solution of phenol-phthalein added, and standard acid is run in, drop by drop, until the pink colour disappears. The quantity of acid required to just decolorise the same amount of baryta water and phenol-phthalein having been previously ascertained, any difference will be due to the CO_2 in the gas, from which the percentage of that impurity can be easily deduced. The apparatus consists of a white-glass "gas bottle," having a capacity of about 24 ounces, or 700 c.c.; a glass measure holding 5 c.c. of nearly saturated baryta water; a glass measure holding 10 c.c. of standard acid, graduated into tenths; and a pipette for transferring the standard acid, drop by drop, to the baryta solution in the gas bottle; a cold saturated solution of baryta water to which 5 or 10 per cent. of water has been added; a solution of phenol-phthalein ($\frac{1}{2}$-gramme in 1,000 c.c. of a mixture of methylated spirit and water); standard sulphuric acid made by taking a fluid ounce of the ordinary 10 per cent. acid used for liquor testing and making it up to exactly 8$\frac{1}{2}$ fluid ounces with water.

The details of the test are as follows. The relative strengths of the baryta and acid are first determined, and the gas bottle is filled with gas by upward displacement; then 5 c.c. of baryta water are added in the manner previously described. After the absorption of the CO_2, the gas bottle is held with the neck upwards, which causes the liquid to run out of the baryta measure into the bottle; the measure is then removed and a few drops of phenol-phthalein added to the liquid in the gas bottle. The standard acid is now added, drop by drop, to the gas bottle until the pink colour disappears. The baryta measure is then reinserted in the neck of the gas bottle and the colourless liquid in the bottle caused to enter the measure so as to wash out the small quantity of baryta clinging to the sides of the measure; this will have the effect of causing the pink colour to reappear, and more acid must be added until the colour again disappears. The quantity of acid used is noted, and the difference between the amount of acid required and the original amount gives the amount of CO_2 in the gas. The relative sizes of the gas bottle and baryta measure and the strength of the acid are so arranged that it is only necessary to multiply by

4 and divide by 10 to arrive at the percentage by volume of CO_2 in the gas. Thus, supposing that 5 c.c. of the baryta water originally required 4·3 c.c. of the acid solution, and that after the absorption of the CO_2 it required 2·2 c.c., then $4{\cdot}3 - 2{\cdot}2 = 2{\cdot}1$ c.c. due to the carbonic acid in the gas. Then $2{\cdot}1 \times 4 = 8{\cdot}4 \div 10 = 0{\cdot}84$ per cent. by volume of CO_2. Should there be 2 per cent. of CO_2 in the gas it will then be necessary to use 10 c.c. of the baryta solution.

SH_2 in scrubbed gas may also be determined by a method devised by Folkard. The apparatus consists of a glass tube about $\frac{3}{4}$-inch in diameter, closed at one end, and having a capacity of 60 septems. This contains the gas to be tested, and it is filled by displacement by holding it with the open end downwards over a lamp cock furnished with a piece of indiarubber tubing 3 or 4 inches long, so that the gas is conducted to the top end of the tube. A smaller tube is also provided, graduated into septems, and furnished with a sliding stopper, which can be adjusted for varying quantities of solution from 1 to 20 septems. The solution employed is iodine of such a strength that each septem is equal to 0·1 per cent. of SH_2 in the sample of gas tested. The apparatus is employed in the following manner. The gas tube is filled with gas in the manner previously described, and while it is filling the sliding stopper in the solution tube is adjusted to the number of septems approximating to the percentage of SH_2 thought likely to be present. The tube is filled to the top with the iodine solution, and while holding the gas tube over the gas supply, the solution tube is inserted up to the stopper, and whilst holding the latter firmly in its place, the solution is briskly shaken up with the gas in the tube. The iodine attacks the sulphuretted hydrogen, and if sufficient of the solution is taken all the SH_2 should be decomposed. In order to ascertain if this is the case or not, a small slip of acetate of lead paper is inserted into the tube by partially withdrawing the stopper. Should the paper become blackened it will be necessary to repeat the operations detailed above, taking a fresh sample of gas and readjusting the stopper of the solution tube so as to add more iodine; on the other hand, should the lead paper remain unaffected it will still be necessary to make another experiment, but this time with a less amount of iodine solution; and the experiments must be continued until a sufficiently close approximate is obtained, which, with a little practice, is soon arrived at. The method of Professor Wanklyn is based on similar principles, but he uses his well-known bottle, and employs a solution of lead acetate in place of a solution of iodine.

Sulphuretted hydrogen may also be rapidly determined by means of iodine and Bunte's burette. The solution of iodine employed should contain 1·134 grains of iodine in the litre; each c.c. of the solution would then correspond to 0·1 c.c. of SH_2. The gas is introduced into the burette in the usual way = 100 c.c.. The remaining water is then sucked down to a lower mark; the iodine solution is now admitted in small quantities, with repeated shaking. At first it will be found to be rapidly decolorised, and the liquid becomes milky through the separation of sulphur, but the slightest excess of iodine makes the milky fluid distinctly yellow, indicating the end of the reaction. From the number of c.c. of iodine solution required to bring about this reaction the percentage of SH_2 is deduced.

CHAPTER V.

GAS ANALYSIS.

(42) Describe, with sketch, Bunte's apparatus, stating the purpose for which it is generally employed.

Bunte's apparatus is shown in Fig. 3, the principal portion being the burettes, A and B, which have a capacity of about 110 cubic centimetres each. The burettes are graduated from zero to 100 c.c. above the zero mark, and to about 10 cubic centimetres below, the graduations being in fifths of a cubic centimetre. Each burette has a three-way stock-cock with a projecting hollow stem for the purpose of conveying gas to the burette, and is surmounted by a funnel, *d*, with a mark engraved on it at about 25 cubic centimetres. The burette has a stop-cock at the bottom terminating in a capillary tube for attaching to an indiarubber tube. A water-bottle, C, and a suction bottle, D, also form a portion of the apparatus.

There are various ways of using the apparatus, the following being the one generally employed:—The burette, A, is filled with water from the bottle, C, the funnel, *d*, being filled to the mark. The tube from the water-bottle is then clamped and disconnected, and the aspirator, D, connected to the burette. A tube conveying the gas to be tested is connected to the projecting portion of the cock, *k*, and by opening the cock, *a*, and the bottom cock, G, the water flows from the burette and is followed by gas, the water being allowed to run nearly out. The bottle, D, is then disconnected and replaced by C, water being run into the burette until the graduation of, say, 6 is reached. The gas being thus compressed, water is allowed to run out until the zero mark is reached, when the stop-cock, G, is closed and *k* steadily opened, so as to allow gas to bubble through the water in the funnel until exactly 100 c.c. are contained in the burette at normal atmospheric pressure. It is not always possible, however, to exactly hit the 100 c.c. mark.

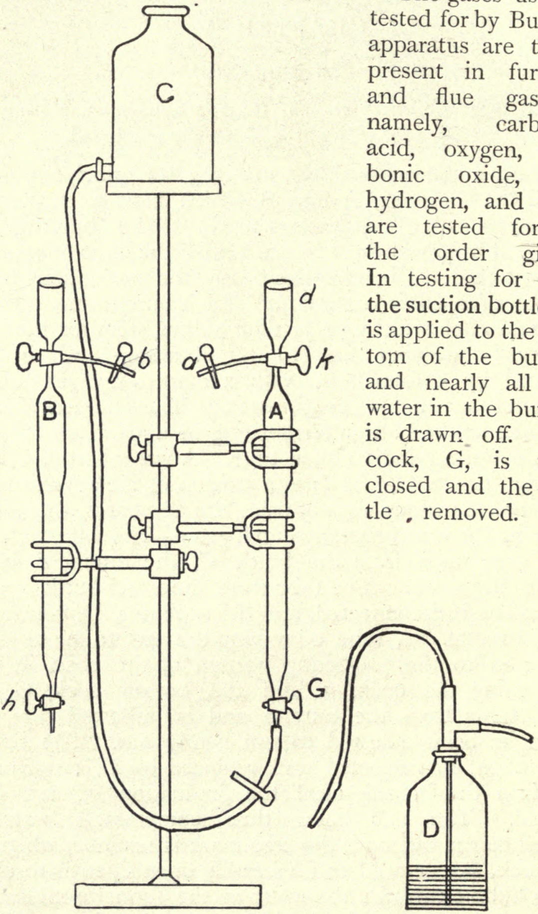


Fig. 3.

The gases usually tested for by Bunte's apparatus are those present in furnace and flue gases—namely, carbonic acid, oxygen, carbonic oxide, and hydrogen, and they are tested for in the order given. In testing for CO_2 the suction bottle, D, is applied to the bottom of the burette and nearly all the water in the burette is drawn off. The cock, G, is then closed and the bottle removed. A solution of caustic potash is next applied to the bottom of the burette, the cock, G, is opened, and owing to the vacuum existing some of the solution will be drawn up; the cock, G, is then closed, and the burette taken from its stand and well shaken. A second application of the potash solution is then made. If no more is taken up the absorption is complete, but if more is taken up, the first operation must be repeated until absorption is complete. The stop-cock, *k*, is next opened and water allowed to flow into the burette. When the flow ceases, the stop-cock, *k*, is closed, when the remaining gas will be at the original atmospheric pressure. The reduction in volume is the amount of CO_2 in the gas, and is read off direct. The determination of oxygen is conducted on the same lines, first drawing off the potash solution by means of the suction bottle, and using a solution of pyrogallate of potash as the absorbent. If oxygen is present the pyrogallate turns a purplish black colour. When absorption is complete the reduction of volume is read off as before; the difference between that due to the treatment with potash and with pyrogallate representing the percentage of oxygen. In order to estimate carbonic oxide the burette must be first cleared of all traces of pyrogallate by opening the top and bottom stop-cocks and allowing a stream of water to run through the burette. An acid solution of cuprous chloride is used as the absorbent, in the same manner as the previous solutions; but before measuring the reduction in volume it is necessary to run in a solution of caustic potash, in order to remove the acid vapours given off from the cuprous chloride. When this has been effected the reduction in volume will show the percentage of carbonic oxide. Hydrogen is estimated by combustion with heated palladium wire. In order to do this it is necessary to mix the hydrogen with a certain proportion of air. This is done by expelling a portion of the gas remaining in the burette until a definite portion of the original sample remains. The cock, *k*, is then opened to the atmosphere and an excess of air allowed to enter the burette. The volume of the mixture is ascertained after establishing atmospheric pressure. The two burettes are then connected by indiarubber tubing and by a piece of hard glass tube, containing palladium wire, which is heated by a bunsen burner. The gas is caused to pass from burette, A, to burette, B, and back again. It is then allowed to cool, and when cool the volume is reduced to atmospheric pressure as before. The hydrogen in burning has been converted into water, so that two-thirds of the reduction in volume will give the amount of hydrogen.

(43) In the estimation of two samples of gas from different portions of a retort setting by means of Bunte's apparatus the following data were obtained. From these, calculate the composition of the gases and state what portion of the setting they were taken from.

	c.c.
(*a*) Original volume of gas in burette	99·4
After treatment with caustic potash there remained	81·4
,, ,, potassium pyrogallate	80·4
,, ,, cuprous chloride	80·4
A portion of the gas expelled, leaving	40·2
Air admitted, making the volume	88·2
After combustion there remained	82·2

	c.c.
(*b*) Original volume of gas in burette	100
After treatment with caustic potash there remained	94·6
,, ,, potassium pyrogallate	94·6
,, ,, cuprous chloride	70·6
A portion of the gas expelled, leaving	35·3
Air admitted, making	87·3
After combustion there remained	76·1

(*a*) 99·4 c.c. – 81·4 c.c. = 18 c.c. reduction ; but as 99·4 c.c. only were used, the percentage would be— 18·11 CO_2.

81·4 c.c. – 80·4 c.c. = 1 c.c. = O 1·00 O.

0·00 CO.

88·2 c.c. – 82·2 c.c. $= 6 \times \frac{2}{3} = 4 \times 2 =$ 8·00 H.

Leaving nitrogen, by difference . . 72·89

100·00

This gas is evidently a spent gas.

c.c.

(*b*) 100 c.c. − 94·6 c.c. = 5·4 CO_2

0·0 O.

94·6 − 70·6 = 24·00 CO.

$87{\cdot}3 - 76{\cdot}1 = 11{\cdot}2 \times \frac{2}{3} = 7{\cdot}46 \times 2$ = 14·92 H.

55·68 N.

100·00

The result of the analysis of this sample shows it to have been taken from the producer. (In the calculation of H the multiplier 2 is used because only half the gas was taken).

(44) **Describe, with sketch, some form of Orsat's apparatus.**

There are various modifications of Orsat's apparatus. The one shown in Fig. 4 is that devised by Lunge. It is contained in a wooden case, with removable back and front, for convenience of transport. The apparatus consists of a measuring burette, *a*, having a capacity of 100 c.c., contained in a water jacket. It is connected at its base with a water-bottle, by means of which the level in the burette can be raised or lowered, so that the gas may be measured under atmospheric pressure. The top of the burette communicates by means of thick-walled narrow-bore glass tubing, provided with stop-cocks, with a number of absorption vessels filled with fine glass tubes placed vertically so as to present a large surface to the gas. The liquid expelled by the pressure of the gas passes through a connecting capillary tube into the hinder portion of the absorption vessel, which is similar in shape to the front, but empty, and is either open at the top or, preferably, connected to a small bladder, so as to exclude air and to furnish pressure to drive the liquid back into the front vessel if required. The end of the capillary tube communicating with the absorption vessels terminates in a three-way cock, by means of which the gas to be tested can be put into communication with the burette, or the contents can be placed under atmospheric pressure. The absorption vessels are filled with various reagents according to the gases to be tested, a common arrangement being the first one filled with a solution of caustic potash for the absorption of CO_2, the second with potassium pyrogallate for the absorption of oxygen, and the third with a solution of acid cuprous chloride for the absorption of carbonic oxide. In order to keep the cuprous chloride solution in an unchanged state it is kept in constant contact with copper spiral placed in the glass tubes with which the vessel is filled.

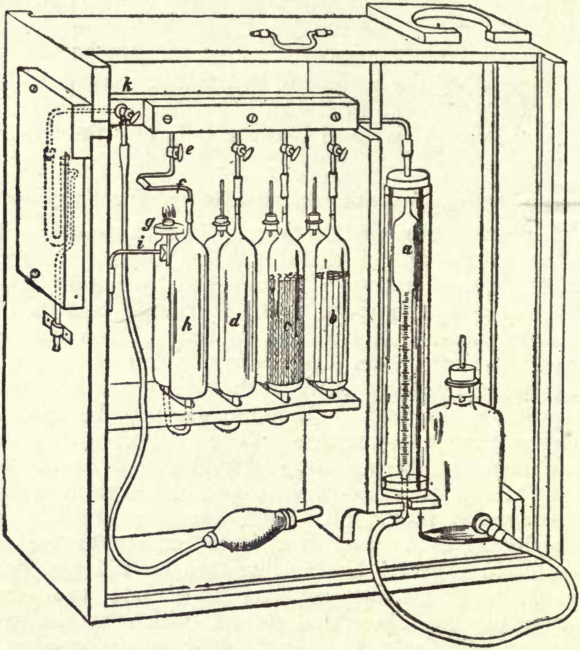


Fig. 4.

The apparatus is manipulated as follows: Place the water-bottle on the top of the case, open the three-way cock, *k*, to the atmosphere and allow the burette, *a*, to fill with water up to the capillary mark. Connect the end of the capillary tube with the gas supply and the lower end of the three-way cock, *k*, with an indiarubber pump, by which the air is removed from the conducting tube. The gas is now aspirated into the burette by lowering the water-bottle and turning the tap, *k*, through 90 degrees. The water in the burette is run off a little below the zero mark, the cock, *k*, is closed, and the gas in the burette is compressed by raising the water-bottle until the water rises above the zero mark. The connecting indiarubber tubing is then lightly squeezed by means of a pinch-cock, and after lowering the water-bottle the excess of water is allowed to run down to the zero mark by cautiously loosening the pinch-cock. The tap, *k*, is then opened for an instant in order to put the burette under atmospheric pressure, when there will be exactly 100 c.c. of gas contained in the burette. The various gases are then absorbed, one at a time, in the order previously given, by raising the water-bottle and opening the cock on the particular absorption vessel, the remaining cocks being, of course, kept closed. The absorption is hastened by causing the gas to travel several times from the absorption vessel to the burette and back, by alternately lowering and raising the water-bottle. When the absorption is complete the level of the liquid in the vessel is adjusted to the correct height and the communicating stop-cock closed. The reading of the contents of the burette is then made by raising the water-bottle until its contents are at the same level as the water in the burette. The decrease of volume found in the first vessel gives the percentage, by volume, of carbonic acid. The amount of oxygen is determined in a similar manner in the second absorption vessel, and the carbonic oxide in the third vessel. After having been passed into the cuprous chloride solution, the gas should be passed into the vessel containing caustic potash before measuring. It will be seen from the above that the apparatus is well adapted for the analysis of generator and flue gases.

(45) Describe, with sketches, some form of apparatus by which the complete analysis of gas can be made.

One of the simplest forms of apparatus for determining the composition of gas is probably that of Hempel, which consists of two glass tubes fitted into stands, one of the tubes (the burette proper) being graduated to 100 c.c. and the other one plain. They are connected at the bottom by an indiarubber tube, as shown in Fig. 5. The burette is used in conjunction with a series of pipettes. These being filled with special absorbents, on submitting the gas originally in the burette to their action, one after another, the composition of the gas may be ascertained. Fig. 6 shows the gas burette connected to an absorption pipette. The burette is filled with the gas to be examined by first filling both tubes completely with water. The cock on the top of the burette is then closed, and the bulk of the water poured out of the plain level-tube, the indiarubber connecting tube being tightly compressed during the operation so as to prevent the ingress of air to the burette. The latter is then connected by a small glass tube with the gas to be examined, when, on lowering the level-tube, the gas flows in and forces the water from the burette into the level-tube. The pressure is then regulated by raising or lowering either of the tubes until both are level, when the volume of gas is read off. The pipette shown in Fig. 6 is one of the series used with the apparatus, and is known as the simple pipette. The portion, *a*, is filled with caustic potash, which reaches into the syphon bend of the capillary tube, the bulb, *b*, remaining nearly empty. In order to make an absorption, the capillary U-tube is connected with the burette containing the measured gas by the small capillary tube, *E*, the pinch-cock, of course, being open; then, on raising the level-tube, the gas is driven over into *a*, where it displaces a portion of liquid into *b*. When the whole of the gas has been transferred, the pinch-cock is closed, and the absorption expedited by well shaking the gas with the absorbent. When absorption is complete, communication with the burette is re-established, and the gas syphoned back into the latter to be measured, the difference representing the percentage of the particular constituent absorbed.

In the analysis of coal gas the following would be the procedure. The gas would first be submitted to the action

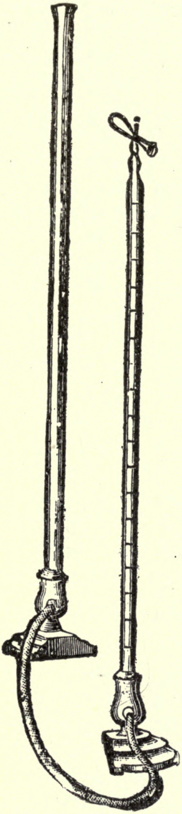


Fig. 5.

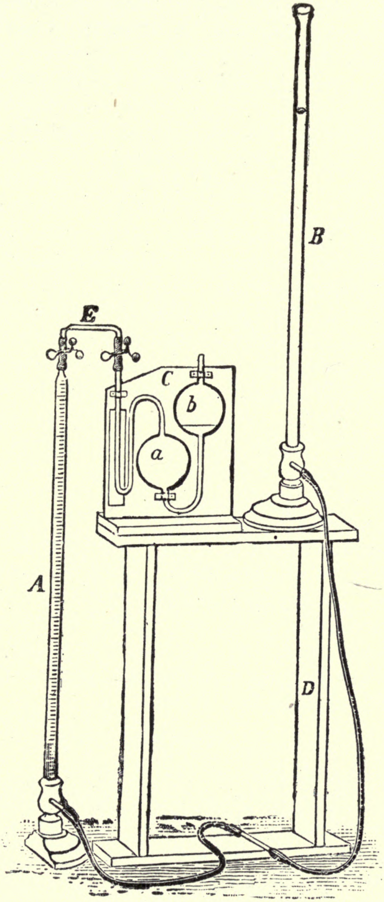


Fig. 6.

of caustic potash, contained in a special pipette, for the absorption of carbonic acid; it would then be transferred to another pipette containing pyrogallate of potash for the absorption of oxygen. This would be followed by another pipette containing fuming sulphuric acid for the absorption of olefines and benzene vapour; and the gas would next be transferred to another one containing acid cuprous chloride for the absorption of carbonic oxide. There will then be left for estimation the hydrogen, marsh gas and nitrogen. The hydrogen is burned and the marsh gas exploded, the nitrogen being estimated by difference. In determining the hydrogen after the absorbable constituents have been eliminated, the remaining gas is returned to the cuprous chloride pipette, and 20 c.c. of the gas is returned to the burette and air added in excess of that required for the complete combustion of the hydrogen, the burette being then attached to an absorption pipette filled with water only. The capillary attachment between the burette and the pipette contains a thread of asbestos, upon which a quantity of finely-divided palladium has been deposited. As the gas is slowly transferred from the burette to the pipette it passes over the prepared asbestos, which is gently warmed by a small flame, and the oxygen and hydrogen are thereby caused to unite. The gas is finally returned to the burette and measured. The amount of contraction, multiplied by $\frac{2}{3}$, will give the volume of hydrogen. Marsh gas is determined by exploding with an excess of air or oxygen in a special explosion pipette containing mercury. The result of the explosion is the conversion of the marsh gas into carbonic acid and water, thus

$$CH_4 + 2O_2 = CO_2 + 2H_2O\,;$$

the marsh gas, on being burned, yielding its own volume of CO_2, and three volumes of mixed gases shrinking to one volume (CO_2), since the amount of space occupied by the water is inappreciable. The contraction, therefore, is two-thirds of the total volume of the reacting gases, or to twice the CO_2 produced, or to twice the volume of the marsh gas burned. After the explosion the gas is transferred to the burette and measured. The explosion pipette is then disconnected and replaced by a pipette containing caustic potash, and the CO_2 is absorbed in the usual manner

(46) In the determination of the composition of a sample of gas by Hempel's apparatus the following results were obtained. From the data given calculate the percentage composition of the gas :—

	c.c.
Gas taken	100
After absorption by caustic potash . . .	98·3
,, ,, potassium pyrogallate . .	98·0
,, ,, fuming H_2SO_4 . . .	93·9
,, ,, cuprous chloride . . .	87·8

20 c.c. of the gas were then transferred to the burette, 46 c.c. of air added and the mixture passed over palladiumised asbestos. The volume after combustion was 50·5 c.c. To the 50·5 c.c. of gas, 22 c.c. of oxygen were added, the mixture exploded and the CO_2 absorbed by caustic potash. The volume after explosion was 54·5 c.c. and after the absorption of CO_2, 45·5 c.c.

$$\begin{aligned}
100 - 98{\cdot}3 &= 1{\cdot}7 = CO_2.\\
98{\cdot}3 - 98 &= 0{\cdot}3 = O.\\
98 - 93{\cdot}9 &= 4{\cdot}1 = \text{Olefines, etc.}\\
93{\cdot}9 - 87{\cdot}8 &= 6{\cdot}1 = CO.\\
&\ 45{\cdot}21 = H.\\
&\ 39{\cdot}51 = CH_4.\\
&\ \ 3{\cdot}08 = N \text{ (by difference).}\\
&\ \overline{100{\cdot}00}
\end{aligned}$$

$$20 + 46 = 66 - 50{\cdot}5 = 15{\cdot}5 \times \tfrac{2}{3} = 10{\cdot}3$$

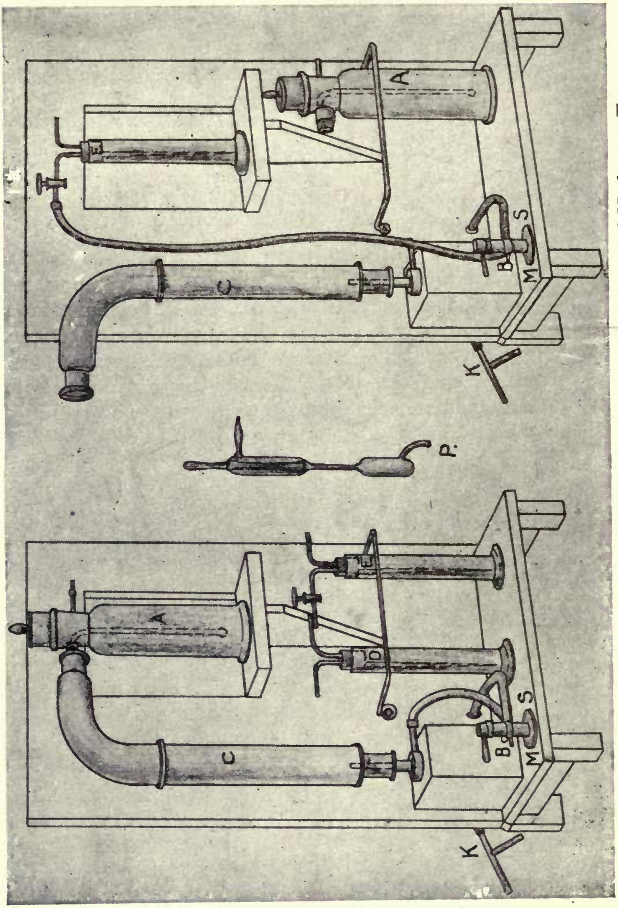
$$\frac{10{\cdot}3 \times 87{\cdot}8}{20} = 45{\cdot}21 \text{ H.}$$

$$\begin{aligned}
50{\cdot}5 + 22 &= 72{\cdot}5.\\
72{\cdot}5 - 54{\cdot}5 &= 18{\cdot}0.\\
54{\cdot}5 - 45{\cdot}5 &= 9{\cdot}0 = CO_2 = CH_4.
\end{aligned}$$

$$\frac{9 \times 87{\cdot}8}{20} = 39{\cdot}51 = \text{percentage } CH_4.$$

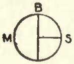
(47) Describe and illustrate Somerville's apparatus as employed for estimating the quantities of sulphur and sulphuretted hydrogen in coal gas.

Somerville's apparatus for estimating the total sulphur

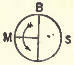


Sulphur Compounds Test. Fig. 7. Sulphuretted Hydrogen Test.

compounds and sulphuretted hydrogen in coal gas is shown in Fig. 7. The apparatus is put together in the following manner:—The gas supply is connected from the main to the inlet of the tee-piece, K, one outlet of which is connected to a test meter and the other to the three-way cock inlet, S. Then the meter outlet is connected to the three-way cock inlet, and, finally, the burner to the three-way cock outlet, B. The meter should have a dial recording $\frac{1}{1000}$ cubic foot.

The gas is then lighted at the burner by turning the cock, thus 

and after placing the burner in the combustion tube, C, it is regulated to burn the gas at the rate of 0·5 cubic foot per hour.

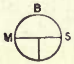
To carry out a test for sulphur compounds, we then proceed as follows:—Take 100 c.c. of iodine solution with about 3 c.c. of starch indicator. Place this into the vessel, A, and fill up to within 1½ inches of the inlet and outlet tubes. Connect the outlet of A to the water jet vacuum pump, P, and start the vacuum. Then turn the gas on to the meter, by turning the cock from S to M, thus 

in the direction indicated by the arrow.

The position of the meter hand should be slightly behind the zero mark when the gas is turned on to the meter, and when the hand passes the zero mark the vessel, A, is connected to the combustion tube by pushing the cork into the mouth. The inlet tube of A should have the cork well up against the heel, so that the end protrudes beyond the cork.

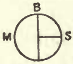
The blue colour of the solution will be discharged by the sulphur in the gas, and the approach of the decoloration may be known by the solution assuming a lavender tint. When the solution is colourless, the gas is immediately turned off, and the reading of the meter taken. From a table supplied with the apparatus, the total sulphur in grains per 100 cubic feet is obtained by noting the gas consumption.

The method employed when testing for sulphuretted hydrogen is as follows:—

Connect the gas to the inlet of the three-way cock, S, and turn the cock, thus 

. Into the vessel, E, place

10 c.c. of iodine solution with 10 c.c. of starch, and fill up with water to within 1 inch of bottom of cork. The inlet tube of E is fitted with a capillary tube, which should have a bore not greater than 0·5 mm., and this should nearly touch the bottom of the vessel, some allowance being made in the rubber connection to prevent breaking when the cork is inserted. Connect the outlet tube with the aspirator, and turn on the aspirator outlet to see that everything is tight. Now place the small measure under the aspirator outlet.

Now turn on the gas thus , and allow it to escape for a second or two, next connect the outlet of the three-way cock, B, to the inlet of the test vessel, E. Turn on the glass stopcock very carefully until a fine stream of water runs from the aspirator.

The H_2S will discharge the colour of the solution when sufficient gas has passed. With gas high in H_2S, the disappearance of the colour will be very rapid.

When the colour has been discharged, the glass stopcock, E, is turned off, and then the aspirator cock and the volume of water in the measure read off. This is equivalent to the gas consumption, and the total H_2S, in grains per 100 cubic feet, will be found opposite the reading in the table provided.

When the gas contains less than 100 grains per 100 cubic feet, the presence of any hydrocyanic acid will interfere with the test, by giving too high a result, as this impurity will also discharge colour if sufficient gas be passed. With gas high in H_2S, the amount of HCN present would not interfere with the test, owing to the small volume of gas used, but with gas containing only traces of H_2S, both impurities are recorded. To obviate this a duplicate test is made. The gas is first tested in the ordinary way, and the representative figure per 100 cubic feet noted. Then it is tested after passing through a purifier containing a convenient lead salt, and the representative figure again noted. This second figure, deducted from the first, gives the H_2S per 100 cubic feet.

Somerville's apparatus is one by which rapid determinations may be carried out. A test—in which the whole of the sulphur is recorded—occupies from 3 to 6 minutes, and a test for sulphuretted hydrogen may be carried out in from 5 seconds to 2 minutes.

CHAPTER VI.

HEATING OF RETORT SETTINGS.

(48) What is the essential difference in principle between heating by the ordinary direct-fired system and the system of gaseous firing?

The essential difference between the two systems of firing depends principally upon the fact that the carbon in the coke, which is the usual fuel employed, is capable of combining with either one or two equivalents of oxygen, according to the manner in which the air necessary for combustion is admitted to the furnace. In a direct-fired furnace, with a shallow fuel bed and an unrestricted supply of air, the carbon in the fuel unites with two equivalents of oxygen, forming carbonic acid, thus $C + O_2 = CO_2$, and the combustion is completed in the furnace itself, whereas in the case of gaseous firing the air supply to the fuel is limited to that which will produce carbonic oxide, which can be burnt to carbonic acid at any desired point by the admission of a second equivalent of oxygen in the form of secondary air, thus $CO + O = CO_2$.

(49) Give the heating values of the various constituents of which the ordinary fuel employed in heating gas retorts is composed.

The following are the heating values of the principal constituents of coke:—

			Heat Units per Pound of Substance.
Carbon	burning to	CO_2	14,500
,,	,,	CO	4,000
CO	,,	CO_2	4,500
Hydrogen	,,	water (vapour) . .	52,000
,,	,,	,, (liquid) . .	62,032
Sulphur	,,	SO_2 . . .	4,100

(50) Show, by calculation, that whether carbon is burned to CO_2 direct, or in two stages, the amount of heat generated per unit weight of carbon is the same in both cases.

This may be explained as follows. For the complete combustion of carbon to carbonic acid one atom of carbon requires two atoms of oxygen, thus $C + O_2 = CO_2$, or 12 parts by weight of carbon require for complete combustion 32 parts of oxygen, or each pound of carbon requires 2·666 pounds of oxygen, producing 3·666 pounds of carbonic acid. In the production of carbonic oxide we require only one equivalent of oxygen, thus $C + O = CO$. Consequently, 12 pounds of carbon require only 16 pounds of oxygen, or 1 pound of carbon requires 1·333 pounds of oxygen, producing 2·333 pounds of carbonic oxide. In the conversion of carbonic oxide to carbonic acid 28 pounds of carbonic oxide require 16 pounds of oxygen, thus $CO + O = CO_2$, or each pound of carbonic oxide requires 0·571 pound of oxygen, producing 1·571 pounds of carbonic acid.

It will be seen, on referring to the table in answer to Question 49, that 1 pound of carbon burning to carbonic oxide generates 4,000 B.Th.U.; and, as just explained, produces 2·333 pounds of carbonic oxide; and since carbonic oxide on burning to carbonic acid produces 4,500 B.Th.U. per pound, $2·333 \times 4,500 = 10,500$ B.Th.U., or a total of 14,500 B.Th.U., which is the same amount as if the carbon had been burned direct to CO_2.

(51) Show how to calculate the amount of oxygen and air requisite for the combustion of 1 lb. of the following substances:—

Carbon	burning to	CO_2
”	”	CO
CO	”	CO_2
Hydrogen	”	H_2O

The atomic weight of carbon being 12 and that of oxygen 16, in the burning of carbon to CO_2 12 parts of carbon require 32 parts of oxygen; consequently 1 pound of carbon requires 2·666 pounds of oxygen—as 12 : 1 : 32 : 2·666.

Air contains 22·5 per cent. by weight of oxygen, or 1 pound of oxygen is equivalent to 4·44 pounds of air.

On multiplying the oxygen equivalent, 2·666, by 4·44 we get 11·837 pounds as the weight of air necessary for the complete combustion of 1 pound of carbon to CO_2. The weight of a cubic foot of air may be taken as 0·0761 pound. On dividing 11·837 by 0·0761 we get the equivalent in cubic feet.

In the case of carbon burning to CO, since the amount of oxygen required is exactly half that required to burn the carbon to CO_2, the amount of air will follow in the same ratio, the amounts being arrived at by dividing the quantities obtained in the first example by 2. In the case of CO burning to CO_2, 28 parts of CO require 16 parts of oxygen, so 1 pound of CO will require 0·571 pound of oxygen. As 28 : 1 :: 16 : 0·571.

And multiplying 0·571 by 4·44 we get 2·535 pounds as the weight of air required; and dividing this by 0·0761 we get 33·3 cubic feet as the volume of air required.

In the case of hydrogen burning to H_2O, 2 parts of hydrogen require 16 of oxygen, or 1 pound of hydrogen requires 8 pounds of oxygen. As 2 : 1 :: 16 : 8.

Multiplying this by 4·44 we get 35·52 pounds as the weight of air, and dividing this by 0·0761 we get the corresponding volume = 466·7 cubic feet..

(52) A fuel has the following composition :—

	Per Cent.
Carbon	89
Hydrogen	2
Oxygen	0·50
Sulphur	1·50
Ash, etc.	7

Show how to calculate the theoretical amount of heat capable of being evolved from the fuel on perfect combustion.

	B.Th.U.
0·89 of carbon burning to CO_2 at 14,500 B.Th.U. =	12,905
0·02 of hydrogen burning to H_2O vapour at 52,000 B.Th.U. =	1,040
0·015 of sulphur burning to SO_2 at 4,100 B.Th.U. =	61·5
	14,006·5

Total heat units per pound of fuel = 14,006·5.

(53) What do you understand by the term specific heat? Give the specific heat of some substances having a bearing on the working of retort furnaces.

The specific heat of a body may be defined as the amount of heat required to heat the body 1° Fahr. as compared with the amount of heat required to raise an equal weight of water through the same range of temperature. The following are the specific heats of some substances which are connected with retort furnaces, the specific heats given being at "constant pressure":—

Water	1·000	Carbonic acid	0·2164
Carbonic oxide	0·2479	Air	0·2379
Oxygen	0·2182	Coke	0·200
Nitrogen	0·2440	Ashes	0·200
Hydrogen	3·4046	Fire-brick	0·200
Sulphurous acid	0·155		

(54) State the rule for obtaining the theoretical temperature of a furnace from the heat of combustion.

The theoretical temperature of a furnace may be obtained by dividing the heat units developed by the combustion of one pound of the fuel by the weight of the products in pounds multiplied by the specific heat of the products.

(55) Taking the fuel whose analysis is given in Question 52, show, by calculation, what the approximate temperature of the furnace would be with (*a*) just sufficient air to burn the carbon of the fuel to carbonic acid, and (*b*) with an excess of 100 per cent. of air as in a direct-fired furnace.

In answering this question we will assume that we are dealing with one pound of fuel. Multiply the percentage of each constituent of the fuel by the amount of air in pounds required for its combustion. Thus

$$\begin{array}{rr}
 & \text{lbs.} \\
89 \times 0{\cdot}1185 = & 10{\cdot}5465 \\
2 - \frac{0{\cdot}5}{8} \times 0\;3550 = & 0{\cdot}6879 \\
1{\cdot}5 \times 0{\cdot}044 = & 0{\cdot}0660 \\
\hline
 & 11{\cdot}3004
\end{array}$$

This gives the weight of air required for combustion, and adding $0{\cdot}89 + 0{\cdot}02 + 0{\cdot}015$ to this, we get $12{\cdot}2254$ as the weight of the gaseous products. It was shown in the answer to Question 52 that the heat units per pound of the fuel were 14,006·5. On dividing this by $12{\cdot}2254 \times 0{\cdot}245$ (the average specific heat) we get

$$\frac{14{,}006{\cdot}5}{12{\cdot}2254 \times 0{\cdot}245} = 4{,}676^\circ \text{ Fahr. as the temperature.}$$

Now, on admitting twice the quantity of air the weight of air will be doubled, so multiplying 11·3004 by 2 we get 22·6008, and adding $0{\cdot}925 = 23{\cdot}5258$. Then in order to obtain the temperature

$$\frac{14{,}006{\cdot}5}{23{\cdot}5258 \times 0{\cdot}242} = 2{,}460^\circ \text{ Fahr.}$$

The item $2 - \frac{0{\cdot}5}{8} \times 0{\cdot}355 = 0{\cdot}6879$ may be explained as follows:—2 parts by weight of hydrogen combine with 16 parts of oxygen to form water, or 1 part of hydrogen with 8 of oxygen. Consequently, in any fuel containing hydrogen and oxygen $\frac{O}{8}$ = weight of hydrogen required to convert the oxygen present into water, and $H - \frac{O}{8}$ represents the hydrogen which is available for the production of heat.

(56) Describe the action of steam in a furnace, and the effect of water vapour on the air admitted.

When steam is admitted to a generator furnace it is decomposed, by passing through the incandescent coke, into carbonic oxide and hydrogen, in accordance with the following equation:—$H_2O + C = CO + H_2$. The decomposition causes a certain amount of heat to be absorbed, which has the effect of reducing the temperature of the gas issuing from the producer, but the heat lost in the producer is regained in the process of combustion in the setting, the ultimate result being that there is no loss of heat. The quantity of primary air, however, is reduced by an amount proportional to the quantity of oxygen in the steam admitted, while the amount of secondary air is increased in a corresponding proportion. The oxygen of the water vapour in the air admitted to a furnace combines with the carbon of the fuel and thus reduces the quantity of oxygen requisite to be supplied by the air admitted.

(57) **State how you would determine the available heat of combustion in a retort furnace.**

In determining the available heat of combustion in a furnace it is necessary to fix upon a figure which will represent the temperature of the waste gases leaving the retort. This, in the case of a regenerative furnace, may be taken as 1,800° Fahr. Taking the answer to Question 55 as typical, $4680 - 1800 = 2880^\circ$ as the available heat.

(58) **State how you would calculate the heating value of tar as a fuel. A tar has the following composition: calculate its heating value, also the resulting temperature in the furnace :—**

Description of Constituents of Tar.	Chemical Formula. Average.	Percentage.	Weight of Combustible.	
			C.	H.
Ammoniacal liquor, etc.	H_2O	3		
Light oil, benzol, naphtha, etc.	C_6H_6	5	4·6155	0·3846
Middle oil, creosote, etc.	$C_{16}H_{14}$	26	24·2320	1·7680
Heavy oil, anthracene, etc.	$C_{14}H_{10}$	4	3·7752	0·2248
Pitch		62	51·0800	0·9900
		100	83·7027	3·3674

The carbon present in 100 pounds of tar being 83·7027 pounds,

Then $83·7027 \times 14,500 = 1,213,689$ B.Th.U.
Similarly, $3·3674 \times 62,032 = 208,886$ B.Th.U.

Or a total of . 1,422,575 B.Th.U.

in 100 pounds of tar, or 14,225 B.Th.U. per pound of tar.

To arrive at the temperature of the furnace burning tar of the above composition we proceed as follows :—

Analysis of Tar.		Air Required for Combustion.	Weight Produced by Combustion.		Specific Heat of Gases.		Multiple of Furnace Gases and Specific Heats.
Carbon .	0·8370	+ 2·2320 (oxygen)	= 3·0690 (CO_2)	×	0·217	=	0·6659
Hydrogen	0·0337	+ 0·2696 do.	= 0·3033 (H_2O)	×	0·480	=	0·1456
H_2O, etc.	0·1200		= 0·1200 (H_2O)	×	0·480	=	0·0576
		8·3803 (N)	= 8·3803 (N)	×	0 244	=	2 0448
							2·9139

Temperature of products of combustion, if undiluted $= \frac{14,225}{2\ 9139}$, or 4,882° Fahr.

(59) What is the difference between hot and cold coke?

Speaking generally, the difference between hot and cold coke is that the hot coke contains about 5 per cent. more carbon than cold coke, owing to the absence of the water which is added in quenching, which may be taken as being, on an average, 5 per cent.

[*For further particulars of heating retort settings, see* "*Modern Retort Settings.*"]

CHAPTER VII.

PHOTOMETRY, CALORIMETRY AND PYROMETRY.

(60) State the rule and give an example of the method by which the graduations on a photometric bar 100 inches long are obtained, and show how to arrive at the point where 9 candle-power would appear.

The rule for obtaining the position of the various graduations on a photometer bar 100 inches in length is as follows:—Find the square root of the number of candles and diminish this by 1. Remove the decimal point two places to the right, if there be decimals, and add two cyphers if there be only integer figures, and divide by the number of candles minus 1. To find the position which 9 candle-power should occupy on the bar, we proceed as follows:—The square root of 9 is 3, and $3 - 1 = 2$. Adding two cyphers we get 200, and 200 divided by the number of candles less 1 $(9 - 1) = 25$ inches as the distance from the candle to the point representing 9 candles. This result can be checked by squaring the two distances 25 and 75, which make up the total length of 100 inches. $25^2 = 625$ and $75^2 = 5625$; and $5625 \div 625 = 9$.

(61) Two equal sources of light are placed on opposite sides of a bunsen disc, one being 20 centimetres and the other 30 centimetres from the disc. Compare the intensity of illumination on the two sides of the disc.

In all questions of this description we make use of the law of inverse squares, *i.e.*, that the intensity of light varies inversely as the square of the distance from the source of the light.

$$20^2 = 400 \text{ and } 30^2 = 900.$$

Consequently, the intensity of illumination is as 9 is to 4.

(62) In measuring the illuminating power of a gas flame by a bunsen photometer, the distance from the gas flame to the disc was 96 centimetres, and from the disc to the standard candle 30 centimetres. What was the candle-power of the gas flame ?

$96^2 = 9216$ and $30^2 = 900$. Dividing 9216 by 900, we get 10·24 as the candle-power of the gas.

(63) In a "shadow" photometer, a rod 18 centimetres from the screen casts, close together, two shadows of equal intensity, the two lights being, respectively, 20 and 30 centimetres distant from the rod. From these data calculate the ratio of the intensity of the two lights.

In answering this question it is necessary to note that the illuminating powers of the two sources of light are directly proportional to the squares of their distances from the screen, and not from the rod. It is, consequently, necessary to add the distance from the screen to the rod to the distances from the rod to the two sources of light. Thus, $20 + 18 = 38$, and $30 + 18 = 48$. Squaring these we get 1444 and 2304, and reducing these to their lowest terms we get 361 : 576, or as 1 : 1·6 as the relative intensities of the lights.

(64) Describe the table photometer, and give a sketch plan of the apparatus.

The different parts of this photometer stand on a firm table, of such a height as will enable the operator to take his readings while seated in a chair. The photometer depends upon the principle usually adopted in photometry, of bringing to equality the illumination of a suitable translucent screen by the flame of the standard lamp and the illumination of the same screen by the gas flame to be tested. The illumination of contiguous portions of the same screen by the lights behind is seen by the observer sitting in front of the screen, both flames being upon one side of the screen and the observer on the other side. The photometer differs, therefore, in its arrangement from the bar photometers usually employed, since in these the lights to be contrasted are placed on opposite sides of the illuminated screen. The several parts of the apparatus consist of:—

(1) A table, 5 feet 6 inches by 3 feet 6 inches, and 2 feet 5 inches high.
(2) The gas meter.
(3) The gas governor.
(4) The regulating tap.
(5) The "Metropolitan" argand burner No. 2 and sliding base.
(6) The flat-flame burner and sliding base.
(7) The slide connecting rod and photometric scale, and index.
(8) The connecting pipes.
(9) The pentane ten-candle lamp.
(10) The photoped.
(11) The aerorthometer.
(12) The stop clock.
(13) Dark screens, mirrors, measuring rod, small block and pulley.

The position of the various apparatus is shown on plan in Fig. 8 (p. 68).

In making a test with the table photometer, one proceeds as follows:—The various portions of the apparatus having been fixed at their proper relative distances by means of standard gauge rods, the lamp flame is adjusted to the correct height; the index of the regulating tap shall be so adjusted that the meter hand makes one complete revolution in not less than 59 or more than 61 seconds. The damper for regulating the air supply to the burner is screwed upwards until the flame is on the point of tailing above the chimney, and then immediately turned down only so far as to ensure that the flame burns without any smoking. The connecting rod is then pushed to and fro until the illumination of the photoped by the argand and pentane lamp is judged to be equal. The reading on the photometric scale is then noted. This observation is made four times in all, and the mean of the results taken to the second place of decimals. The time that the meter

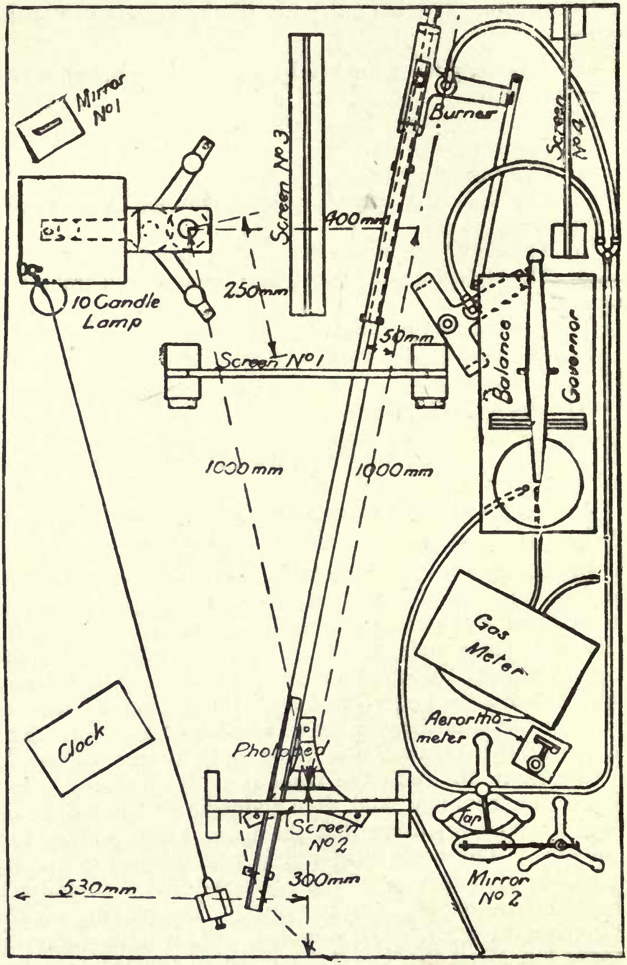


Fig. 8.—Table Photometer.

hand takes to make two complete revolutions is next noted; the stopcock is employed for such purpose, in conjunction with the test meter. The mean of the four observations of the photometric scale is then multiplied by the number of seconds in the time recorded and by the aerorthmeter reading and divided by 120. The quotient is the illuminating power of the gas under test.

This modified form of table photometer enables gas of from 8 to 18 candles to be accurately tested, is a great improvement over the former type, and enables the examiner to make tests more rapidly than was possible with the older apparatus.

(65) Describe and give a sketch of Harcourt's 10-candle standard.

The source of light in the Harcourt pentane lamp is the flame produced by burning a stream of carburetted air. The carburetting liquid is the light petroleum spirit known as pentane. This is prepared from light American petroleum by fractional distillation, the portion which distils over at 45° being further subjected to a process of purification. The liquid thus prepared is of a constant quality. The action of the lamp depends upon the fact that liquid pentane evaporates with great rapidity at ordinary temperatures, and that the resulting vapour is rather more than two and a-half times heavier than atmospheric air. Accordingly, when the liquid is exposed to the air it is constantly evolving vapour, which, on escaping, tends to fall in the air.

The lamp, shown in Fig. 9 (p. 70) consists of a burner, B, on the argand principle, made of steatite, supported by an arm, F, projecting from a hollow rod, E, which is in communication with the lower portion of the burner. From the top of the rod a bracket projects which supports the vessel containing the pentane, known as the carburettor. The latter is provided with a cock for the admission of air, and the resulting mixture of air and pentane vapour flows, by gravity, through a piece of black indiarubber tubing to the burner. Fixed above the burner is a long brass tube, C, which serves as a chimney to draw the flame into a

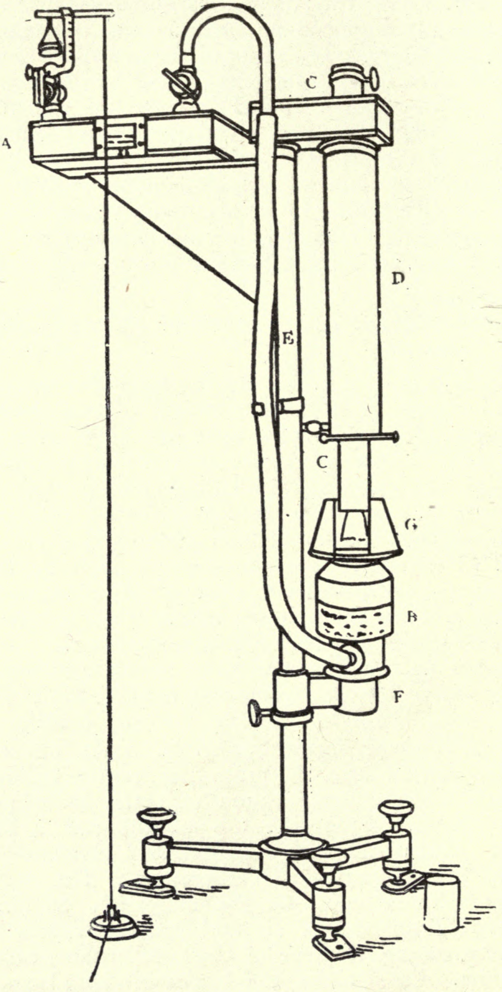


Fig. 9.—HARCOURT'S 10-CANDLE PENTANE STANDARD.

definite form. Surrounding this tube is another tube, D, 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, the interior of the burner is fed with a continuous current of hot air. It should be mentioned that the portion of the flame which forms the standard is naked. In the base of the brass chimney tube there is a mica window having a horizontal brass bar across its centre. The tube must be turned round so that no extraneous rays of light fall upon the photoped, the height of the flame being observed by reflection from a mirror. The flame of the burner is adjusted so that the mean height of the tips of the flame is between the bottom of the mica window and the middle bar.

(66) What is the aerorthometer and for what purpose is it used?

The aerorthometer, shown in Fig. 10, is intended to show at a glance the volume which 1,000 volumes of a gas under normal temperature (60° Fahr.) and pressure (30 inches) assume under the conditions of temperature and pressure prevailing at any particular time. The apparatus consists of a bulb and stem like a thermometer, containing air enclosed over mercury. The mercury, which is in communication with a reservoir of mercury, stands at a certain height in the stem, and rises and falls as the enclosed air contracts or expands with change of temperature and atmospheric pressure. The volume of the air is read off by means of a scale engraved on the stem and on the wooden backing behind it. Each graduation of the scale marks a portion of the stem whose capacity is one-thousandth part of the volume of the enclosed air when under a pressure of 30 inches of mercury and at a temperature of 60° Fahr. The line at which the mercury stands under these conditions is figured, accordingly, 1,000, and any other reading of the instrument at a different pressure or temperature gives the volume to which the 1,000 volumes have been expanded or contracted. A small drop of water is passed into the bulb, so that the expansion caused by a rise of temperature includes that due to the increased tension of aqueous vapour. In order that the volume of air enclosed in the bulb of the aerorthometer may be measured under atmospheric pressure, a second tube is placed by the side of the graduated stem, and is of the same calibre and connected with the same reservoir of mercury, but open above. By the pressure of a screw upon the leathern top of the reservoir, the mercury is raised in both tubes, and when it stands at the same level in both, the enclosed air is under atmospheric pressure. Since the volume of any portion of gas contained in a holder, or passing through a meter near which an aerorthometer is placed, bears the same relation to the volume the gas would occupy under standard conditions as the volume read on the stem of the aerorthometer bears to 1,000, the figures expressing the corrected volume of the gas are obtained by multiplying the observed volume by 1,000 and dividing it by the aerorthometer reading.

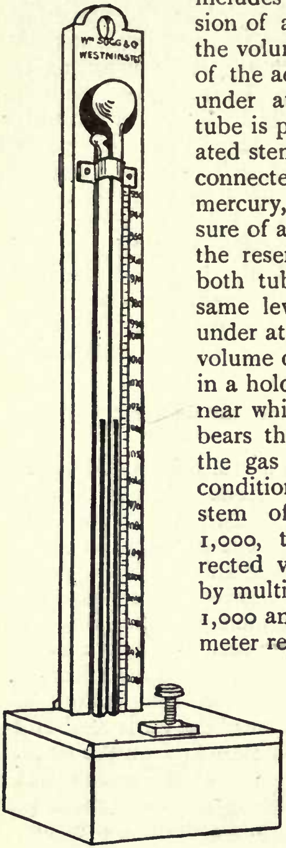


Fig. 10.

(67) Give a sketch of the No. 2 argand test burner. Why is it advantageous to use this in preference to the No. 1 London argand?

The advantage of the No. 2 over the No. 1 London argand lies in the fact that all gases may be properly tested in the former, since the air supply to the burner can be regulated to the quantity necessary for obtaining the highest luminosity from the gas under test from time to time. The old, or No. 1

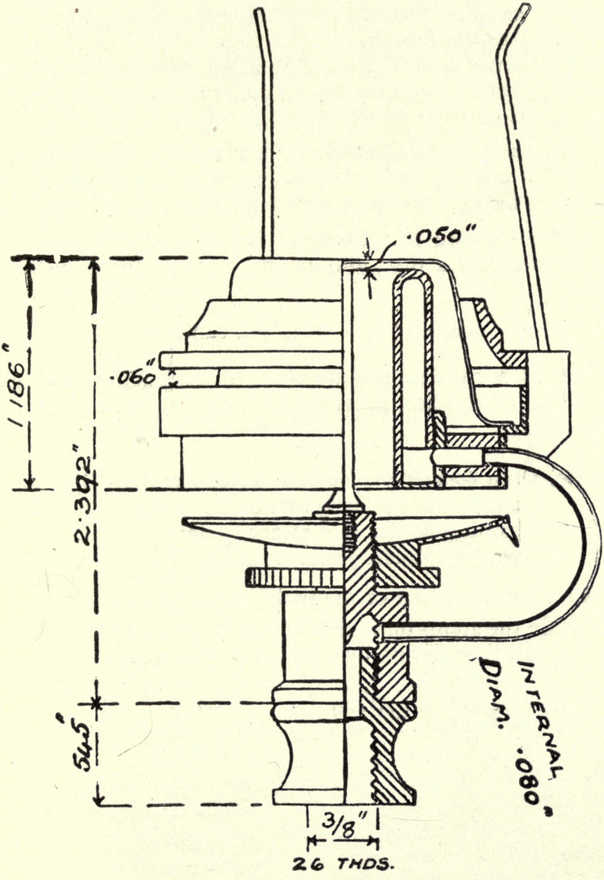


Fig. 11.—No. 2 London Argand Burner.

argand, did not do justice to the gas; the same gas tested in a No. 2 London argand will show a higher reading of about 2 candles, brought about simply by regulating the air supply to the burner.

This burner is now prescribed in all parliamentary Bills, and will, before long, be the only test burner employed for testing gas of from 13 to 16 candle-power.

(68) On a 60-inch photometer bar the disc is equally illuminated when the distance from the candles is 15 inches. What is the candle-power of the gas?

Rule:—Square the distances between the candles, the gas standard and disc, and divide by the candle distance figure—

$$60 - 15 = \frac{45}{15} = (3)^2 = 9 \text{ candles.}$$

But as 2 candles are always used in practice, this gas would be 18 candles, providing the candles burned at the proper rates.

(69) On a 60-inch photometer the disc was equally illuminated at 15 inches from the candles, the latter burning at the rate of 123 grains per hour. What was the candle-power of the gas?

Rule for correction of grains burned—

Divide the grains burned by 3 and multiply by the reading on the bar, then divide by 2, since 2 candles are used—

$$60 - 15 = \frac{45}{15} = (3)^2 = 9$$

$$\begin{array}{r} 3)123 \\ \hline 41 \\ 9 \\ \hline 2)369 \\ \hline 18{\cdot}45 \text{ candles.} \end{array}$$

(70) On a 60-inch photometer bar the disc was equally illuminated at 15 inches from the candles. These were burned at the rate of 123 grains per hour,

the temperature being 64° Fahr., and the barometer standing at 30·3 inches. What was the candle-power of the gas?

$$60 - 15 = 45 = \frac{45}{15} = (3)^2 = 9 \text{ candles, uncorrected.}$$

$$\begin{array}{r} 3(123 \\ \hline 41 \\ 9 \\ \hline 2)369 \\ \hline \end{array}$$

18·45 candles corrected for rate of sperm.

Then—

$$\text{Candle-power} \div \frac{17{\cdot}33 \times 30{\cdot}3}{64 + 460 = 524} = 1{\cdot}002.$$

1·002)18·45(18·41 corrected candles for rate,
temperature and pressure.

(71) Describe some forms of calorimeter and explain the methods of using them.

Junkers' calorimeter, which is made of copper, is shown in Fig. **12.** It consists of a combustion chamber surrounded by a water jacket, passing vertically through which are a number of tubes open at both ends. Surrounding this water jacket is another jacket, which forms an air space to prevent loss of heat by radiation. The water, after passing through the inlet funnel (provided with an overflow to keep the head of water constant), flows through a regulating cock and over the bulb of the inlet thermometer. Thence it circulates around the vertical tubes previously mentioned, and, becoming heated by the products of combustion, rises, and flows past a series of baffle plates and an outlet thermometer to the outlet funnel. From there it is conveyed by a piece of flexible rubber tube either to a measuring flask or to waste; the tubing being manipulated by hand. The gas is burnt in a bunsen burner (after being measured and governed), and the products of combustion, rising up through the com-

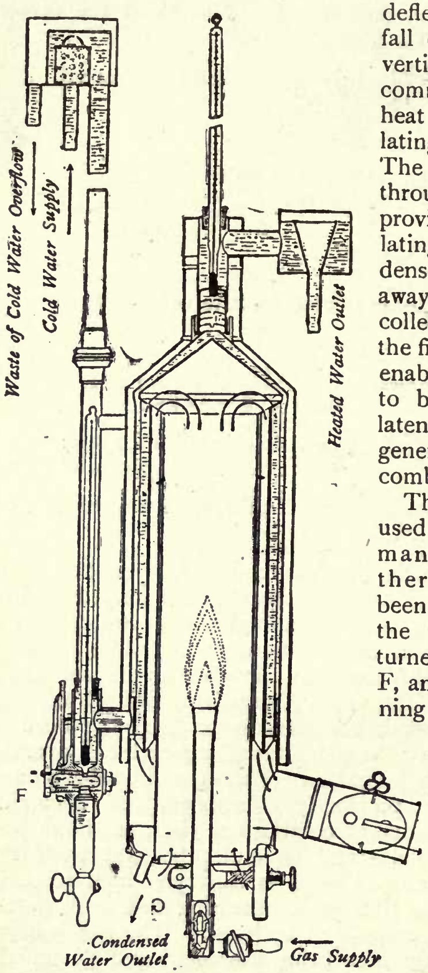


Fig. 12.—JUNKERS' CALORIMETER.

bustion chamber, are deflected at the top and fall down through the vertical tubes, the latter communicating their heat to the water circulating around them. The products issue through a large tube provided with a regulating valve. Any condensed water is led away by a tube and collected and measured; the figure thus obtained enabling a correction to be made for the latent heat of the steam generated during the combustion of the gas.

The apparatus is used in the following manner:—After the thermometers have been placed in position the water supply is turned on by the cock, F, and when it is running from both overflows the gas is lit, and burned at the rate of from 4 to 8 cubic feet per hour. The temperature of the water at the discharge will now begin to rise and after a few minutes the outlet thermometer will remain practically stationary. The speed of the water passing through the apparatus is then regulated by the cock, F, so that there is a difference in temperature between the inlet and outlet thermometers of 10° to 20° C. As soon as the difference is nearly constant and the condensed water is dripping regularly from the pipe, G, the test is commenced. Wait until the index of the gas meter, which registers the gas consumed by the flame, passes any particular point, and then rapidly shift the hot water tube from over the funnel into the measuring glass, and place a smaller glass under the condensed water outlet. The readings of the inlet thermometer and of the outlet thermometer are taken every minute. The test is continued until about 1 cubic foot of gas has passed, the measuring vessel employed being of sufficient size to hold the requisite amount of water. This should be shown by a mark, and when the water reaches this mark the gas is shut off.

Simmance and Abady's calorimeter is shown in vertical and cross section in Fig. 13. The inlet and outlet thermometers are placed side by side, for convenience in reading ; and there is also a water-level tube provided to enable the operator to see that there is a constant head of water, and, therefore, a constant flow through the calorimeter. The water flows three times from the bottom of the instrument to the top, through narrow annular chambers ; being conducted from the top of one chamber to the bottom of the succeeding one by four small tubes, as indicated in the cross-section. Finally, it flows past the outlet thermometer to the measuring vessel or to waste, as indicated by the arrows. The tilting funnel shown attached to the outlet enables the outlet water to be diverted as required without disturbing the rate of flow through the instrument. If an indiarubber tube be used for the purpose, a variation in the bend of the tube may affect the rate of flow. The course of the gases from the flame is shown by arrows ; and in making a test a shutter on the outlet for the products is adjusted till the thermometer at this point indicates atmospheric temperature. The burner is fitted with a mirror which enables the flame to be observed during a test ; and the opening into the combus-

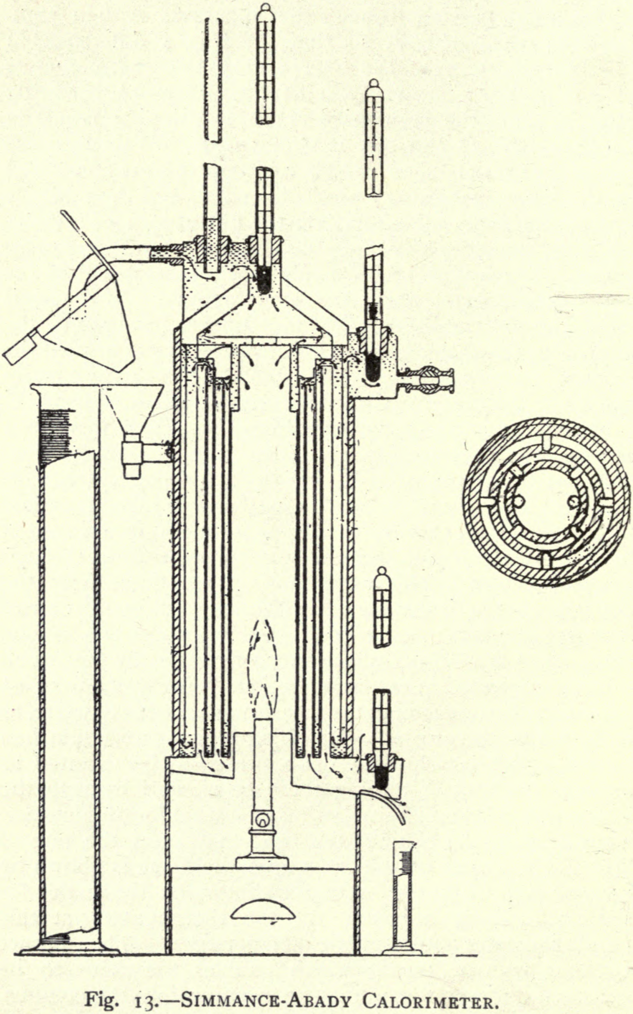


Fig. 13.—SIMMANCE-ABADY CALORIMETER.

tion chamber is protected by a glass draught-screen. The instrument is packed with asbestos and lagged with mahogany to avoid disturbing effects from radiation or absorption of heat. A glass measure graduated in c.c. is provided to enable a rapid test to be made (when desired) by collecting only a small quantity of water. The condensed water is collected in the small measuring vessel shown on the right-hand side of the illustration, when it is desired to distinguish between the "gross" and "net" calorific value.

The calorimeter of Professor Boys, one of the Gas Referees, is shown in Figs. 14, 15 and 16.

This calorimeter consists of three parts, which may be separated, or which, if in position, may be turned relatively to one another about their common axis. The parts are (1) the base, A, carrying a pair of burners, B, and a regulating tap. The upper surface of the base is covered with a bright metal plate held in place by three centring and lifting blocks, C. The blocks are so placed as to carry (2) the vessel, D, which is provided with a central copper chimney, E, and a condensed water outlet, F. Resting upon the rim of the vessel, D, are (3) the water circulating system of the calorimeter, attached to the lid, G. Beginning at the centre, where the outflow is situated, there is a brass box which acts as a temperature equalizing chamber for the outlet water. Two dished plates of thin brass, K K, are held in place by three scrolls of thin brass, L L L. These are simply strips bent round like unwound clock springs, so as to guide the water in a spiral direction inwards, then outwards, and then inwards again to the outlet. The lower, or pendant, portion of this box is kept cool by circulating water, the channel for which may be made in the solid metal, as shown on the right side, or by sweating on a tube, as shown on the left. Connected to the water channel at the lowest point, by a union, are five or six turns of copper pipe, such as is used in a motor car radiator of the kind known as Clarkson's. In this a helix of copper wire, threaded with copper wire, is wound round the tube, and the whole is sweated together by immersion in a bath of melted solder. A second coil of pipe of similar

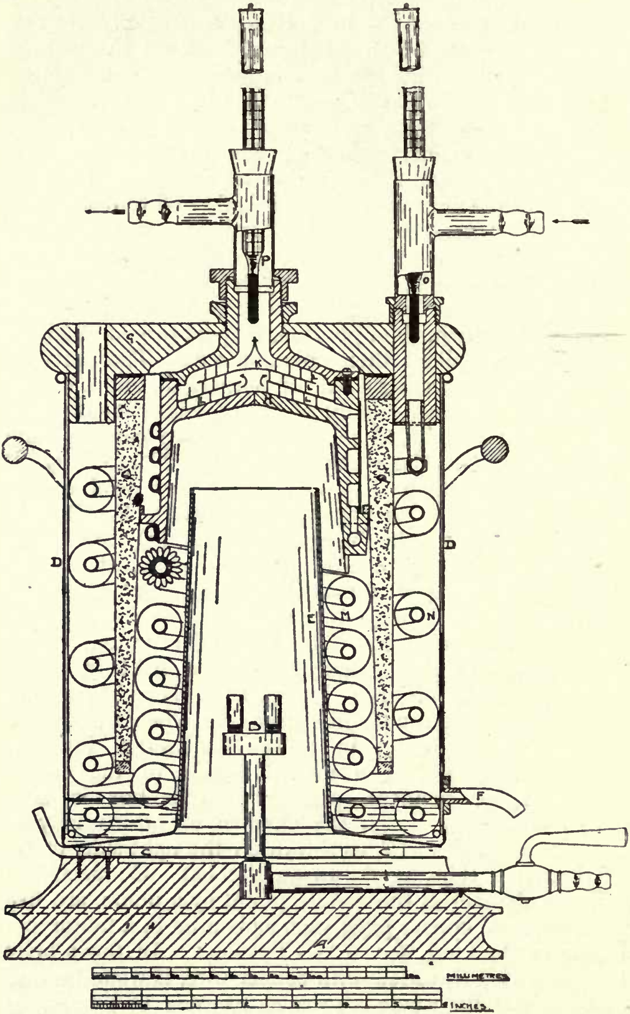


Fig. 14.—Boys' Calorimeter.

construction surrounding the first is fastened to it at the lower end by a union. This terminates at the upper end in a block, to which the inlet water box and thermometer holder are secured by a union, as shown at O. An outlet water-box, P, and thermometer holder are similarly secured above the equalizing chamber, H. The lowest turns of the two coils, M N, are immersed in the water which, in the first instance, is put into the vessel, D.

Between the outer and inner coils, M N, is placed a brattice, Q, made of thin sheet-brass, containing cork dust to act as a heat insulator. The upper annular space in the brattice is closed by a wooden ring, and that end is immersed in melted rosin and beeswax cement, to protect it from any moisture which might condense upon it. The brattice is carried by an internal flange which rests upon the lower edge of the casting, H. A cylindrical wall of thin sheet-brass, a very little smaller than the vessel, D, is secured to the lid, so that when the instrument is lifted out of the vessel and placed upon the table the coils are protected from injury. The narrow space between this and the vessel, D, also serves to prevent interchange of heat between the calorimeter and the air of the room.

The two thermometers for reading the water temperatures, and a third for reading the temperature of the outlet air, are all near together, and at the same level. The lid may be turned round into any position, relatively to the gas inlet and condensed water drip, that may be convenient for observation, and the inlet and outlet water boxes may themselves be turned so that their branch tubes point in any direction.

A regular supply of water is maintained by connecting one of the two outer pipes of the overflow funnel, shown in Fig. 15, to a small tap over the sink. The overflow funnel is fastened to the wall about one metre above the sink, and the other outer pipe is connected to a tube in which there is a diaphragm with a hole about 2·3 mm. in diameter. This tube is connected to the inlet pipe of the calorimeter. A piece of stiff rubber pipe long enough to carry the outflow water clear of the calorimeter is slipped on to the outflow branch. and the water is turned on so that a little escapes

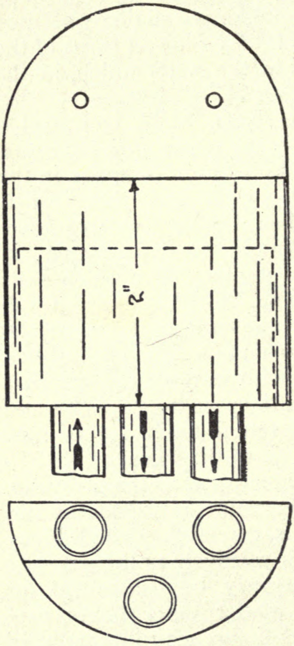


Fig. 15.—WATER-FLOW REGULATOR.

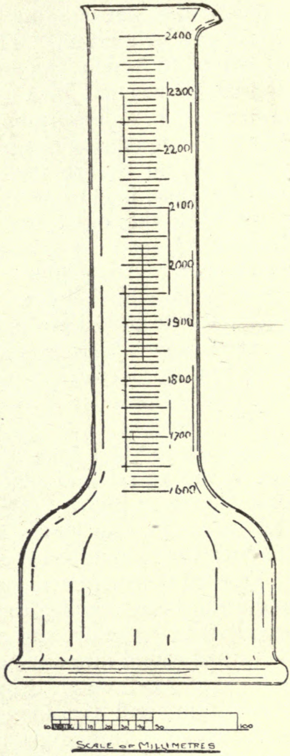


Fig. 16.—GRADUATED WATER RECEIVER.

by the middle pipe of the overflow funnel, and is led by a third piece of tube into the sink. The amount of water that passes through the calorimeter in four minutes should be sufficient to fill the graduated vessel, shown in Fig. 16, to some point above the lowest division, but insufficient in five minutes to come above the highest division. If this is not found to be the case, a moderate lowering of the overflow funnel or reaming out of the hole in the diaphragm will make it so.

The thermometers for reading the temperature of the inlet and outlet water should be divided on the centigrade scale into tenths of a degree, and they should be provided with reading lenses and pointers that will slide upon them. The thermometers are held in place by corks fitting the inlet and outlet water boxes. The thermometers for reading the temperature of the air near the instrument and of the effluent gas should be divided on the centigrade scale into degrees.

The flow of air to the burners is determined by the degree to which the passage is restricted at the inlet and at the outlet. The blocks, C, which determine the restriction at the inlet, are made of metal $\frac{3}{16}$-inch thick, or about 5 millimetres, while the holes round the lid, which determine the restriction at the outlet, are five in number, and are $\frac{5}{8}$-inch, or 16 millimetres, in diameter. The thermometer used for finding the temperature of the effluent gas is held by a cork in the sixth hole in the lid so that the bulb is just above the upper coil of pipe.

The calorimeter should stand on a table by the side of a sink so that the condensed water and hot water outlets overhang and deliver into the sink. A glass vessel must be provided of the size of the vessel, D, containing water in which is dissolved sufficient carbonate of soda to make it definitely alkaline. The calorimeter after use is to be lifted out of its vessel, D, and placed in the alkaline solution, and there left until it is again required for use. The liquid should not, when the calorimeter is placed in it, come within 2 inches of the top of the vessel. The liquid must be replenished from time to time, and its alkalinity must be maintained.

(72) What is the difference between "gross" and "net" calorific power?

The gross calorific value of a gas represents the total heat generated by the combustion of the gas, including the latent heat of the steam produced, which steam is condensed to water in the calorimeter, giving up its latent heat of vaporisation to the circulating water. This latent heat is, however, rarely made use of in practice, since in gas fires and in gas engines all the water formed escapes as steam. In order to obtain the calorific power with all the water formed escaping as steam, it is necessary to deduct about 10 per cent. from the gross value or, to be more exact, an amount corresponding to the quantity of condensed water obtained. It may be assumed that each c.c. of condensed water evolves a quantity of heat corresponding to 0·6 calorie; so on multiplying this number by the number of c.c. of water condensed and dividing by the gas consumed, we obtain the amount in calories which must be deducted from the gross value to obtain the calorific power with the steam in the form of vapour. This result is called the net calorific value. The number of calories are multiplied by 3·96 to reduce them to B.Th.U.

(73) In an experiment with Junkers' calorimeter, 0·24 cubic foot of gas was burned and 5,000 c.c. of water collected. The average of the readings of the cold-water thermometer was 15° C. and of the hot-water thermometer 22·5° C. What was the calorific power of the gas?

The heating value of a gas when burned in Junkers' calorimeter is obtained from the following formula :—

$$H = \frac{WT}{G}$$

Where H is the calorific value of 1 cubic foot of gas.
W is the quantity of water heated, in litres.
T is the difference of temperature, in degrees C., between the inflowing and the outflowing water.
G is the quantity of gas burned during the experiment, in cubic feet.

In the example :—

$$W = 5,\ T = 22·5 - 15 = 7·5,\ G = 0·24.$$

Consequently, $H = \frac{5 \times 7·5}{0·24} = 156·2$ calories per cubic foot.

(A calorie is the quantity of heat required to raise the temperature of 1 litre of water 1° C.) In order to convert calories into British thermal units we multiply by 3·96. $156·2 \times 3·96 = 618·552$ B.Th.U.

(74) Calculate the calorific power of Mond gas having the following composition:—

Hydrogen	24·8 per cent.
Marsh gas	2·3 „ „
Carbonic oxide	13·2 „ „
Carbonic acid	12·9 „ „
Nitrogen	46·8 „ „
	100·0

In answering this question we make use of the data given in answer to Question No. 30, thus:

	Per Cent.	B.Th.U.
Hydrogen	24·8 × 325	=8,060
Marsh gas (methane) . . .	2·3 × 1,024	=2,355·2
Carbonic Oxide	13·2 × 330	=4,356
Carbonic acid	12·9	...
Nitrogen	46·8	...
	100	14,771·2

or 147·71 B.Th.U. per cubic foot of gas.

(75) Calculate the calorific power of Dowson gas having the following composition:—

	Per Cent.
Hydrogen	19·8
Marsh gas	1·3
Carbon monoxide	23·8
Carbonic acid	6·3
Nitrogen	48·8
	100·0

	Per Cent.	B.Th.U.
Hydrogen . . .	19·8 × 325	= 6,435
Marsh gas . . .	1·3 × 1,024	= 1,331·2
Carbonic oxide . .	23·8 × 330	= 7,854
Carbonic acid . . .	6·3	...
Nitrogen . . .	48·8	...
	100·0	15,620·2

or 156·2 B.Th.U. per cubic foot of gas.

(76) Give a description of a recording calorimeter.

There are two well-known types of recording calorimeters, Junkers' and Beasley's. The former records the gross value of a gas, and is of similar construction to the ordinary Junkers' calorimeter, as illustrated in Fig. 12. It is fitted with a regulating arrangement, which consists of a combined water and gas meter. These two deliver constant quantities of water and gas. Consequently, the rise in temperature is directly proportional to the calorific value. The rise is measured by a thermocouple, which, in turn, actuates a needle and a pen, the gross values being recorded upon a chart, or it may be read upon a galvanometer scale.

Beasley's recording calorimeter consists essentially of a tube in the form of the letter U, communicating at both ends with reservoirs containing floats arranged differentially. The one limb of the U-tube is formed by an annular vessel, in the centre of which the gas under test is consumed. The U-tube is filled with an oil of high specific gravity, both limbs being fitted with surface plates, to ensure perfect radiation, and so increase the sensitiveness of the apparatus. The expansion of the oil in the warm limb is employed to measure the heat value of the gas. This expansion of the oil raises the float in its own particular reservoir, and thus causes the needle attached to the differential shaft to make a movement. A pen is attached to the lower end of the needle, and a clockwork arrangement is employed to move the chart, upon which the pen is lightly held.

The apparatus is fitted with a suitable gas governor and anti-fluctuator, to regulate the gas supply and ensure a steady flame. This instrument records the gross value of the gas, uncorrected for temperature and pressure.

(77) Briefly describe the various types of pyrometers in use and fully describe the one you consider the best for gasworks' use.

The various types of pyrometers may be grouped under several different headings—namely, (*a*) those which indicate the degree of heat by fusing at a known temperature, such as Seger's cones, Watkins' heat recorders and others of a similar kind. These consist of fusible mixtures—generally clay, sand and fluxes, of known melting points. The fluxes used consist generally of soda or lead oxide. The mixtures are made up in the form of cones, and are numbered according to their melting points, which may be ascertained on reference to a table supplied by the manufacturers. It is usual to employ several of these cones, the temperature being assumed to be between the melting point of the last fused cone and the first unaffected one.

The next type (*b*) is the water pyrometer, that known as Siemens' pyrometer being the instrument usually employed for gasworks' purposes. It consists of a cylindrical copper case, fitted with a thermometer and specially graduated brass scale. The case is of annular construction, and is lagged, to prevent loss of heat by radiation. A measured quantity of water is placed in the pyrometer, and the zero of the brass scale adjusted to the height attained by the mercurial column of the thermometer. An iron bob, of known weight, is now placed in the retort or other plant, the temperature of which is desired, and allowed to remain until it has attained an identical temperature. The iron bob is then withdrawn, and immediately dropped into the water in the pyrometer. The rise in temperature of the water is then noted on the thermometer and on the brass scale—the sum of the two readings indicating the temperature.

Thermo-electric couples (*c*) may next be taken. These consist of two wires, of different metals, either platinum with platinum-rhodium or platinum with platinum-iridium, encased in a steel tube, varying from 300 to 1,500 mm. long by 19 mm. in diameter. The wires are fused at their junction, and carefully insulated, the whole being surmounted with a boxwood head. Insulated copper wires are connected to the couple and to a galvanometer. The couple is placed in the retort or furnace, and the heating at the junction of the two metals sets up an electric current, the electromotive force of which is proportional to the degree of heat, and since the couple is connected to the galvanometer, the intensity of heat is registered thereby. In connection with such pyrometers, the temperatures may be arranged to be recorded upon a chart.

There yet remain the Féry types of pyrometers to be described—the earlier ones being made in two varieties—namely, the mirror and lens types. These, however, have, to some extent, been improved upon by the introduction of the Féry spiral pyrometer. The former consists of a telescope, through which the hot body whose temperature it is desired to ascertain is sighted, and the radiation is brought to a focus, by means of a concave mirror or lens, upon the junction of a copper thermo-electric couple, which is arranged in the form of a plus sign within the telescope. This thermocouple is suspended upon brass strips, connected to the body of the telescope. The apparatus is connected by a cable to a delicate galvanometer. By focussing, it is possible to raise the thermo-junction to a temperature proportional to the radiation emitted by the hot body, and the electromotive force thus generated is measured by the galvanometer, and the temperature read off directly from a graduated scale.

The spiral form of Féry pyrometer is similar to that described, but instead of the radiation being focussed on a thermocouple, it is thrown upon a spiral, cut from a sheet made of two dissimilar metals, of unequal expansion, soldered together. It is suspended centrally on a small steel stem, carried from the body of the telescope, the outer end carrying an aluminium pointer. Any radiation passing through the convolutions of the spiral is reflected back to the spiral, by means of a small mirror fixed behind. The spiral expands or contracts as the temperature is raised or lowered; the pointer moving over a scale which is graduated in degrees of temperature. This is the best type of pyrometer to employ, since it is self-contained, and requires no galvanometer or wires, though it is not quite as accurate as the mirror or lens type of Féry pyrometer.

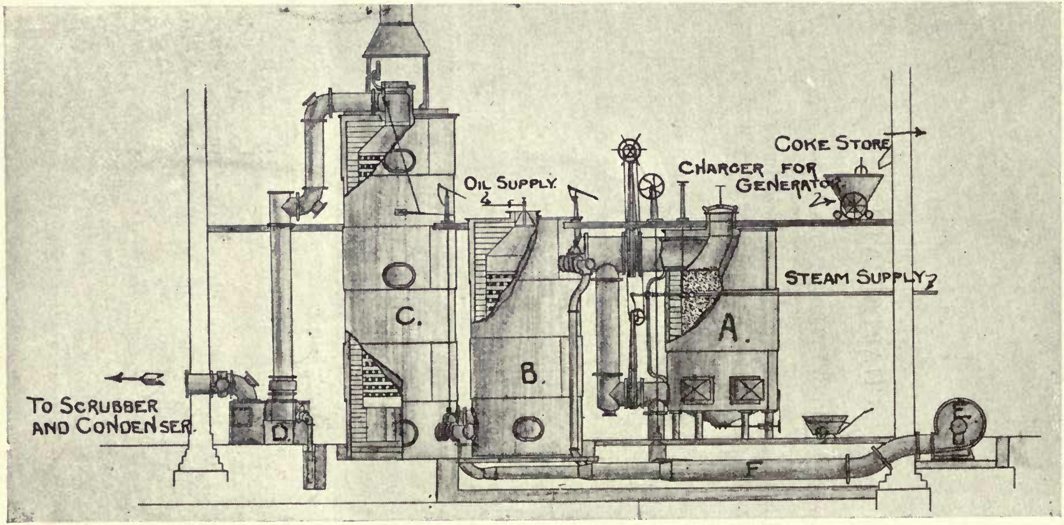
CHAPTER VIII.

CARBURETTED WATER GAS.

(78) Give a description of the manufacture of carburetted water gas and explain the chemical principles involved.

Water gas is produced by passing steam through incandescent coke. The oxygen of the water vapour (steam) combines with the carbon of the coke to form the inflammable gas, carbon monoxide, leaving the hydrogen from the same source in the "free" condition. Theoretically, then, water gas should consist of a mixture of equal volumes of carbon monoxide and hydrogen, but in practice this result is never attained, carbon dioxide and nitrogen being always present. The gas produced by the process, known as "blue" water gas, burns with a non-luminous flame. Its heating value is about half that of coal gas. Carburetted water gas is produced by passing "blue" water gas into a heated vessel, known as the carburettor, into which oil is sprayed. This results in the oil being gasified, and, mixing with the plain water gas, it forms carburetted water gas. This next passes into another vessel, known as the superheater or fixing chamber, in order to render the gas permanent.

The above is a general outline of the process, of which the details are as follows. The plant employed, shown in Fig 17, consists of generator, A, carburettor, B, superheater, C, seal pot, D, fan, E, and blast pipe, F. The generator, A, is filled with coke, which is raised to incandescence by an air blast under a pressure of about 18 inches of water. The resulting producer gas passes



A. Generator. B. Carburettor. C. Superheater. D. Seal Pot. E. Fan. F. Blast Pipe.

Fig. 17.—Humphreys and Glasgow Carburetted Water Gas Plant.

to the carburettor, entering at the top, where it meets a supply of air, which causes combustion to take place, resulting in the chequer brickwork of the carburettor being heated. The producer gas then travels to the superheater, which it enters at the bottom and there meets another supply of air for combustion; the products of combustion passing away at the top to the chimney stack. The superheater is also filled with chequer brickwork. When the carburettor and superheater are both at the proper temperature, the stack valve at the top of the superheater is closed, and the gas valve at the top of the oil superheater is opened. The time occupied in the "blowing up" is from 2 to 4 minutes, according to the condition of working. Steam at a pressure of about 120 lbs. per square inch is then admitted under the grate bars of the generator, and in passing through the incandescent coke it becomes decomposed in the manner previously explained. Oil is now pumped into the top of the carburettor, in the form of fine spray, which, as it comes in contact with the water gas, is vaporised. The vapour is fixed in the superheater. The gas then passes through the oil superheater to the scrubber and condenser, which cool it and get rid of any tar. The process of gasmaking usually lasts for 6 to 7 minutes, or until the heat in the generator is not sufficient to decompose the steam. When this occurs the oil and steam valves are closed, the stack valve is opened, and the process of raising the heat in the generator, carburettor and superheater, by means of the air blast, is repeated. After leaving the condenser, the gas passes to a relief gasholder, on the outlet of which is an exhauster, which forces the gas through the purifiers.

The chemical principles involved in the manufacture of water gas are as follows. At certain temperatures up to about 1,100° Fahr., the following reaction takes place:—$C + 2H_2O = CO_2 + 2H_2$. Above this temperature and up to about 1,850° Fahr., the carbon dioxide (CO_2) takes up another atom of carbon; thus $CO_2 + C = 2CO$, making $2CO + 2H_2$. But in practical working this result is never attained, as CO_2 is always present; but it should not exceed 3 per cent.

(79) Give analysis of purified carburetted and of uncarburetted water gas.

Carburetted water gas :—

Hydrogen	37·00
Saturated hydrocarbons, methane, etc.	17·67
Unsaturated hydrocarbons, ethylene, etc.	13·00
Benzene (estimated)	2·00
Carbon monoxide	29·10
Oxygen	0·0
Nitrogen, etc.	1·23
	100·00

Uncarburetted water gas :—

Carbon monoxide	45·56
Hydrogen	50·96
Carbonic acid	3·45
Nitrogen	0·03
	100·00

(80) State the effects of the following points in the manufacture of carburetted water gas :—(*a*) Variation in the quantity of air admitted during the blow, (*b*) variation in the quantity of steam admitted during the "run," (*c*) variation in the temperature of the carburettor and superheater.

A deficiency of air will result in the generator not attaining the necessary degree of incandescence for the production of the maximum amount of CO, and also in a deficiency of producer gas for heating the carburettor and superheater. An excess of steam during the run will result in a large percentage of CO_2 in the gas, while a deficiency of steam will be accompanied by a reduction in the yield of gas. A low temperature in the carburettor and superheater will result in the oil not being properly gasified, causing a deposit of tar, while too high a temperature will cause a deposit of carbon, in the form of lamp-black, which will be deposited on the chequer work of the vessels and destroy their efficiency. If a heavy oil is to be gasified it is advisable to have the carburettor at a dull red heat, the superheater being worked at a heat gradually increasing to a cherry red towards the outlet. On the other hand, a light oil is more easily gasified, and in this case the carburettor should be worked at a brighter heat. It is advisable when using an oil whose behaviour is not known to gradually increase the heat from a dull red to the brightest heat the oil will stand without depositing lamp-black on the chequer bricks; which is indicated by soot being deposited on a white paper held at a jet on the outlet gas.

(81) Calculate the calorific value of the carburetted water gas whose analysis is given in the answer to question 79.

Hydrogen	37·00 × 325 =	12,025
Saturated hydrocarbons (methane)	17·67 × 1,024 =	18,094
Unsaturated hydrocarbons (ethylene)	13·00 × 1,603 =	20,839
Benzene (estimated)	2·00 × 3,718 =	7,436
Carbon monoxide	29·10 × 330 =	9,603
Oxygen	0·00	...
Nitrogen	1·23	...
		67,997

=680 B.Th.U. per cubic foot.

(82) State, approximately, the quantities of materials required to produce 1,000 cubic feet of 24-candle carburetted water gas, and give an estimate of the cost of manufacture.

The materials employed in the production of 1,000 cubic feet of 24-candle carburetted water gas may be approximately taken as follows:—Coke for gasmaking, 32 lbs.; coke for steam raising, 8 lbs.; water, 50 gallons; oil, 3½ gallons.

The approximate cost would be:

	Pence.
40 lbs. of coke at 15s.	3¼
3½ gallons of oil at, say, 3¼d.	11½
Labour (total)	1½
Purification (material)	½
Repairs and maintenance	¾
Superintendence	½
Total cost into holder	18

(83) State what you know concerning the oils employed in carburetted water gas manufacture, and explain how you would test a sample of oil.

The principal oils used in the manufacture of carburetted water gas are Russian solar, which has a specific gravity ranging from 0·870 to 0·890 and a flash-point of about 150° Fahr., by Abel's close test; and American gas oil, which has a specific gravity of from 0·845 to 0·865 and a flash-point between 80° and 120° Fahr. Borneo, Texas and shale oils are also used.

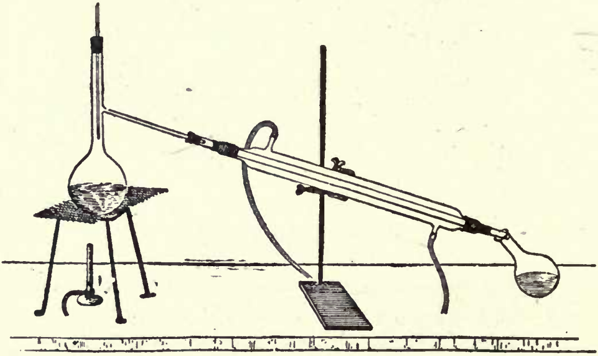


Fig. 18.

Much valuable information as to the value of an oil for gasmaking purposes is yielded by a fractional distillation. The operation is performed in the apparatus shown in Fig. 18. A suitable quantity for the test is one litre, which should be weighed after being placed in the flask. The distillates are collected in quantities of about 10 per cent. of the original sample. The temperature at which each fraction comes over is recorded, also the volume and weight, and the nature of the fraction (colour, etc.). When all volatile matter has been driven off, the residue (pitch) is weighed. This should not amount to more than 1 per cent. of the original quantity. The amount of water, if any, should also be noted; this, of course, should be small. Each fraction should be tested for SH_2 by a lead paper. The heat should be applied gradually and adjusted to the extent necessary to cause the distillates to fall from the condenser into the collecting vessel in drops. The sum of the fractions plus the pitch should total up to within 1 per cent. of the original quantity taken.

(84) **How would you determine the specific gravity of a sample of oil? What precautions have to be taken in ascertaining stock of oil? How do you reduce the quantity stored as stated by volume to quantity by weight?**

The specific gravity of an oil may be determined by means of the hydrometer, or, with greater exactness, by means of the specific gravity bottle, shown in Fig. 19. The bottle is capable of holding 50 or 100 grammes of distilled water, and it has in its neck a perforated glass stopper which enables the bottle to be entirely filled with liquid without any air bubbles. The bottle is used in the following manner:—It is first filled with the oil, preferably at a temperature of 60° Fahr. The stopper is then inserted; causing the bottle to be entirely filled with the liquid, which will overflow from the perforation in the stopper. The bottle is next wiped dry with a clean cloth, and the top of the stopper by the dry hand. The bottle is then weighed, and from this is deducted the weight of the empty bottle. This gives the weight of the oil, and this weight divided by the weight of the quantity of distilled water which the bottle can hold gives the specific gravity of the oil. It is very important that all calculations relating to the specific gravity of oils should be referred to the common standard of 60° Fahr., and in case it is not possible to attain that temperature, then the exact temperature must be determined and the correct specific gravity at 60° calculated by means of the co-efficient of expansion, which, in the usual way of working, may be taken as 0·00036 per degree Fahr. The co-efficient is used in the following manner:—Taking the specific gravity of the petroleum oils used in gasmaking at 0·850, and assuming

Fig. 19.

that in place of the temperature being 60° Fahr. it was 68° Fahr., then the specific gravity 0·850 at 68° would be corrected to a temperature of 60° Fahr. as follows :—

$$\begin{array}{rr} 68 & \\ 60 & \\ \cline{1-1} 8 \times 0{\cdot}00036 = & 0{\cdot}00288 \\ & 0{\cdot}85000 \\ \cline{2-2} & 0{\cdot}85288 \end{array}$$

The specific gravity at 60° Fahr. would therefore be 0·85288.

The precautions to be employed when taking stock of oil are to distinguish between oil and water, the latter being always present, and to ascertain with exactness the temperature of the oil, since a few degrees difference in temperature will make an appreciable difference in the quantity of oil in stock. The water present may be ascertained by means of a paper "water finder," and difference in volume due to divergence from the temperature of 60° Fahr. should be corrected by means of the coefficient of expansion, as already explained.

In order to obtain the weight from the volume, since a gallon of water weighs 10 lbs., on multiplying the specific gravity by 10 we obtain the weight of a gallon of oil. To obtain the weight of a cubic foot of oil we multiply the specfic gravity by 62·425. To find the cubic feet in a ton, divide the specific gravity into 35·9, and to obtain the number of gallons in a ton divide the specific gravity into 224.

(85) What is the flash-point of an oil? Give a brief description of the method of determining it.

The flash-point of an oil may be defined as the temperature at which the oil commences to give off sensible quantities of inflammable vapour; from which it follows that the lower the temperature at which an oil flashes the more dangerous its transportation, storage and use become. The flash-point may be determined by means of the apparatus shown in Fig. 20, which is known as the Abel test, from the name of the inventor. The oil is contained in the cup, A, and is heated by the water bath, B. The bath is filled by pouring water into the funnel, *d*, until it begins to flow out at the spout of the vessel. The temperature of the water at the commencement of the test must be exactly 130° Fahr. The test flame may be either that of an oil lamp or of a gas jet. The water bath, B, having been raised to the proper temperature, 130° Fahr., the oil to be tested is poured into the cup, A, until the liquid just touches the point of the gauge, C, which is fixed at exactly 1½ inches from the bottom of the cup. The lid, D, of the cup, with the slide closed, is then put on, and the cup is placed in the water bath. The thermometer, E, in the lid of the cup is adjusted so as to have its bulb just immersed in the oil. When the cup has been placed in the proper position, the scale of the thermometer faces the observer. The test lamp is then placed in position upon the lid of the cup, and a pendulum fixed in a convenient position in front of the operator is set in motion, and the rise of the thermometer in the cup is watched.

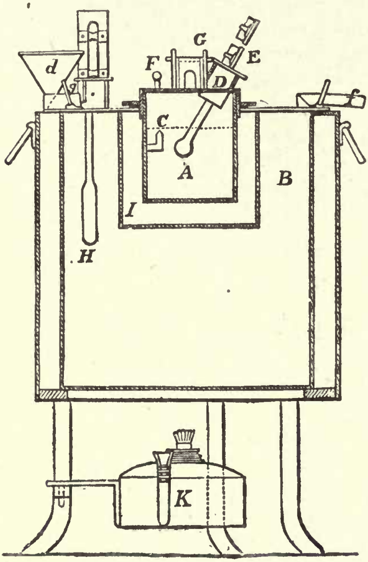


Fig. 20.

When the temperature has reached about 66° the operation of testing is commenced, by applying the test flame once for every rise of one degree of temperature, in the following manner. The slide covering the top of the cup is slowly drawn open while the pendulum performs three oscillations and is closed during the fourth oscillation. In moving the slide so as to uncover the holes, the oscillating lamp, G, is caught by a pin fixed in the slide, and tilted in such a way as to bring the flame below the surface of the lid. Upon the slide being pushed back so as to cover the holes, the lamp returns to its original position. The temperature at which the vapour of the oil gives a blue flash on applying the test flame is taken as the flash-point of the oil.

(86) State what you know concerning the impurities in carburetted water gas and the method of their removal.

The impurities present in carburetted water gas are carbonic acid, sulphuretted hydrogen, and small amounts of carbon bisulphide. The gas contains more carbonic acid and less sulphuretted hydrogen than coal gas does; about 3 per cent. by volume of CO_2 and from 90 to 150 grains of SH_2, corresponding to 0·15 to 0·25 per cent. by volume. The SH_2 is chiefly derived from the coke, though some oils contain appreciable quantities of sulphur, necessitating care in purchasing this raw material. The amount of CS_2 is infinitesimal. The purification can be effected by means of lime or oxide of iron, according to whether it is wished to take out the CO_2 or not, and it may be carried out in separate vessels or in the ordinary coal-gas purifiers.

(87) Describe the Dellwik system of gasmaking, explaining how it differs from ordinary carburetted water gas manufacture.

In the Dellwik system the coke is heated to the temperature necessary for the manufacture of water gas in a shorter time than in the ordinary method of making such gas. The fuel bed is not so deep, and a more powerful air blast is employed, in order to ensure an excess of air. This results in CO_2 being formed in the generator, instead of CO. The coke in the generator is raised to the necessary temperature more quickly when CO_2 is formed within the generator than when the generator gas consists of CO. In the Dellwik system the time occupied in blowing up has been reduced to less than 2 minutes, and the time occupied in the run is prolonged to 10 minutes, resulting in 70,000 cubic feet of gas being produced per ton of coke, in place of 34,000 cubic feet in the ordinary Lowe system. But in the Lowe plant a portion of the fuel is designedly appropriated for the gasification of the oil. The producer gas from the Dellwik plant, owing to the large proportion of CO_2 it contains, is not combustible, and cannot therefore be used for heating the carburettor and superheater employed in making carburetted water gas.

CHAPTER IX.

SULPHATE OF AMMONIA MANUFACTURE.

(88) State the principal systems of making sulphate of ammonia and discuss their relative advantages.

There are two systems of manufacturing sulphate of ammonia, the intermittent and the continuous, but the former method of manufacture is now almost obsolete. One of the earliest forms of apparatus consisted of an old boiler-shell, into which the liquor was pumped, the boiler being heated by means of a fire placed underneath. The ammonia given off was conveyed by a pipe, fixed on the top of the boiler, into a vessel containing sulphuric acid, known as the saturator, in which the formation of the sulphate of ammonia took place. As soon as all the ammonia had been disengaged from the liquor, the fire was withdrawn, the boiler emptied of the waste liquor, and the operations just described repeated. This method of making sulphate is, however, inconvenient, owing to its being non-continuous; it is wasteful in fuel, and the fixed ammonia cannot be recovered without risk of danger to the boiler by the introduction of lime, which forms a hard incrustation on the surface of the plates. An improvement on this method of manufacture consists in driving off the ammonia by means of steam, in place of firing the boiler direct. In this case lime can be employed and the fixed ammonia recovered. A further improvement consists in the employment of two boilers in place of one, the apparatus being so arranged that the ammonia is driven off in a boiler placed at a higher level, by means of steam from a lower boiler in which the liquor is treated with lime. As soon as all the ammonia is driven off from the lower boiler, this boiler is emptied and the liquor from the higher boiler, containing fixed ammonia, is run into it. This liquor is then treated with lime, and the steam evolved is passed into the boiler above, which is filled with fresh liquor. The principle of the modern continuous still is shown in Fig. 21. The apparatus consists of a cylindrical or rectangular vessel divided horizontally into a number of compartments. The liquid to be distilled passes gradually downwards from one compartment to another by means of the overflow pipes shown. A strong current of steam is blown in at the bottom of the vessel and passes upwards through the perforated hoods placed in the centre of each compartment. These hoods have the effect of causing the steam to blow through the liquid in each compartment; and as all the liquor has to pass through each of the compartments in turn, by the time it reaches the bottom of the still it has undergone a thorough boiling. The result is that there is always a current of steam mixed with large quantities of ammonia passing continuously away from the top of the still, and a stream of liquid, free from volatile ammonia, passing away continuously at the bottom.

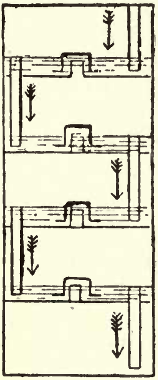


Fig. 21.

One of the advantages of the continuous system of manufacture is that the fresh steam passing in at the bottom of the still, meeting the descending liquor already partially freed of its ammonia, is in a suitable condition for driving off the whole of the free ammonia, whereas under the old intermittent system, where boilers are employed, much fuel and time are spent in attempting to remove the last traces of ammonia from a large bulk of liquor. Further, since the flow of ammonia gas in a continuous still is fairly constant, this must tend to lessen the labour incidental to the working of the saturator, and also to increase its efficiency, owing to the regular precipitation of the salt. The waste gases, also, are more easily purified, owing to their more regular flow. The disengagement of the fixed ammonia is also more easily accomplished by treating a regular flow of liquor with milk of lime, as compared with the older method of introducing the lime in bulk into the boiler.

(89) Give a sketch and description of a modern sulphate plant and explain the method of working.

A modern form of continuous still which is extensively used is shown in Fig. 22, and is known as Feldmann's from the name of the inventor, Dr. Feldmann. This particular apparatus is in use at the Huddersfield gasworks, and the drawing and accompanying description are reproduced from a paper by Mr. Harman, gas engineer at Huddersfield, read before the Manchester District Institution of Gas Engineers. Ammoniacal liquor is pumped from the storage wells into an overhead tank, from which it flows to the superheater, B, in which it is heated to a temperature of about 200° Fahr. by the waste gases coming from the saturator, H. From the superheater the liquor passes into the free ammonia still, C, into which steam is admitted by the pipe, O. In this still the liquor falls from one tray, T, to another, and is constantly exposed to the hot gases and steam given off below, and which are constantly ascending. After passing the trays it flows to the lower portion of the still, where milk of lime is pumped in from the lime-mixer, F. The greater portion of the fixed ammonia is here driven off, but in order to secure the whole of it, the mixture of lime and ammoniacal liquor are caused to pass down another series of trays in the fixed-ammonia still, D, where a further supply of steam is admitted. The waste liquor passes away at W. The resulting ammoniacal and other gases from the still pass into the saturator, H, containing sulphuric acid of a strength of between 54° and 58° Twaddel. In the saturator the ammonia gas neutralises the acid and deposits crystals of sulphate of ammonia, which are removed by a scoop or self-discharging apparatus. At intervals, fresh acid must be added to the saturator, in order to keep the strength up to about 58° T. The gases leaving the saturator pass into the superheater, B, where, as previously remarked, they heat the ammoniacal liquor, after which they pass through a condenser and coke scrubber, and thence either through

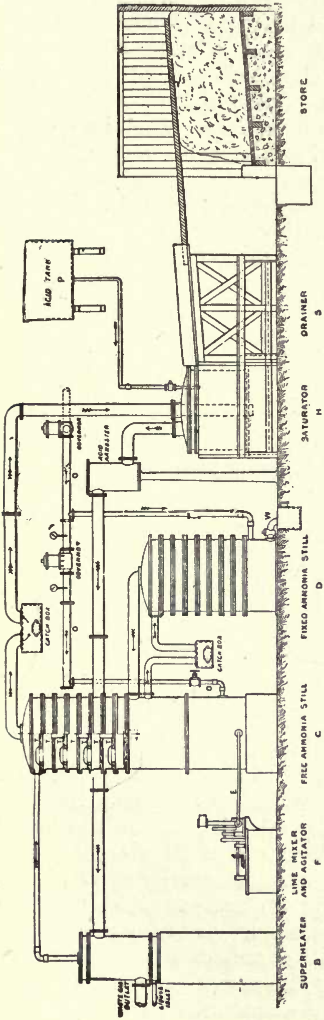


Fig. 22.

an oxide purifier or to a Claus kiln. The crystals of sulphate of ammonia are placed upon the drainer, S, which allows the mother-liquor to drain back into the saturator. From the drainer the "salt" is deposited in a sulphate store having suitable draining channels leading to a receiver. The drainage liquor is again placed in the saturator to be used over again.

(90) Describe the vacuum system of sulphate making, explaining how it differs from the process in ordinary use.

The general arrangement of a sulphate of ammonia plant on the vacuum system is somewhat similar to that of an ordinary continuous plant working under presture with a closed saturator, but there is an addition to the latter plant in the shape of an engine and vacuum pump, for the purpose of keeping the plant under vacuum while the process of sulphate making is in operation. The vacuum produced may be as high as 29 inches of mercury, which is equal to lifting a column of water 32 feet, and this can be made use of in drawing the liquor and acid into the still and saturator respectively from the floor level, thus obviating the necessity of providing overhead tanks. Since the whole plant is worked under a vacuum all the steam required in driving off the ammonia may be obtained from the exhaust steam from other engines on the works, the only live steam required, with the exception of a small jet in the still to prevent frothing, being that used by the engine of the vacuum pump. The temperature of the still is much lower than that of an ordinary plant working under pressure, since being under vacuum the liquor boils and the ammonia is driven off at a much lower temperature; and the lower temperature results in the formation of a much larger crystal. The wear and tear on the plant is less than in the ordinary system, owing to the fact that being under vacuum the gases and liquor are pulled away from the sides of the containing vessels, whereas when under pressure the opposite effect is produced, the gases and liquor being pressed or forced into the interior surface of the vessels, thereby causing more rapid wearing away of the metal. The principal advantages of the vacuum process may be briefly summarized as less cost in labour, large saving in fuel, due to the use of exhaust steam, and the production of a salt free from arsenic from the cheapest form of pyrites acid.

(91) State what you know concerning the materials used in the manufacture of sulphate of ammonia.

The materials employed in the manufacture of sulphate of ammonia are sulphuric acid, ammoniacal liquor, and lime. Sulphuric acid is obtained commercially in three varieties :—(1) Acid of 106° Twaddel, or of a specific gravity of 1·5, containing 60 per cent. H_2SO_4; (2) acid of 142° Twaddel, or of a specific gravity of 1·7, containing 78 per cent. H_2SO_4; (3) acid of 168° Twaddel, or 1·83 specific gravity, containing 92 to 93 per cent. H_2SO_4. Sulphuric acid is obtained from pyrites or brimstone, the latter yielding the purest variety and giving the best coloured sulphate of ammonia. In the manufacture of sulphate of ammonia, acid of a strength of 142° Twaddel is usually employed. The impurities commonly found in commercial sulphuric acid are arsenic, iron, and lead; also sulphurous, nitrous, and nitric acid. Arsenic is especially objectionable, owing to the fact that it causes a discoloration of the sulphate. Ammoniacal liquor is a mixture of various acid radicles in combination with ammonia. A portion of the liquor consists of ammonia in combination with carbonic and hydrosulphuric acids; it is known as "free" ammonia, since it may be driven off from the liquor by extended boiling. The remainder of the ammonia is in combination with sulphuric, hydrochloric, and thiosulphuric acids, and requires the employment of lime in order to drive it off.

The lime employed should be well burned, and should not contain more than 5 per cent. of carbonic acid.

(92) State the approximate quantities of material employed in making 1 ton of sulphate and show how to calculate the amount of sulphuric acid required.

The approximate quantities of material required in the manufacture of sulphate of ammonia are as follows:—Sulphuric acid, of a strength of 142° T., and containing 78 per cent. pure H_2SO_4; of this acid, four times the quantity of ammonia contained in the ammoniacal liquor treated, or, say, 17½ cwts. of acid will be required to produce 1 ton of sulphate. The lime required will be 8 lbs. of slaked lime for every 100 gallons of liquor of 9-ounce strength, or 3 cwts. of lime will be required to make 1 ton of sulphate. 2,500 gallons of 10-ounce liquor will be required to make 1 ton of sulphate.

The quantity of 10-ounce liquor required to produce 1 ton of sulphate is obtained from the following data:—

10-ounce ammoniacal liquor contains 2·1692 per cent. NH_3.

1 ton of ammoniacal liquor contains 0·021692 tons NH_3.

Sulphate of ammonia contains 24·76 per cent. NH_3.

1 ton of sulphate of ammonia contains 0·2476 tons NH_3.

Therefore one ton of sulphate of ammonia requires $\frac{0{\cdot}2476}{0{\cdot}021692} = 11{\cdot}414$ tons of ammoniacal liquor, and, taking this at 218 gallons per ton, the specific gravity being 1·025, $11·414 \times 218 = 2488·2$ gallons.

In determining the quantity of sulphuric acid required to make 1 ton of sulphate we proceed as follows. The reactions which occur in the manufacture of sulphate of ammonia are :—

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4,$$
$$\textit{i.e.}, \quad 34 + 98 = 132.$$

132 parts of sulphate of ammonia require 98 of acid; consequently,

as $132 : 2240 :: 98 : x = 1663$ lbs. of acid,

that is, if the acid were of absolute strength; but as the acid usually employed is of a strength of 142° T., and this contains only 78 per cent. of real acid, we say,

as $78 : 100 :: 1663 : x = 2132$ lbs. of acid of the strength 142° T.

(93) Give an approximate estimate of the cost of making 1 ton of sulphate of ammonia.

The approximate cost of manufacturing 1 ton of sulphate of ammonia may be taken as follows :—

	£	s.	d.
Sulphuric acid	£1	13	0
Fuel	0	9	0
Labour (including packing) . . .	0	11	0
Bags, gas, etc.	0	3	6
Lime, oil and water	0	4	0
Repairs (wages and materials) . . .	0	4	6
	£3	5	0

(94) Discuss the methods of getting rid of the spent gases and spent liquor given off in the process of sulphate making.

There are several ways of getting rid of the waste gases given off in the manufacture of sulphate of ammonia. One which is not to be recommended is that of burning the sulphuretted hydrogen to SO_2 by passing it through a furnace. The plan most commonly adopted is to pass the sulphuretted hydrogen through an oxide purifier, as used in a gasworks. Another plan is to pass the gases through a

Claus kiln and decompose the sulphuretted hydrogen so as to obtain brimstone or flowers of sulphur. The waste liquor and lime from the stills should be thoroughly cooled and passed through a settling tank before being allowed to enter any sewer or water-course. The tank should be covered in, and none of the lime deposit should be allowed to enter the drains, etc. The waste liquors may be further clarified by adding a sufficient quantity of sulphate of iron and enough lime to completely precipitate the base; this will throw down a precipitate of hydrated oxide of iron, leaving a nearly colourless and harmless liquid.

(95) What are the impurities in sulphate of ammonia and how may they be removed?

The impurities present in sulphate of ammonia are principally due to the acid used in the saturator. The impurities produce a grey or yellow salt, in place of the desired white salt. Acid made from brimstone is employed where a white salt is required, because acid made from pyrites contains arsenic and iron, both of which discolour the sulphate. White sulphate can be produced with arsenical acid by skimming off the arsenic bisulphide from the top of the saturator when the latter is of the "open" description. In order to produce sulphate of a good colour it is necessary to use clean water in reducing the strength of the sulphuric acid in the saturator. Another point to be observed is that the crystals should not be allowed to accumulate in the saturator. A white salt may sometimes acquire a yellow colour owing to the gradual accumulation of iron salts in the saturator. The remedy is the periodical cleaning out of the latter.

An objectionable impurity sometimes present in sulphate is ammonium sulphocyanide, which is very injurious to vegetation. This impurity, however, is not generally present in sulphate made in a modern still; it can readily be detected by means of the red colour given to a solution of a ferric salt. Blue sulphate is due, in some instances, to the priming of the still.

(96) Describe a Claus kiln and state the object of its employment.

The Claus kiln is an apparatus for decomposing the sulphuretted hydrogen given off in the process of making sulphate of ammonia. Before describing the apparatus it is advisable to state the principles upon which it works. If sulphuretted hydrogen is passed into new hydrated ferric oxide, with a certain admixture of air, heat is generated, and the hydrogen combines with the oxygen to form water and the sulphur is deposited in the free state. The heat is maintained so long as there is a sufficient quantity of air. If an

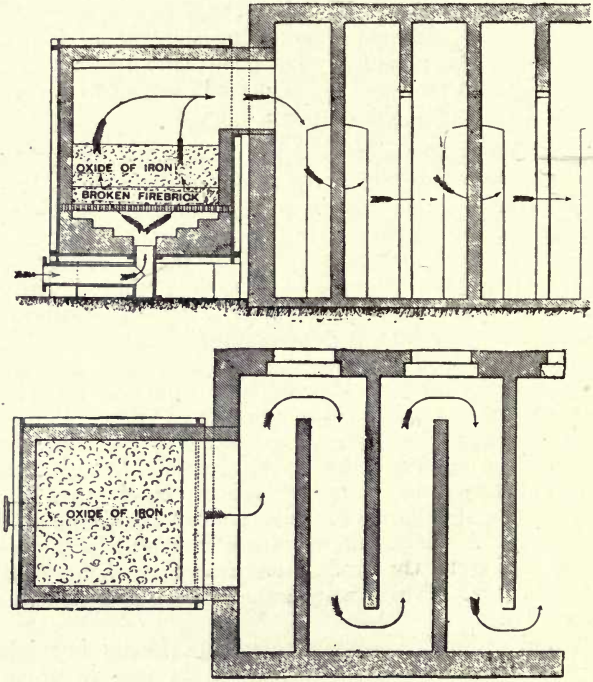


Fig. 23.

excess of air is admitted to the apparatus, however, a portion, or even the whole, of the sulphur will be burned into sulphurous acid (SO_2); while, on the other hand, should there be a deficiency of air, a portion of the SH_2 will remain undecomposed. One form of the kiln is shown in Fig. 23. The gases leaving the saturator, after being thoroughly cooled in a condenser, pass into the air inlet box of the kiln, where they mix with air pumped in by an air engine. The mixed gas and air (in the proportion of $2\frac{1}{2}$ parts of air to 1 of SH_2) then enter the kiln, containing oxide of iron, in which heat is generated. The gases enter at the bottom and pass through some broken perforated tiles, upon which are placed small pieces of broken firebrick, and on this a layer of oxide of iron. The oxide may be either hydrated or anhydrous, but in the latter case it will be necessary, at first starting, to heat it. The sulphur disengaged is carried forward and deposited in the cooling chambers.

In addition to getting rid of an objectionable waste, the employment of the Claus kiln is a source of revenue. Assuming that the whole of the SH_2 given off in the manufacture of sulphate is made available, there will be in an 8-ounce liquor about 1,900 cubic inches per gallon to deal with, and assuming that we obtain 30 gallons per ton of coal there will be in the liquor $2\frac{3}{4}$ lbs. of sulphur, about 90 per cent. of which can be recovered, in place of being wasted.

(97) How would you determine the value of a sample of sulphate of ammonia?

In the valuation of sulphate of ammonia it is necessary, in the first instance, to be careful in taking the sample, which should be well mixed and placed immediately in a well-stoppered bottle so as to avoid loss of moisture. The moisture should be determined by heating in a flat dish for several hours a weighed quantity of the salt, and then re-weighing. The loss of weight gives the water contained in the original salt. Theoretically, sulphate of ammonia should give a neutral reaction, but as usually met with it is slightly acid, by reason of the fact that the contents of the saturator are never allowed to become quite neutral, thus avoiding loss of ammonia. In testing, a portion of the sample is well ground up and poured through a sieve having 10 holes to the inch and a smaller sample taken from this. Twenty grammes of the latter are weighed out and dissolved in 500 c.c. of distilled water, and 25 c.c. of the solution—equal to 1 gramme—together with an excess of caustic soda, are placed in the flask, A (Fig. 24), and the evolved ammonia led into 20 c.c. of normal sulphuric acid, previously diluted with distilled water, contained in B and C. At the end of the distillation the acid is titrated with normal caustic soda solution, using methyl-orange as indicator. It will be found that about 6 c.c. of the normal caustic soda solution will be needed for neutralisation, leaving 14 c.c. as the equivalent of the ammonia which has entered into combination with the acid; and as each c.c. of standard acid is equal to 0·017 of ammonia, on multiplying the number of c.c. of acid neutralised by the ammonia in the sulphate by 0·017, and moving the decimal point two places to the right, we obtain the percentage of ammonia in the sample of sulphate of ammonia. It is sometimes necessary to determine the

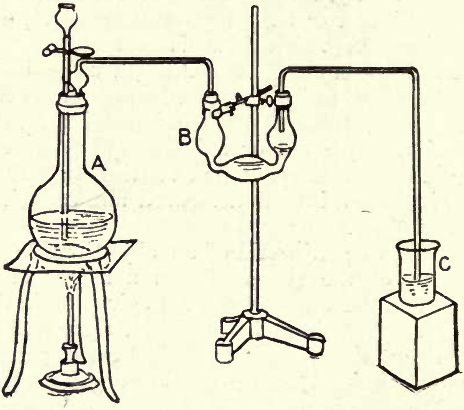


Fig. 24.

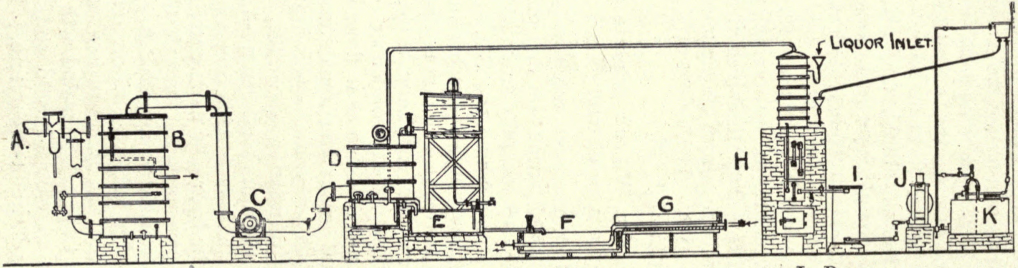
amount of sulphocyanide in a sample of sulphate. This may be determined by evaporating, say, 50 c.c. of a solution of the ammonium sulphate, containing a definite weight of the salt, to dryness, and heating the residue for three or four hours at a temperature of 212° Fahr. It is then digested with strong alcohol, filtered, and washed on the filter with alcohol. All the alcoholic solutions are evaporated to dryness, dissolved in water, filtered from any residue, and a mixed solution of sulphurous acid and copper sulphate added, and the whole gently heated, which will cause cuprous sulphocyanide to be precipitated. The precipitate is washed into a flask, dissolved in nitric acid, boiled for some time, and the copper precipitated as copper oxide (CuO) by caustic soda. The weight of $CuO \times 0{\cdot}96 =$ the equivalent amount of NH_4CNS.

(98) Sketch and describe Wilton's sulphate of ammonia plant, suitable for a small works.

The manufacture of ammonium sulphate on a small gasworks may profitably be carried out in a plant such as is illustrated (Fig. 25). This was fully described in a paper read by Mr. P. G. G. Moon before the Southern District Association of Gas Engineers and Managers in November 1910, from which the following description is reproduced :—

The gas, as it leaves the hydraulic main, is passed through a specially constructed condenser washer, so arranged that as the liquor condenses it flows in a reverse direction to the gas, and leaves the apparatus warm, and containing very little free ammonia. This liquor is conveyed to a direct-fired distillation apparatus, where it is treated with alkali, and the ammonia driven off to the acid washer, through which the main stream of gas passes.

The hot gases from the hydraulic main enter the washer, B, at the bottom, and pass upwards through the six trays. The two top trays may be used as naphthalene washers, by filling them with a suitable solvent, such as oil tar, which also serves to remove the last traces of coal tar from the gas. The two middle trays are provided with cold water circulating pipes, which may be adjusted so that the exit gases are reduced to any desired temperature. The bottom



A. Gas Main.
B. Condenser Washer.
C. Exhauster.
D. Acid Washer.
E. Sulphate Liquor Tank.
F Evaporator.
G. Drainer.
H. Direct-Fired Liquor Still.
I. Spent Liquor Receiver.
J. Pump.
K. Liming Apparatus.

Fig. 25.—Wilton's Sulphate of Ammonia Plant.

two trays receive the condensed liquor from the trays above, and also the tar and liquor from the hydraulic main. The hot gas bubbling through the liquor in these two trays raises its temperature considerably, driving off most of the free ammonia, and the liquor passes away from the washer at about 100° to 120° Fahr., or very little lower than the temperature of the inlet gas.

Through the exhauster, C, the gas now passes to the acid washer, D. This is arranged with trays, so that the gas is washed three times. Sulphate of ammonia solution is formed, and is constantly circulated through the receiver or sulphate liquor tank, E, and through the overhead tank in communication with it, acid being added at intervals, so that the liquor entering the washer contains 1 per cent., and leaving the washer 0·1 per cent. of free acid. The strength of the sulphate liquor gradually increases, and when it reaches 45° to 50° Twaddel, it is run into the evaporator, F, where it is concentrated, by means of a small steam coil, and crystallized. The salt drainer, G, is also provided with a steam coil, so that each batch of sulphate can be dried before removal, thus making it unnecessary to have a lead-lined store.

The virgin liquor containing the fixed ammonia is pumped from the outlet of the condenser to an overhead tank, from which it flows, by gravity, to the direct-fired still, H. A direct-fired still is used in preference to the usual type, so as to prevent increase in bulk of the effluent liquor due to condensed steam.

Finally, the effluent liquor is pumped into tanks and evaporated.

CHAPTER X.

LABOUR-SAVING MACHINERY.

(99) State the various means of saving labour in gasworks.

The labour-saving appliances in the retort house embrace coal elevators and conveyors, manual stoking machines, power stoking machines, electric projectors, inclined retorts, vertical retorts, and hot-coke conveyors.

(100) Describe some form of machine which will reduce the work of the stoker in a small gasworks.

A type of machine suitable for use in a small gasworks is that devised by Messrs. Biggs, Wall and Co., and known as the "Rapid" charging machine (Fig. 26). The apparatus consists essentially of a drum worked by a chain wheel. One end of a steel-wire rope or chain is attached to the drum, and to the other end there is fixed a cradle, which slides over the scoop containing the charge of coal. Upon the side of the drum there is a ratchet wheel and pawl,

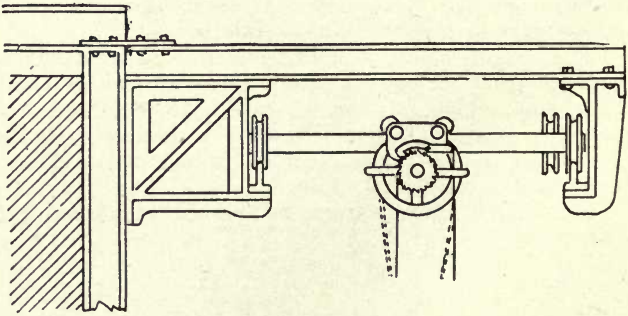


Fig. 26.

which, engaging with the drum, enables the load to be suspended at any desired height. The lifting gear, as above described, is slung from a travelling carriage, which travels to and from the retort by means of two pairs of wheels running on a double line of rails, whilst the carriage itself travels on another set of rails fixed parallel to and in front of the retort bench, so as to enable the machine to charge any number of beds.

The apparatus is worked in the following manner. The scoop, resting on the carrier, is filled with coal. The chain wheel is then set at work and the wire rope is "fed" over the drum. As soon as the scoop arrives opposite the mouth of the retort to be charged the scoop-driver pushes the machine, and the impetus derived from the travel of the lifting-gear carriage, amounting to something like 5 feet, carries the scoop the full length of the retort. The scoop is then turned and withdrawn for refilling with coal.

(101) Describe West's manual stoking machine.

West's manual stoking machine is used in conjunction with a system of coal-breaking and elevating machinery which lifts the coal into overhead coal hoppers fixed in a convenient position in the retort house and provided with sliding outlet doors for supplying coal to the charging machines as they pass under. The machine consists of a square upright frame on wheels, which run on tram rails laid in front of, and parallel to, the retort bench. The machine is propelled by a hand wheel and gear fitted to one side of it, while fixed on the opposite side there is a hand wheel and gearing for the purpose of hoisting and lowering an adjustable coal hopper from one tier of retorts to another. The adjustable coal hopper on the charging machine receives a supply of coal for a number of retorts from the fixed overhead coal hoppers in the retort house, and is free to move up or down between the four uprights of the charging machine frame, being guided by them and suspended by chains leading over pulleys carried by the top cross-members of the frame. At the bottom of the hopper, and directly over the charger, is a feeder-box controlled by a hand wheel when supplying the charger with coal. The charger itself consists of a light carriage running on three wheels and having two semicircular scoops at the bottom. These scoops are arranged to turn over in opposite directions, placing the coal on the floor of the retort, by the twisting of a long driving rod actuated by the stoker.

The method of working the charging machine is as follows:—The machine receives a supply of coal from the overhead hopper. Arriving opposite the retort it is wished to charge, a drawbridge, hinged to the frame carrying the charger, is allowed to fall until it rests on the front of the floor of the mouthpiece. The stoker then gives the hand wheel controlling the feeder-box a few turns, causing the coal to flow from the hopper until the charger is full. The charger is then pushed into the retort by means of the long driving rod, and on arriving at the end of a single retort, or just past the middle of a through, the rod is turned so as to reverse the scoops forming the bottom of the charger, and the coal falls out. The charger is then drawn back and is filled as before. It is then pushed into the same retort to a previously arranged distance, the scoops turned over and the charger withdrawn. After charging any particular retort the machine is propelled to the next retort in the same tier, and the operations above described are repeated as often as required. A removable platform is used for charging the top tier of retorts.

West's manual drawing machine consists of a light frame on three wheels carrying an adjustable arm which supports the rake rod, together with its head. The frame is provided with hoisting gear for the purpose of adjusting the rake rod and head to the several tiers of retorts, and the top tier is reached by means of a removable platform, as in the case of the charging machine. By means of the assistance afforded by this machine the stoker is enabled to use a large, wide rake head.

(102) Describe some form of West's power machine.

West's power stoking machinery embraces rope, compressed-air, and electrically driven machines.

In the compressed-air machine air is compressed in an air compressor to about 60 lbs. per square inch, and is stored in cylindrical receivers, which are frequently fixed above the retort bench. The compressed air is conveyed to the machines by means of flexible hose, which is wound round drums, the latter being so arranged that the "pull" of the hose is counterbalanced by weights, which enables the drums to let out or wind up the hose according to the relative position of the machines as they travel along to the drums, which are suspended from above.

The machines are actuated by means of cylinders with reciprocating pistons, the motion being communicated to the charger and rake respectively by means of multiplying chain pulleys. The charging machine consists of a steel framework and carries a hopper capable of holding about 5 tons of coal. Suspended from the coal hopper is a steel hanging frame for carrying the charger. The gear for driving the charger is fitted to the hanging frame, and consists of an air cylinder having controlling cylinders and valves driving a rack and pinion and chain drum with chains leading to the chain drum in the charger carriage.

The charger consists of a scoop and carriage containing the necessary mechanism for emptying the contents of the scoop and righting the latter for a fresh supply. The scoop is so arranged that it enters the retort twice in order to make a complete charge, first turning over in one direction and then in the other. The coal hopper and the charging carriage frame are raised or lowered to the level of the various tiers of retorts by an air motor, the same motor also supplying the power for propelling the machine on rails in front of the retort bench.

The various operations are controlled by four levers, one of which is fitted with a clutch for putting into action (one at a time) either the travelling or hoisting gears, while another is used for actuating the gears referred to, and a third for starting the charger into the retort. After this point the motions—for stopping the charger when in the retort, holding it while the scoop is reversed, bringing the charger back into the hanging frame and reversing the scoop for a fresh supply—are self-acting. The fourth lever on the charger is for directing the scoop to deliver the coal to the right or left side of the retort.

West's compressed-air drawing machine consists of a light steel framework, provided with suitable travelling gear for propelling it along the front of the retort bench, and with gear for hoisting the rake bar and frame to the level of the different tiers of retorts. The drawing is effected by means of a steel rake bar connected to a cast-steel head, which is carried by a channel-iron framework, having stays and supports for a series of multiplying chain pulleys, by means of which the rake rod is drawn in and out of the retort. The power for driving the rake bar in and out of the retort is derived from a vertical air cylinder fixed to the main frame. The rake head, on entering the retort, is raised above the coke by a hand lever and afterwards lowered into the coke for drawing it out.

(103) Describe the Arrol-Foulis stoking machine.

The motive power in the Arrol-Foulis stoking machine is hydraulic pressure. A general idea of its construction will be gathered from Fig. 27. The charging machine consists of a light steel framework having two horizontal hydraulic rams fixed to a beam, the larger one of the two being used for pushing in the charge of coal and the smaller one for pulling out the pusher rod, to which the rams are attached by means of a block sliding along the beam. On the top of the framework of the machine, in front of the retort bench, is a hopper capable of holding about 5 tons of coal. The coal from this hopper falls on to a movable shoot which is placed in the mouthpiece of the retort, and the coal is pushed into the retort by a pusher, something after the manner in which mud is pushed in front of a broom. The quantity of coal which drops on to the shoot is controlled by a revolving drum which is divided into several compartments by a series of diaphragms, each compartment holding about 50 lbs. of coal. The drum is rotated by a small vertical hydraulic ram which is provided with a rack and pinion arrangement which communicates with the shaft of the coal drum. At each stroke of the rack the drum revolves such a distance as will bring one of the compartments (inverted) over the shoot, causing the coal in that particular portion of the drum to fall on to the shoot, and immediately afterwards to be pushed into the retort. In order to charge a retort equally throughout its length, it is necessary that each stroke of the pusher shall be shorter than the preceding one, and in order to effect this shortening of the stroke there is a revolving shaft, placed parallel with the charging ram, having fixed upon it at equal distances six stops or projections placed radially out of line. The shaft is caused to revolve a certain distance by a ratchet and pawl arrangement actuated by the lever which works the pusher. This brings the stops previously referred

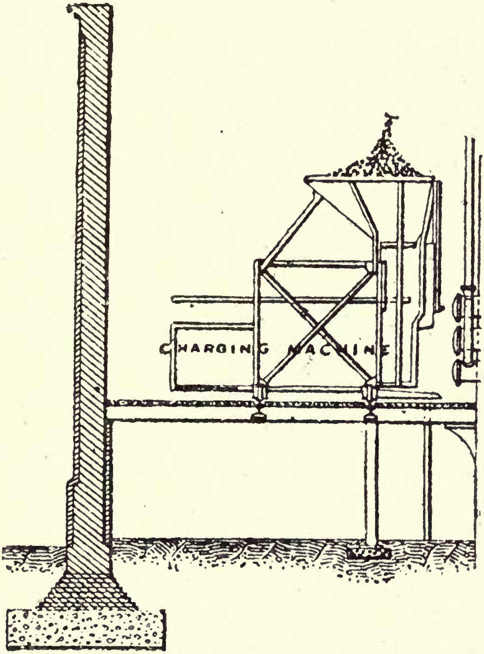


Fig. 27.

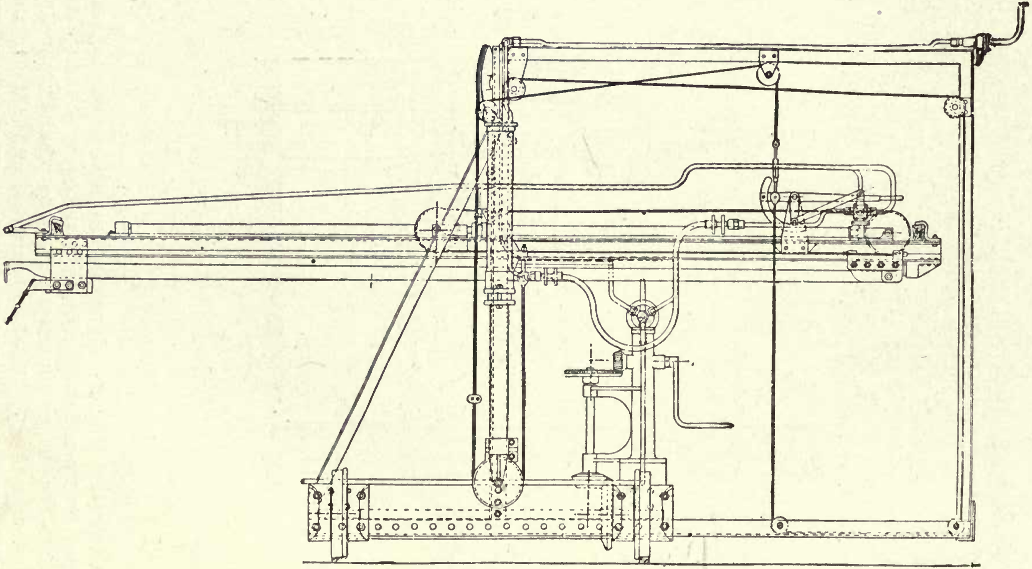


Fig. 28.

to in the path of the ram and shortens the stroke a definite distance each time, until the seventh or last stroke, when the charge is complete. The raising and lowering of the beam is effected by the direct action of a vertical ram, the beam being supported by chains passing over sheaves at the top of the framing and connected to the vertical head of the ram. The whole of the operations of charging the retort are controlled by one lever communicating with the various valves. The machine is propelled by a hydraulic motor. The exhaust water is returned to be used over again. The hydraulic power is supplied by a high-pressure pumping engine working into an accumulator weighted to give a pressure of 400 lbs. to the square inch. This machine is suitable for working heavy charges, as is now the practice, a ram discharger or pushing machine being employed in conjunction with it.

The Arrol-Foulis drawing machine (Fig. 28) consists of the usual light steel framework, carrying a beam of I-section, on the under side of which works a slide attached to a steel rake rod. On the upper side of the bar there are two small horizontal rams, one for propelling the rake into the retort and the other for withdrawing it, the action being similar to that previously described in connection with the charging machine, but in the case of the drawing machine the larger ram is required for withdrawing the rake with its accompanying coke. The rake is suspended about the centre of its length by a chain connected with a vertical ram, by means of which it is raised and lowered to suit the various tiers of retorts. The working of one lever performs the four successive operations of raising, propelling, lowering and withdrawing the rake, while a second lever in connection with the vertical ram raises and lowers the rake bar. As much exhaust water as is required is used for cooling the rake head, the excess being returned to be used over again.

(104) Show, approximately, the comparative cost of carbonizing by hand and some form of power machine.

According to figures by Mr. J. Tysoe, of East Greenwich (which figures leave out of account the wages of the firemen, coke wheelers and others, which are common to the two systems), the cost of hand work is 22·15d. per ton and of maintenance 0·75d., making a total of 22·90d. per ton, while the cost by machinery is 9·6d. per ton and that of maintenance and repairs 2·1d. per ton, making a total of 11·7d. per ton. The saving over hand work is therefore 11·20d. per ton, or, roughly speaking, there is a saving of 1s. per ton by the employment of machinery.

Since the foregoing particulars were published, Mr. Bell, of Derby, has shown that with De Brouwer charging and pushing machines working on eleven through beds of eight retorts, 88 retorts in all, or 176 mouthpieces, the costs ran out as follows:—

6-hour charges	7d. per ton.
8, 10 and 12-hour charges . .	6d. ,,

These costs include all labour, from coal out of waggons to coke into store.

(105) Give a cross section of a retort house, showing the method of raising coal into an overhead hopper.

Fig. 29 shows a cross section of a retort house with a simple form of elevator delivering coal into an overhead hopper for supplying West's manual charging machine, the arrangement having been designed by Mr. John West.

(106) Describe some form of electrical stoking machine.

One of the best known electrical stoking machines is that of M. De Brouwer, as manufactured by Messrs. W. J. Jenkins and Co., of Retford, a sketch of which is shown in Fig. 30. The machine is contained in a channel-iron framework, and the working parts consist of a large grooved pulley and three smaller plain pulleys having an endless belt running round them. The belt also passes round a portion of the circumference of the grooved pulley. The groove in the large pulley is deep and wide, in proportion to the size of the coal to be dealt with. The action of the apparatus is as follows:—

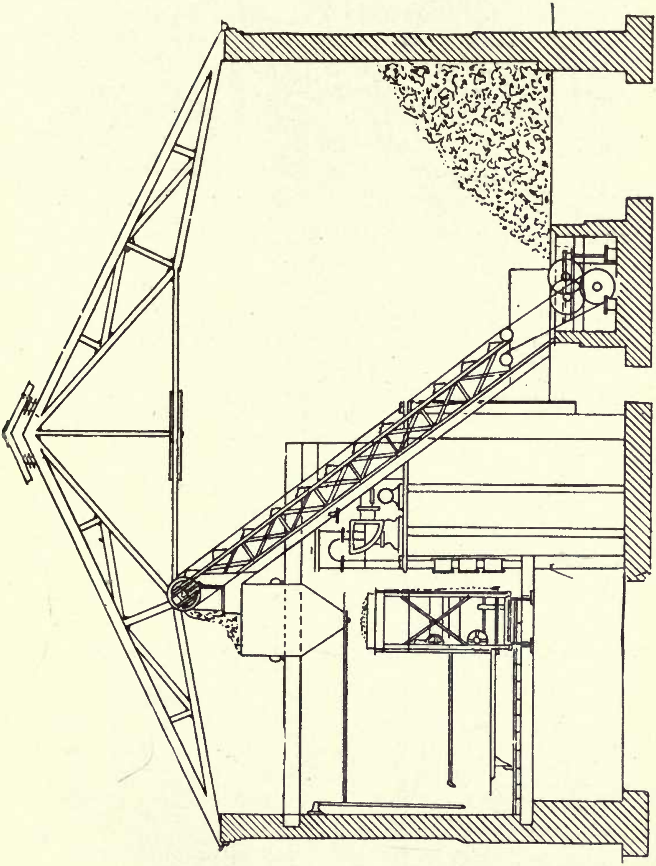


Fig. 29.

The belt is set in motion by a suitable motor (electric). A supply of coal is then dropped from a feeding-shoot into the groove of the pulley, and is prevented from flying off by that portion of the belt which encircles the pulley. The coal rapidly acquires the velocity of the belt, while its centrifugal tendency keeps it closely in contact with the belt as the

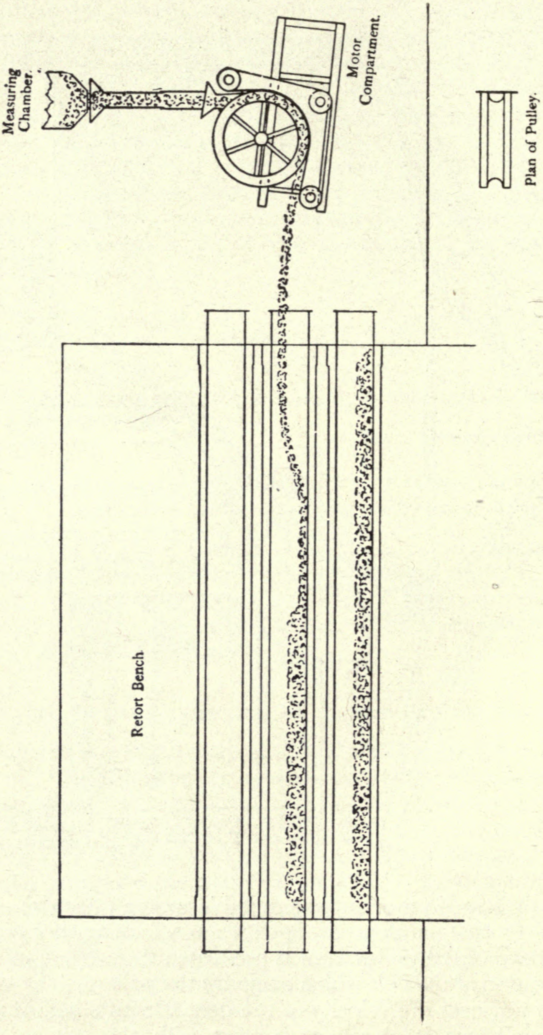

Measuring Chamber.
Motor Compartment.
Plan of Pulley.
Retort Bench.

Fig. 30.

latter takes a horizontal direction and leaves the grooved pulley. The belt travels a short distance horizontally and then doubles back round a plain pulley. The coal, however, maintains a straight line, and, finally, is projected direct into the retort. On arriving inside the retort the coal strikes the floor, slides along to the end, piles up to a certain depth, which is governed by its velocity, and, finally, covers the retort from the end to the mouthpiece.

(107) Describe the Fiddes-Aldridge stoking machine.

This is a machine which simultaneously discharges and charges a through retort in one operation. It consists of a specially designed chain, mounted on a chain drum and carried in a suitable framing fitted with axles and travelling wheels, actuated by an electric motor, for travelling up and down the floor in front of the retort bench. The same motor is employed for raising the chain drum to the several tiers of retorts and for driving the chain in and out of the retort. This chain consists of parallel plates, held in a vertical position by push-plates, pivoted near the top side of the parallel plates at such a point that, when in their natural position, they stand at an angle of 60 degrees. The plates are spaced 2 or 3 feet apart, and arranged to freely lift in one direction, but will not go beyond the vertical in the other direction. By this means each plate pushes a quantity of coal along the floor of the retort, which supply has been received from an overhead storage hopper and fed into the chain before the latter has been set into motion by the motor, which is connected, by suitable gearing, to the chain. On the backward stroke, the push-plates automatically lift and pass over the top of the coal, and assist to level the charge. The front push-plate is heavier than the others, and is specially constructed. During the operation of charging the retort with coal, this heavy plate pushes out the coke from the retort.

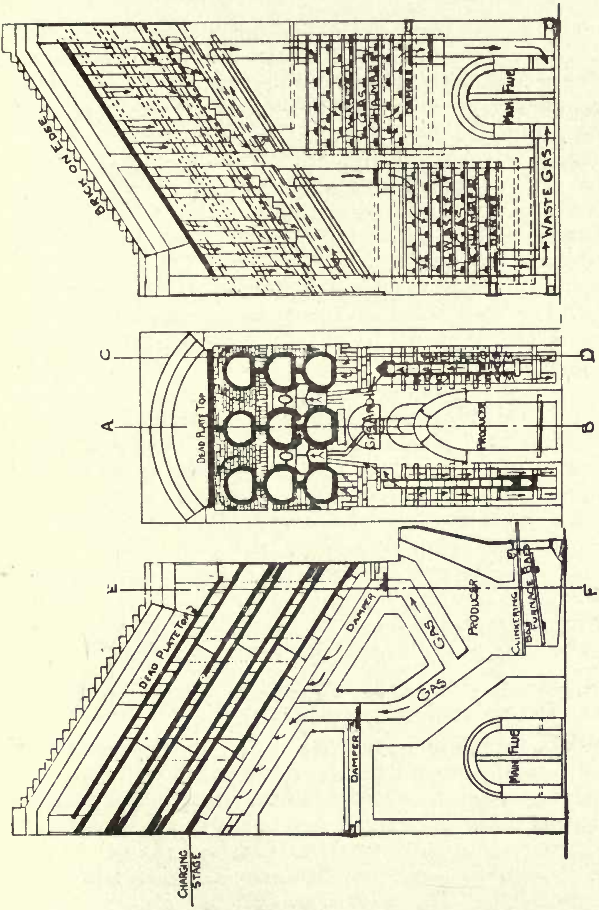
CHAPTER XI.

INCLINED AND VERTICAL RETORTS.

(108) **Describe the inclined system of retort setting and state the points to be attended to in order to ensure an equal heating of the setting.**

In the inclined system of retort setting, instead of the retorts being placed horizontally, they are set at an angle with the horizontal, which varies from 28° to 34°, with the object of enabling the retorts to be charged and discharged by the force of gravity, the coal sliding in at the top and the coke sliding out at the bottom. The angle at which the retorts are set is determined by the angle of repose of the coal to be dealt with, which varies according to the physical constitution of the coal and its behaviour during carbonization. As a general rule, inclined retorts are set at an angle of 31° or 32°, their length being usually 20 feet, but in some instances they are only 15 feet long. Inclined retorts are heated in a similar manner to horizontal retorts, but exclusively by regenerative furnaces. The coal is raised from the crushers on to the top of the retort stack and deposited into a continuous hopper having a conical pocket depending from it immediately over the centre line of each tier of retorts. Attached to the pocket is a measuring chamber somewhat resembling the old-fashioned powder flask. Between the measuring chamber and the conical pocket there is a sliding valve, with a similar arrangement fixed at the bottom of the measuring chamber, both being actuated by one lever.

The retorts are charged by means of shoots fitted with funnels, and travelling on carriages running on light rails. The shoots are of varying length corresponding to the three rows of retorts, and are fitted with a shoe which can be adjusted to enter the mouthpiece of the retort to be charged,



Section on A B. Section on E F. Section on C D.

Fig. 31.—Herring's Inclined Retort Setting.

with its lip just inside the mouthpiece. When the stoker pulls the lever in connection with the measuring chamber, the slide at the top closes and the bottom one opens, allowing the coal to fall down into the charging shoot. The shoot is provided with baffle plates in order to prevent the coal running down too fast. When the charge has all run out, the stoker puts the lever back to its original position, which closes the bottom slide and opens the top one. The coal from the continuous hopper will then fill the measuring chamber, ready for the charging of the next retort. When the charge is burnt off the bottom doors are opened, and the coke is tickled with a slice, which has usually the effect of causing the coke to run out in a continuous stream. The ascension pipes are all fixed to the mouthpieces at the lower ends of the retorts.

In order to ensure the equal heating of an inclined retort setting, it has been found advantageous to practically divide the setting into quarters. The central division wall divides the upper from the lower half of the setting in a similar manner to that adopted in horizontal settings, and each half is likewise divided from front to back and is under the control of its own dampers on either side, there being thus four waste heat outlets from the one setting. The travel of the heat around the retorts should be so arranged that the gases are finally drawn from the lower half of the setting to the front walls and downwards from the upper half. The object of this is to cause a more equal pressure throughout the setting. The method of carrying out the above arrangement is shown in Fig. 31, which represents the patented setting of Mr. W. R. Herring, of Edinburgh.

(109) Sketch fully and briefly describe an installation of Dessau vertical retorts.

As will be seen from the sketch (Fig. 32), the retorts are set vertically, usually ten in a bed, in two rows, though recently some have been set in beds of eighteen retorts, in three rows; three retorts being discharged and re-charged at one time. The retorts are usually 4 metres (13 feet 1½ inches) in height, though in some installations 5-metre retorts have been employed. The retorts are oblong, with rounded corners, in cross section, and tapered from bottom to top, the measurements being 22½ inches by 9 inches at the top and 27¼ inches by 13¾ inches at the bottom. This allows the retorts to be easily discharged, which operation takes place usually every twelve hours. The retorts are worked on the intermittent principle in this system. The retorts

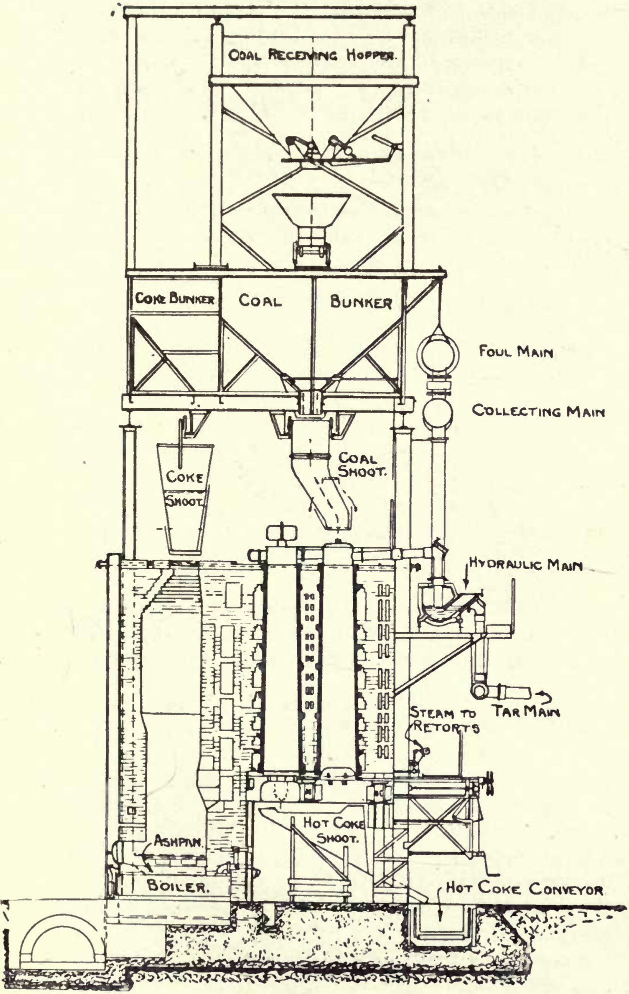


Fig. 32.—Installation of Dessau Vertical Retorts.

occupy one side of the setting, the producer, together with the regenerator, occupying the other. Steam is introduced into the retorts during the last two hours of the charge, and for this purpose a boiler is fixed as shown, which is heated by the waste gases leaving the setting.

(110) What advantages are claimed for vertical retort systems generally?

The following advantages are claimed for the Dessau vertical retorts, as compared with inclined retorts or horizontals worked by machinery:—

Low labour charges; about 4d. per ton.
Low cost of repairs.
Good quality of coke and freedom from breeze.
Larger yield of tar and ammonia, the former being thin, with consequent avoidance of stopped pipes and mains.
Satisfactory yield of gas, with good calorific value, and low in impurities.
Avoidance of machinery.
Saving in ground space.

The one drawback is the high initial cost.

(111) Give sketches of two systems of continuous vertical retort installations. What advantages are claimed for continuous settings over those worked intermittently?

The two systems illustrated are the Woodall-Duckham and the Glover-West.

The chief advantages claimed for the continuous system as compared with the intermittent method of working vertical retorts are as follows:—

Lower labour costs.

Entire absence of smoke, flame and steam.

The retorts are not open either for discharging or recharging, and thus are not subjected to cold air currents, which would tend to crack them.

Saving in time in carbonizing, or, in other words, they produce a larger quantity of gas in a given time.

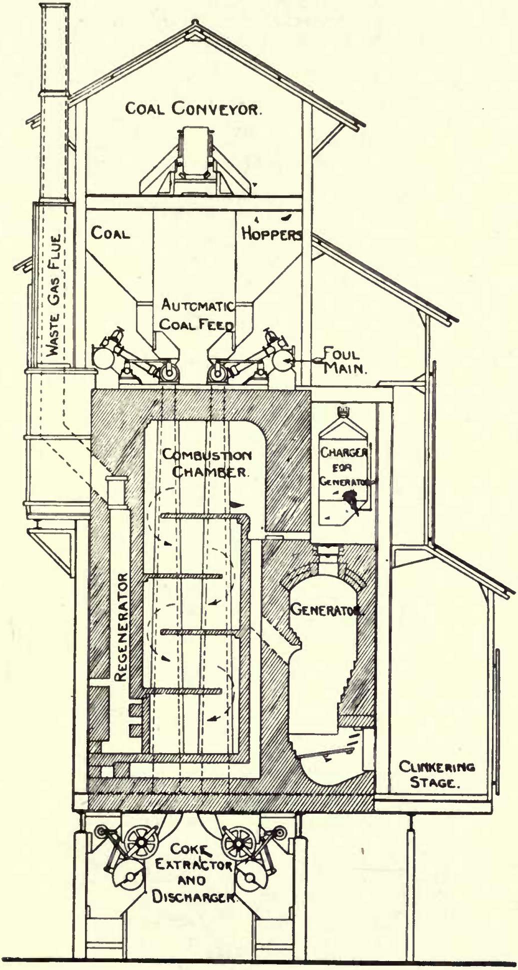
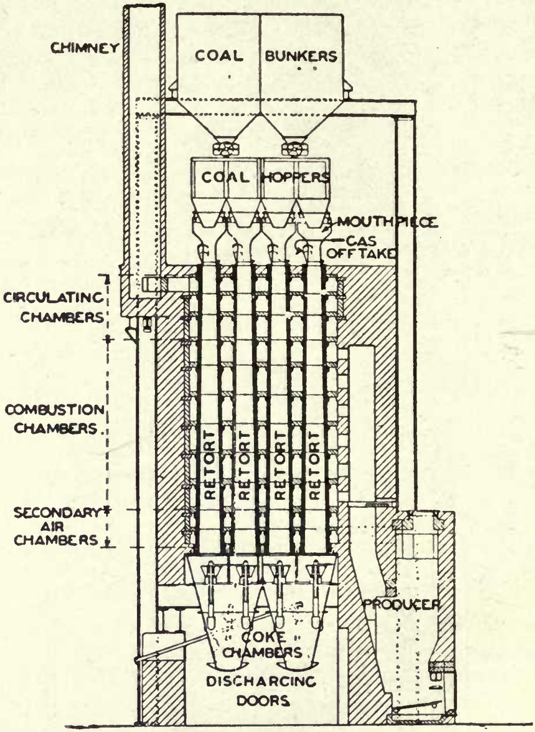
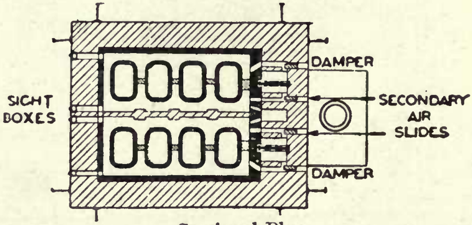


Fig. 33.—Woodall-Duckham System of Continuous Carbonization.



Sectional Elevation.



Sectional Plan.

Fig. 34.—Glover-West Vertical Retort Setting.

Retorts should last longer, since dumping of heavy charges is avoided, and regular flow of coal in and coke out tends to keep retort temperatures constant, providing the producer and kindred appliances receive ordinary attention.

The hydraulic main is dispensed with.

Low fuel account.

CHAPTER XII.

CARBURATION AND NAPHTHALENE.

(112) Describe Young's process of oil-gas manufacture.

The object of Young's oil-gas process is the conversion of the whole of the oil into gas without the deposition of any liquid residue, anything not capable of being gasified remaining in the retort in the form of a dense hard coke. The process depends upon the principle of washing the oil gas by means of the same oil that is afterwards to be decomposed. The decomposition is effected in cast-iron retorts, about 10 feet long, set so as to incline downwards to the far end. The retorts are fitted with doors and ascension pipes in the usual way, each door being provided with a small cock for observing the colour of the gas that is being evolved, which should be of the palest lemon, since a deeper tint indicates the decomposition of tar. The oil to be cracked is admitted through a small cock, about 2 feet up the ascension pipe, and falls down through the ascending gas on to steel plates, which extend about 3 feet into the retort, so as to prevent, as far as possible, the direct impact of the oil upon the bottom of the retort. As the gas leaves the retort it passes up the ascension pipe to the hydraulic main and through a horizontal condenser to a scrubber. The oil cistern is on the top of the scrubber, and the oil first passes through the scrubber, next through the horizontal condenser in an opposite direction to that in which the gas is passing, and then into the hydraulic main. From the latter point it passes through a seal into a small cistern containing a float, which is in connection with an indicator adjacent to the oil-feed taps in front of the retort bench, so that if the oil is either flowing faster than it is being decomposed, or is not flowing sufficiently fast, the supply of oil from the cistern can be regulated so as to maintain a constant balance.

(113) Describe the Dinsmore process.

The object of the Dinsmore process is the conversion of the tar formed in the distillation of coal into permanent illuminating gas, which, being generated in conjunction with the ordinary coal gas, increases the quantity and quality of the gas produced, as compared with gas made from the same coal in the ordinary way. The most successful results from the Dinsmore process were obtained at the gasworks at Widnes by Mr. Isaac Carr. The plant comprised a setting of six ordinary retorts, which were charged at hourly intervals. The primary retort communicated with a secondary empty fire-clay vessel known as the "duct," which was heated to a bright cherry red for two-thirds of the length at the inlet end, and cooled down at the outlet end to a dull red. The action of the apparatus was extremely simple. The gas from the coal gas retorts was forced, by reason of a heavy seal on the dip pipes, into the empty "duct," where a portion of the tarry vapours in suspension in the gas were, by the influence of heat, fixed as permanent illuminating gas. The velocity of the gases passing through the duct was maintained fairly equal by the retorts being charged at hourly intervals. The retorts were shut off from the duct before opening the door preparatory to drawing the charge, and the gas then took its usual course through the hydraulic main.

The quantity of tar used in the process was about 4 gallons per ton of coal carbonized, and it is claimed for the process that it yields an increased quantity of gas equal to 10 per cent., and an increase in quality of from 4 to 5 candles.

[The use of the process was discontinued at Widnes in 1901, on account of the introduction of cheap benzol enrichment, the appreciation in the price of tar, and the great reduction in the price of cannel. These changes, especially that of cheap benzol enrichment, altered the whole commercial aspect of the process (Mr. Carr reports), and so brought about its discontinuance.]

(114) State the principles upon which the carburetting of gases by means of volatile liquids depends.

When coal gas is carburetted by benzol or other volatile hydrocarbon liquids the quantity that will be taken up and permanently retained depends upon the constitution of the gas and the vapour tension of the hydrocarbon used. The quantity of hydrocarbon vapour that can be retained by a gas depends upon temperature and pressure.

The various hydrocarbons used as carburetting materials have different vapour tensions, as shown in the following table, by Mr. T. S. Lacey :—

TENSION IN INCHES OF MERCURY.

Temperature, Degrees Fahr.	Gasoline.	Carburine.	"Mixture."	Benzene.
32	3·2	2·5	2·0	1·1
40	4·0	3·0	2·5	1·5
50	5·2	3·9	3·2	2·0
60	6·7	4·9	4·1	2·7
70	8·3	6·1	5·1	3·5
80	...	7·5	6·1	4·7
90	...	9·3	7·1	5·7

The vapours of the hydrocarbons already present in coal gas have also their own vapour tensions, and as some of these are very low, the gas cannot carry the vapours of light hydrocarbons of a high vapour tension without depositing a portion of the same, together with an equivalent of each of the hydrocarbons which it contains.

The addition to gas of the vapours of such liquids as are capable of freely mixing results in the vapour tension being about the mean of the two components, and causes less of each to be carried than if only one vapour were added.

(115) Describe some form of carburettor for enriching gas by carburine or benzol, and give an estimate of the cost of such carburetting.

One well-known form of carburettor consists of a vertical tubular boiler, the tubes running between two plates fixed at a distance of about 8 inches from the top and bottom of the casing. Steam is introduced between these plates and the outside of the tubes. The enriching material is pumped from a store tank, by a small steam pump, into the evaporator at a point below the bottom plate, and is forced up inside the tubes, resulting in the evaporation of the spirit and the production of a vapour at a pressure, which vapour is conducted, by a tube fixed above the top plate of the evaporator, to a regulating valve placed on an injector, which is connected to the gas main containing the gas to be enriched by small pipes at two points a short distance apart. The vapour under pressure passes through the regulating valve into the injector and produces a partial vacuum at the top of it, to which one of the small gas pipes is connected. This results in the coal gas being drawn into the injector, where it mixes with the hot vapour, forming an extremely rich gas, which is then forced through the second pipe, previously referred to, back into the gas main to mix with the bulk of the gas at a point nearer to the gasholder or the place of consumption, according to circumstances. The quantity of vapour is regulated by the valve in the injector. Should the pressure of vapour in the evaporator be increased by reason of a smaller consumption, the effect will be that the pump will deliver less spirit. In the case of an increased consumption of vapour the reverse action would take place.

One gallon of carburine has been proved in practical working to be capable of raising 8,000 cubic feet of 15½-candle gas to 16½ candles, so that 10,000 cubic feet would require 1¼ gallons. Taking the price of carburine at 9d. per gallon, 1¼ gallons would cost 11·25d., for 10,000 cubic feet, or 1·12d. per thousand cubic feet.

(116) State what you know concerning the causes of the production of naphthalene, and mention some proposals for its removal.

The production of naphthalene is, in the first instance, dependent on the temperature of distillation. The higher the temperature the greater the amount of naphthalene present in the gas. The cause of its deposition in the mains and services is rather a debatable point, but one thing is certain, that temperature plays an important part in the deposition, the reason being that the tension of naphthalene vapour is greatly affected by differences in temperature, and consequently the quantity of naphthalene capable of being held in the form of vapour decreases very rapidly with a reduction in temperature. Gas made on a hot day will probably deposit naphthalene on a cold night at all seasons of the year, but in the winter, when the mains are often at a higher temperature than the gas leaving the works, if the mains are clear to start with, then it is probable that there will not be much trouble from naphthalene deposits, whereas in the summer the conditions are reversed, since the mains are cooler than the gas, the result being that naphthalene is deposited. As the consumption of gas in the summer, however, is small the presence of the naphthalene is hardly noticed; but as the autumn approaches and the nights grow longer and colder it is again in evidence.

A method for the removal of naphthalene which has been found to give satisfactory results on the practical scale depends upon the fact that naphthalene can be dissolved by washing with certain solvents; and this is effected on the works. Mr. J. Ferguson Bell, of Derby, has worked out a scheme embodying the above mentioned principle which gives exceedingly good results. The apparatus in which the washing is conducted may be either a Livesey washer or some form of rotary washer. Mr. Bell, in his process, first washes the warm gas with warm tar, following this by washing it with the heavy naphtha from the distillation of tar. The naphtha has a specific gravity of from 910 to 920, 90 per cent. of which distils at a temperature of 190° C. and 8 per cent. at a temperature of 200° C., leaving a residue of 2 per cent. The quantity of naphtha employed averages about 0·2 gallon per ton of coal carbonized, and the total cost of working the process, including the necessary solvent, labour, pumping, etc., works out at 0·74d. per ton.

(117) State how you would determine the amount of naphthalene in gas.

The amount of naphthalene in gas is usually determined by the method of Dr. H. G. Colman and Mr. J. F. Smith. This method is based upon the fact that picric acid combines with naphthalene, forming naphthalene picrate, the formula of which is $C_{10}H_8, C_6H_3N_3O_7$, a substance which is sparingly soluble in aqueous picric acid. In making a test a solution of picric acid is employed of such a strength that it is nearly saturated at ordinary temperatures. The strength of the solution is determined by titrating it with $\frac{N}{10}$, a tenth normal, baryta water, using lacmoid as the indicator, which changes in colour from brownish yellow to green in the presence of an excess of alkali. The test is performed by bubbling from 10 to 15 cubic feet of gas at the rate of from 0·5 to 1 cubic foot per hour through a series of four bottles, three of which contain picric acid. The first bottle has a capacity of about 300 c.c. and contains 100 c.c. of picric acid solution; the second and third bottles contain 50 c.c. of the picric acid solution; while the fourth bottle is empty, the object of its presence being to retain any splashings of picric acid carried over from the other bottles. The gas passes from the fourth bottle to the meter. At the completion of a test the gas is shut off and the contents of the second and third bottles are added to the first. The bottle containing the whole of the solutions is then closed with an indiarubber cork, passing through which is a glass tube closed at the lower end but having a small hole blown in at the side, about an inch from the bottom. The tube is placed so that this hole is just below the bottom of the stopper. The bottle is then exhausted as completely as possible by a vacuum pump. While the process of exhaustion is proceeding the tube is raised so that the small hole is well above the bottom of the stopper, thus ensuring the bottle being sealed. The bottle is then placed in a water bath containing sufficient water to cover it. The water is raised to the boiling-point, at which it is kept until the liquid becomes quite clear. The bottle is then removed and allowed to cool, being shaken occasionally in order to remove any naphthalene which may sublime on to the upper portion of the bottle. After standing for some time the naphthalene picrate separates out completely, and it is then filtered off, and washed with a small quantity of water. The combined filtrate and washings are made up to 500 c.c., well mixed, and 100 c.c. titrated with decinormal baryta water. From these data the quantity of picric acid which has combined with the naphthalene can be readily calculated. In naphthalene picrate 229 parts of picric acid are united with 128 parts of naphthalene, and, therefore, the quantity of picric acid found multiplied by $\frac{128}{229}$, $=0{\cdot}559$, gives the quantity of naphthalene in the volume of gas passed. The principle of the test depends upon the fact that the relationship of the picric acid to the barium hydrate is known, and a quantity of the picric acid is absorbed by the naphthalene in the gas. Consequently, the difference between the quantity of BaO,H_2O required to neutralise the picric acid before and after the experiment gives the quantity of acid formed into naphthalene picrate.

CHAPTER XIII.

CYANOGEN RECOVERY AND PURIFICATION.

(118) Give particulars of some method for recovering the cyanogen in gas. How much cyanogen is usually present, and how would you determine the amount?

A method of cyanide extraction which is extensively practised consists in precipitating sulphate of iron (8 lbs. per ton of coal carbonized) by weak ammoniacal liquor. This throws down sulphide of iron, which is pumped into a rotary washer. The cyanogen in the gas combines with the iron, producing a solution of ammonium ferrocyanide. This liquor can be worked up into prussian blue, or into potassium or sodium ferrocyanide, as required. In Germany and in some English works considerable quantities of cyanides are obtained from spent oxide of iron in the form of ferrocyanide.

The method of extracting cyanogen patented by the late Mr. Wm. Foulis consists in adding ferrous chloride to a solution of sodium carbonate, in order to produce ferrous carbonate. The precipitated ferrous carbonate is allowed to settle and the clear solution of sodium chloride is run to waste. The wet ferrous carbonate is allowed to run into a tank placed below containing the theoretical quantity of sodium carbonate in solution to form sodium ferrocyanide upon treatment. From this tank the mixture of sodium and ferrous carbonate is run into the first bay of a washer-scrubber, the gas having previously passed through an ammonia scrubber. The hydrocyanic acid contained in the gas combines with the mixture to form ferrocyanide of soda, which is run from the last bay of the washer as fast as produced, this being ascertained by occasionally testing the liquor in the last two bays for the presence of free alkali. The crude ferrocyanide which is run from the washer and evaporated nearly to dryness in large pans is ladled into barrows, and when cool and solid wheeled to the stores. In this condition it is said to contain about 75 per cent. of sodium ferrocyanide.

Another method for cyanogen recovery is that of the British Cyanides Company, as described by Mr. C. Meiklejohn, of Rugby, at a meeting of the Midland Association of Gas Managers in February 1903. In this process solid sulphur in granulated form is added to a rotary washer into which has been run strong ammoniacal liquor of 5½° to 6° T. The sulphur is dissolved and unites with the ammonium sulphide (Am_2S) in the liquor to form ammonium polysulphide (Am_2S_2), and the hydrocyanic acid in the gas is absorbed by the ammonium polysulphide, forming ammonium sulphocyanide ($AmCNS$) and ammonium sulphide (Am_2S). The liquor is worked up to 18° to 20° T.; and the average yield of ammonium sulphocyanide is about 4 lbs. per 10,000 cubic feet of gas.

The amount of cyanogen in gas is a variable quantity, which is greatly influenced by the temperature of distillation, a high temperature being favourable to a large yield of cyanogen. Immediately after leaving the retort the gas may contain from 84 to 132 grains of HCN per 100 cubic feet.

The method of determining the amount of hydrocyanic acid in coal gas consists in passing a measured quantity of the gas through a strong solution of an alkali (potash) to which a small quantity of ferrous sulphate has been added. The hydrocyanic acid in the gas then forms ferrocyanide of potassium, which is afterwards converted into prussian blue, and from the weight of this the amount of HCN in the gas is calculated. The apparatus employed consists of three small Woulff's bottles containing a mixture of caustic potash and sulphate of iron. The gas is measured by an experimental meter, about 5 cubic feet being passed through at the rate of from 1 to 2 cubic feet per hour. At the end of a test the solution in the Woulff's bottles is washed out into a flask, boiled for about fifteen minutes, allowed to cool, and filtered, the filter being washed two or three times with cold water. A slight excess of HCl is added to the filtrate, which produces a precipitate of impure prussian blue.

The precipitate is collected on a filter, redissolved in caustic potash, and reprecipitated as prussian blue by adding a boiling solution of ferric chloride. The precipitate of prussian blue is allowed to settle, washed first by decantation, and afterwards on a filter with hot water until the filtrate is free from ferric chloride. It is then ignited in a platinum crucible until nothing but ferric oxide remains. 560 parts of ferric oxide correspond to 860 parts of prussian blue; and since prussian blue contains 468 parts of CN, the amount of HCN in the gas passed can be readily calculated.

(119) In an experiment for determining the amount of cyanogen on the outlet of condensers, it was found that 1·5 cubic feet of gas gave 5·12 grains of prussian blue. Calculate from this the grains of CN per 100 cubic feet of gas

The formula for prussian blue is Fe_7Cy_{18}, and its molecular weight is

$$\begin{array}{r} Fe = 56 \times 7 = 392 \\ Cy = 26 \times 18 = 468 \\ \hline 860 \end{array}$$

Consequently, 860 parts of prussian blue contain 468 parts of CN. Then, to obtain the grains of CN equivalent to 5·12 grains of prussian blue, we say,

As 860 : 5·12 :: 468 : 2·78.

And as 1·5 cubic feet gave this quantity, in order to obtain the quantity in 100 feet, we say,

As 1·5 : 100 :: 2·78 : 185,

which represents the grains of cyanogen per 100 cubic feet.

(120) State the principles upon which the removal of the sulphur compounds from gas depends, and give the chemical formulæ of the various reactions involved.

The elimination of the sulphur compounds in gas is effected by means of sulphided lime. The essential condition for the carrying out of the process is the absence of carbonic acid, either in the initial sulphiding of the material or subsequently. The carbonic acid can be kept back in two ways, viz., by the Beckton or by the rotation system. In the Beckton system there are two vessels which are filled with sulphided lime, and used exclusively for dealing with the sulphur compounds. The carbonic acid is kept back by means of two carbonate vessels in front, the first vessel in the series being changed when it shows carbonic acid, and when recharged placed second in the series. In the rotation system four lime vessels are used in series, but no special sulphide vessels are provided; each vessel in turn is sulphided, and does its share in taking out the sulphur compounds. At the same time the carbonic acid gradually creeps forward, and would eventually drive out the SH_2 and the CS_2 already taken up; but as soon as CO_2 shows half-way in the second vessel, the first vessel in the series is shut out and emptied, and when it is recharged it is placed last in the series. It will then take up SH_2, so that there is always one vessel at least containing sulphided lime in an active condition for taking out the sulphur compounds.

There is a difference of opinion as to what are the chemical reactions taking place in a sulphide purifier, as the reactions are extremely complicated. The following appear as feasible as any :—

$$CaH_2O_2 + 2H_2S = CaSH_2S + 2H_2O,$$

and on adding air or oxygen to the above we get

$$CaSH_2S + O = CaSH_2O + S,$$

and this combines with CS_2, as under,

$$CaSH_2O + CS_2 = CaCS_3 + H_2O.$$

Another theory which has been suggested makes calcium pentasulphide (CaS_5) the active agent for arresting CS_2. Calcium pentasulphide is produced by acting on calcium hydrosulphide, which is formed as in the first equation given above, thus :—

$$5CaSH_2S + 8O = 2CaS_5 + 3CaOH_2O + 2H_2O$$

and

$$CaS_5 + CS_2 = CaS_2CS_2 + S_3.$$

(121) Discuss the use of ammonia as a purifying agent and describe some method for employing it for this purpose.

The use of ammonia as a purifying agent depends upon the fact that, being an alkali, it is capable of combining with the carbonic acid (CO_2) and sulphuretted hydrogen (an acid) (SH_2) in crude gas, in accordance with the following equations:—

$$2NH_4HO + H_2CO_3 = (NH_4)_2CO_3 + 2H_2O$$
$$NH_4HO + H_2CO_3 = NH_4HCO_3 + H_2O$$
$$2NH_4HO + H_2S = (NH_4)_2S + 2H_2O$$
$$NH_4HO + H_2S = NH_4HS + H_2O.$$

The limiting factor in the amount of purification work capable of being effected by ammonia is the quantity of ammonia in the crude gas, which is about 476 grains per 100 cubic feet, or $1\frac{1}{2}$ per cent. by volume, while the impurities, CO_2 and SH_2, collectively, amount to at least 3 per cent.; so it will be seen that there is not sufficient ammonia available for dealing with the impurities present. The only way of obtaining a sufficiency of ammonia is to treat the ammoniacal liquor which has already taken up CO_2 and SH_2 in such a way that the acids are driven off.

The purification of gas by means of caustic ammonia is carried out by the Claus process. The apparatus employed consists of a series of six scrubbers filled with broken ganister. The crude gas is passed through each of the scrubbers in succession, and cooled spent liquor is pumped over the last scrubber. After removing the last traces of ammonia from the gas the liquor is pumped from the bottom of this scrubber to the top of the second scrubber, where it meets with the gas which has already passed through the first scrubber (where the bulk of the carbonic acid is removed) and also with gaseous ammonia from an ammonia decomposing still. The result is that by the time the liquor reaches the bottom of the second scrubber it will have absorbed a considerable quantity of ammonia and will have consequently removed the bulk of the sulphuretted hydrogen in the gas. This liquor is now brought into contact with solid sulphur, resulting in the production of ammonium bisulphide, which is passed down scrubbers 5, 4 and 3 in succession and removes the carbon bisulphide from the gas, whilst the bulk of the carbonic acid is removed in the first scrubber, a quantity of sulphuretted hydrogen being at the same time liberated. From the bottom of the first scrubber the liquor is pumped to another portion of the plant (the decomposing towers), where it is heated, the acid gases are expelled and the ammonia retained in solution. The acid gases are passed to a Claus kiln, where the SH_2 is decomposed and free sulphur produced. The caustic ammonia liquor is pumped to a still, and the ammonia expelled in the gaseous condition and conducted to the top of the second scrubber previously referred to.

(122) Describe the method of making a complete analysis of ammoniacal liquor.

Ammoniacal liquor consists of a mixture of

Ammonium	sulphide	NH_4HS,
„	monocarbonate	$(NH_4)_2CO_3$,
„	chloride	NH_4Cl,
„	thiocyanate	NH_4CNS,
„	sulphate	$(NH_4)_2SO_4$,
„	thiosulphate	$(NH_4)_2S_2O_3$,
„	ferrocyanide	NH_4FeCy_6,

The first operation is to determine the total ammonia, by boiling 25 c.c. of the liquor with magnesia and collecting the evolved ammonia in 50 c.c. of standard sulphuric acid, which is afterwards titrated with standard soda solution. The total sulphur is next determined by allowing 25 c.c. of the liquor to fall from a burette drop by drop into distilled water acidified with hydrochloric acid and containing an excess of bromine. The excess of bromine is evaporated off, the solution filtered from the precipitate which is deposited, and the sulphur precipitated from the filtrate by barium chloride as barium sulphate. The sulphides in the liquor are next determined by adding a solution of zinc sulphate and ammonium chloride to 25 c.c. of the liquor, the resulting precipitate being filtered off and well washed. The filter paper is then perforated and small portions of the precipitate are gradually washed through into water acidified with HCl and containing an excess of bromine. When the whole of the precipitate has been washed through, the excess of bromine is evaporated off. The precipitate is then filtered, and an excess of barium chloride added, which will precipitate $BaSO_4$, from which the amount as sulphide can be calculated. The next operation is the determination of the carbonates, by adding an ammoniacal solution of calcium chloride to 25 c.c. of the liquor. This will throw down a precipitate of calcium carbonate, which is filtered off, dissolved in 50 c.c. standard hydrochloric acid, and the solution titrated back with a standard soda solution. The chlorides are next determined, by evaporating 50 c.c. of the liquor to dryness in the water bath. Distilled water is added and the undissolved tarry matters filtered off. The filtrate is then treated with a solution of copper and ferrous sulphates in about equal proportions, for the purpose of removing thiocyanates, and the liquid is again filtered. Nitric acid and silver nitrate are added to the filtrate and the solution is boiled. The resulting precipitate of silver chloride is allowed to settle and the supernatant liquid passed through a filter. Before the silver chloride precipitate is deposited in the filter it is digested several times with hot nitric acid, in order to dissolve out the silver sulphide which is formed from the decomposition of silver thiosulphate. The thiocyanates are next determined, by evaporating 50 c.c. of the liquor to complete dryness and heating the residue for three or four hours at a temperature of 212° Fahr. The residue is then digested with strong alcohol, rinsed on to a filter, and washed with alcohol. The alcoholic filtrate is evaporated to dryness, water is added, and the insoluble organic matter filtered off, leaving a solution of ammonium thiocyanate, to which is next added a solution of copper sulphate and sulphurous acid, the latter acting as a reducing agent. This will throw down a precipitate of cuprous thiocyanate, CuCNS. The liquid is gently warmed, and after settling the copper precipitate is filtered off. It is now washed into a flask, dissolved in nitric acid, and the liquid boiled for some time. The copper is then precipitated as copper oxide (CuO) by means of caustic soda. On multiplying the weight of CuO by 0·96, the equivalent amount of NH_4CNS is obtained. The sulphates in the liquor are next determined by first evaporating 250 c.c. to dryness. Distilled water is then added, any organic matters filtered off, and the solution boiled with HCl. A small quantity of zinc oxide is then added, the liquid filtered, and the sulphates precipitated by barium chloride as barium sulphate. The amount of thiosulphate in the liquor is arrived at by subtracting from the amount of total sulphur the sulphur in the sulphides, thiocyanates, and sulphates. The last determination is that of the ferrocyanides, which is carried out by evaporating 250 c.c. of the liquor to dryness and dissolving the residue in distilled water, filtering the solution, and adding ferric chloride to the filtrate. This will yield a precipitate of prussian blue, which is filtered off, washed, and decomposed with caustic soda. The resulting ferric hydroxide is, after filtering and washing, dissolved in dilute sulphuric acid, reduced by means of pure zinc, and the solution titrated with a centinormal solution of potassium permanganate. The amount of iron obtained multiplied by 5·07 will give the amount of ammonium ferrocyanide $(NH_4)FeCy_6$.

(123) How would you test a sample of lime for its value as a purifying agent?

A method for the evaluation of lime is given in "Self-Instruction for Students in Gas Engineering—Elementary," question 69, p. 55. The method now given furnishes more detail, and is applicable either to lime or to the chalk from which it is produced. 5 grammes of the sample are first treated for moisture by drying in a platinum dish in an air bath at a temperature of 103° C. until a constant weight is obtained. 5 grammes are next taken for the estimation of silica, iron, etc. This should be first heated to bright redness in a muffle furnace for an hour. When cool the sample is moistened with strong HCl and allowed to stand for twenty minutes, which will render the silica insoluble. Water is then added and the whole poured on to a filter paper, well washed until free from chloride, and the filter paper and contained silica dried and ignited thoroughly and weighed. The filtrate from the silica is neutralized with a slight excess of ammonia, raised to the boiling point and filtered, the washed and dried precipitate being weighed as the mixed oxides of iron and alumina. In order to separate the two oxides, the weighed precipitate is re-dissolved in HCl and the iron estimated by means of a standard solution of bichromate of potash, after reducing the iron to the ferrous state by means of stannous chloride. The filtrate obtained in the precipitation of the oxide of iron and alumina is then treated with an excess of oxalate of ammonia. This will throw down the lime, which can be estimated volumetrically by dissolving the precipitate in warm dilute sulphuric acid and titrating with standard permanganate of potash. The carbonic acid is eliminated by treating 2 grammes in a Schrötter's carbonic acid apparatus. HCl is placed on the material, which drives off the carbonic acid, and this passes through strong sulphuric acid, which retains the moisture. The apparatus is weighed when charged with the material plus the HCl and H_2SO_4, and the loss in weight before and after represents the CO_2 driven of from the sample.

(124) **How would you ascertain, approximately, the extent to which a sample of spent lime has been carbonated?**

In estimating the amount of carbonate in a sample of spent lime, the latter is treated with hydrochloric acid in an evolution flask, the delivery from which first of all enters a train of bulbs containing a little concentrated sulphuric acid, followed by a **U**-tube containing pumice saturated with sulphuric acid, then a **U**-tube containing dehydrated copper sulphate, followed by a small **U**-tube containing pumice saturated with sulphuric acid, then a set of Liebig's bulbs filled with a strong solution of potash, followed by two **U**-tubes filled with calcium chloride, and the last of these tubes by a series of bulbs filled with strong potash solution. The potash bulbs and the calcium chloride tube following it are weighed before and after the experiment, the gain in weight representing the amount of carbonic acid driven off by the action of the hydrochloric acid on the carbonate in the lime. The object of the sulphate of copper tube is to retain the hydrochloric acid vapour carried forward as well as the sulphuretted hydrogen present in the form of sulphide in the lime. By adding a solution of potassium chromate to the contents of the evolution flask the sulphuretted hydrogen will be oxidized and the hydrochloric acid vapours only will be carried forward to the copper sulphate tubes.

(125) How would you test a sample of oxide of iron for purifying purposes?

In testing oxide of iron we require to ascertain the amount of ferric oxide and free and combined moisture. In order to ascertain the amount of free or uncombined water, a weighed quantity of a powdered sample is dried for a few hours in the water oven at a temperature of 212° Fahr. until the weight is constant. For the combined moisture a small quantity of the dried sample is placed in a tared platinum crucible and ignited at a moderate heat. The loss after heating will represent the combined moisture and organic matter. To ascertain the amount of ferric oxide, weigh out about 2 grammes of the dried and ignited oxide, transfer to a beaker, and digest with fairly strong hydrochloric acid until the iron is extracted, which is ascertained by adding a drop of the solution to a solution of potassium sulphocyanide, which should not give a decided red coloration. When all the iron has been extracted, distilled water is added and the solution filtered, the filtrate and washings being made up to a definite quantity. The next step is to reduce the iron which exists in the ferric, to the ferrous state, by placing a known quantity of the filtrate and washings in a flask and adding two or three small pieces of zinc free from iron and gently heating until the change in colour indicates that the iron has been reduced to the ferrous state. The complete reduction can be tested by placing a drop of the solution upon a white tile and adding a drop of a freshly prepared solution of potassium ferricyanide, which will give a blue colour if ferrous salts are present and a brown if the reduction is not complete.

The solution is then cooled out of contact with the air and titrated with a standard solution of $\frac{N}{10}$ bichromate of potash, using potassium ferricyanide as an indicator. When the conversion of the ferrous to the ferric salt is complete a drop of the solution of ferricyanide of potassium should produce a brown colour. The number of cubic centimetres of decinormal bichromate solution used in completely converting an iron solution from the ferrous to the ferric state multiplied by 0·0056 will give the amount of iron present in grammes. If the amount of ferric oxide be required, the multiplier is 0·0080; and if the amount of monohydrated ferric oxide be required, the multiplier is 0·009. Having obtained the amount of ferric oxide in the quantity operated on, it is an easy matter to obtain the percentage.

(126) How would you analyze a sample of raw and spent Weldon mud?

The most important constituent to estimate in a sample of raw Weldon mud is the amount of manganese dioxide (MnO_2). In order to determine this we require a decinormal solution of potassium permanganate, made by dissolving 3·156 grammes of that substance pure and dry in a litre of distilled water. The strength of this solution is then checked by titrating it against a known weight of pure iron wire dissolved in sulphuric acid. 0·112 gramme pure iron requires 20 c.c. decinormal potassium permanganate in order to effect its oxidation from the ferrous to the ferric state. The solution of potassium permanganate alters its strength with keeping; it is necessary, therefore, to check it periodically by means of a solution of ferrous sulphate. This is done by dissolving 100 grammes of pure clean ferrous sulphate in distilled water, adding 100 c.c. of pure strong sulphuric acid, and making up to a litre at 16° C. 20 c.c. of the iron sulphate solution are then titrated against the permanganate solution, and should require about 72 c.c. of the latter; the exact amount of permanganate required should be noted, and it should be ascertained on each occasion the iron solution is used, since the latter suffers gradual oxidation.

In making a test, about 0·5 gramme of Weldon mud is carefully weighed out, washed into a small flask, and 20 c.c. of the sulphate of iron solution added. In order to bring the Weldon mud into solution it should be gently heated, and any gritty particles broken up by means of a glass rod. When completely dissolved the solution is titrated with the standard permanganate, and the volume of the latter required for the oxidation of the unoxidized ferrous sulphate is noted. This will give the amount oxidized by the MnO_2, from which the amount of the latter is obtained. Thus supposing, in the first instance, 20 c.c. of the ferrous sulphate solution required 70 of the permanganate, and 0·5 gramme of Weldon mud were then added, and it then required only 45 c.c. of the permanganate solution to oxidize the iron solution, then $70 - 45 = 25$ c.c. = the manganese dioxide equivalent of 25 c.c. decinormal potassium permanganate. Now, 1 c.c. of decinormal permanganate solution is equivalent to 0·00435 MnO_2, consequently $0{\cdot}00435 \times 25$ = the manganese dioxide contained in 0·5 gramme Weldon mud. $25 \times 0{\cdot}00435 = 0{\cdot}10875$, and as 0·5 gramme was taken

$$0{\cdot}5 : 100 :: 0{\cdot}10875 : x. \quad x = 21{\cdot}75 \text{ per cent.}$$

In testing spent Weldon mud the principal information required is the amount of sulphur it contains, and this is obtained by dissolving 100 grammes of the spent mud in HCl, filtering, and well washing the residue on the filter, the latter being afterwards dried in the water oven. The filter paper, with its content, is then transferred to the drawn-out test tube of a Stephenson's sulphur extraction apparatus, and the sulphur is extracted in the manner described under oxide of iron in "Self-Instruction for Students in Gas Engineering (Elementary)." The moisture is estimated on a separate portion of the mud.

(127) 2 grams of a sample of oxide of iron were taken for an analysis and dissolved in HCl. One-fourth of the solution obtained was then titrated with decinormal potassium bichromate solution, and required 32 c.c. of the latter solution for oxidation. Calculate from the data given (*a*) the amount of iron in the sample, (*b*) the amount of ferric oxide, and (*c*) the amount of monohydrated ferric oxide.

One-fourth of 2 grams = 0·5 gram, and each c.c. of the decinormal bichromate solution multiplied by 0·0056 will give the amount of iron present. Consequently, 0·0056 × 32 = 0·1792 in 0·5 gram of the oxide. In order to obtain the percentage, we say,

As 0·5 : 100 :: 0·1792 : 35·8 = percentage of iron.

In order to obtain the amount of ferric oxide we use the multiplier 0·0080 in place of 0·0056. The calculation is then as follows:—

32 × 0·0080 = 0·2560
and 0·5 : 100 :: 0·2560 : 51·2.

To obtain the percentage of monohydrated ferric oxide, we use the multiplier 0·0089.

32 × 0·0089 = 0·02848
and 0·5 : 100 :: 0·02848 : 56·92.

(128) **In testing a sample of raw Weldon mud it was found in the first instance that 20 c.c. of ferrous sulphate solution required 71 c.c. of $\frac{N}{10}$ permanganate of potash. 0·5 gram of the mud was then dissolved in 20 c.c. of the ferrous sulphate solution and afterwards titrated with the permanganate solution, when it was found that it only required 41·6 c.c. of the latter solution. From the above data work out the percentage of MnO_2 in the Weldon mud.**

20 c.c. of ferrous sulphate solution required 71 c.c. $\frac{N}{10}$ permanganate solution. 0·5 gram of the Weldon mud dissolved in 20 c.c. of the ferrous sulphate solution then required 41·6 c.c. permanganate solution. The Weldon mud therefore contained as much MnO_2 as is equivalent to 29·4 c.c. $\frac{N}{10}$ permanganate solution. 1 c.c. of decinormal solution of potassium permanganate is equal to 0·00435 grain MnO_2, consequently in 0·5 gram Weldon mud there was 29·4 × 0·00435 = 0·12789 gram MnO_2. Then in order to obtain the percentage we say,

As 0·5 : 100 : : 12,789 : 25·57 = the percentage.

(129) **Describe the "reverse" or "backward rotation" method of working oxide purifiers, and state the**

advantages of this method of working compared with the old or forward rotation system.

In the old method of oxide purification—namely, the forward rotation system, it was the general practice to employ four purifiers, filled with oxide, three of which were always at work and the fourth box held off for changing. The gas was made to enter, say, No. 1 box, then through No. 2 and No. 3 boxes, No. 4 being off, charged with oxide ready for work, to be put on when a foul test was found on the outlet of No. 2 box. When this was fouled, No. 1 was shut out and the gas made to first enter No. 2 box, then through No. 3, and, finally, through the clean box, No. 4, then made third in the series. No. 1 was then emptied, freshly charged and put to work when a foul test was shown in the outlet of the second taker, in this case No. 3, and so on in forward rotation, the second taker being put first after every change, and the clean box placed last in the series.

In the "reverse rotation" method we still retain the four purifiers, but work them as follows, say, Nos. 1, 2, 3 and 4, either the first three or all the purifiers being at work. As the sulphuretted hydrogen creeps forward, it is carefully watched until it shows itself at No. 3 outlet. A change is now made, No. 4 box being placed first in the set, the flow of gas now being through Nos. 4, 1, 2, 3. Then when a foul test is obtained at the outlet of No. 2 purifier, the last box (No. 3) is placed first, the order now being 3, 4, 1, 2, and so on; when a foul test is obtained at the outlet of the third box, the last box is placed first in the series.

By this method of working, purifying costs have been considerably reduced, owing to the boxes lasting so much longer than formerly, since, when a change in order is made it is not always, or even often, necessary to empty a purifier, some having been known to run for over two years without changing. To obtain such long runs, the purifiers must be of large area. The reason why this method of working gives such good results is not clearly understood, but it is thought that by putting the fouled vessels last, the oxygen admitted with the foul gas comes through the clean purifiers, which are busy absorbing sulphuretted hydrogen, and so on to the foul boxes, which are, consequently, revivified *in situ* by the oxygen, and their lifetime considerably lengthened.

[The general methods of dry and wet purification are thoroughly dealt with in the fourth edition of "Self-Instruction in Gas Engineering—Elementary," and the student is referred to that, which also includes, in an appendix, full particulars of all up-to-date washers, scrubbers and washer-scrubbers, as illustrated and described in a paper by Mr. W. H. Johns, of Saltley, Birmingham.]

CHAPTER XIV.

GASHOLDER CONSTRUCTION.

(130) **State the rule and illustrate, by an example, the method of determining the thickness of the wall of a gasholder tank in order to resist the water pressure exerted against it.**

To arrive at the thickness the wall of a gasholder tank should be of at any given point in order to enable it to resist the internal pressure of water exerted against it, we make use of the following formula :—

$$\frac{PD}{K-P} = \text{thickness in inches,}$$

P being pressure of water in lbs. per square inch ;
D ,, radius of tank in inches ;
and K ,, safe cohesive force in lbs. per square inch.

Taking as an illustration a gasholder tank 120 feet in diameter and 25 feet deep, constructed of brickwork set in Portland cement mortar and puddled, we will assume that we require to know the thickness of the wall directly above the footings. The first operation is to obtain the pressure of the water on each square inch, thus :—

$$\frac{62{\cdot}5 \times 25}{144} = \text{(say) } 10{\cdot}9 \text{ lbs.}$$

The safe cohesive strength of brickwork set in Portland cement mortar may be taken at $220 \div 2 = 110$. Then applying the formula previously given, we have :—

$$\frac{10{\cdot}9 \times 720}{110 - 10{\cdot}9} = \frac{7848}{99{\cdot}1} = 79 \text{ inches, or 6 feet 7 inches}$$

as the required thickness of the wall, without taking into consideration the support given by the earth backing or the resistance offered by the weight of the material comprising the wall. The support given by the earth backing may be taken as being equal to the resistance of the wall, and the figure obtained, 6 feet 7 inches, can safely be divided by 2, making the thickness of the wall above the footings 3 feet 3½ inches.

(131) How does the pressure of water act on the walls of a brick and puddle and on a cement-rendered tank, respectively?

In a cement-rendered tank the bursting pressure of the water is exerted against the tank walls, and the tightness of the tank depends, to a great extent, upon the material of which the earth backing is formed and the care with which it is filled in and rammed and watered. In the case of a brick and puddle tank the pressure of the water contained in the tank is transmitted through the brickwork of the tank walls (which are more or less porous) to the clay puddle and earth backing behind, which are not absolutely rigid but slightly elastic.

(132) Give a brief description of the operations involved in the construction of a gasholder tank.

The first operation in the construction of a gasholder tank is to ensure that the site is suitable, by making a number of trial borings in order to ascertain the character of the ground which will have to be excavated. Should water be found in abundance it will be necessary, before starting excavating, to make adequate provision for its removal, by sinking a sump close to the site of the tank and carrying it down 3 or 4 feet lower than the lowest part of the excavation, and fixing duplicate pumps sufficiently large to deal with the water likely to be met with. The diameter of the tank and the thickness of the tank wall determine the area of excavation. A circular trench is formed of the full width at the bottom, allowing for the footings and also for the puddle required. In setting out the trench sufficient space must be left for timbering, since it is necessary to securely shore up and strut the excavation as it proceeds. In a brick and puddle tank, after the necessary excavation has been made, a layer of puddle 2 feet thick—prepared by well soaking good stiff clay with water, cutting it up, and turning it over until it is of a proper consistency—is placed all over the bottom for a depth of 1 foot 6 inches to 2 feet 6 inches, and under the footings. A portion of the tank wall is then built up for a height of 3 feet. Puddle is thrown in between the excavation and the brickwork, another 3 feet of brickwork is built up, and the same operations are gone through until the top of the tank is reached. It is necessary to exercise great care in filling in with earth at the back, so as to have the backing as solid as possible. At the lower part of the tank the filling in will principally consist of puddle, but as the trench becomes wider at the top and the wall is reduced in thickness, it is necessary to back-up the puddle with carefully selected earth well watered and punned. In order to ensure the correct dimensions and curvature of the tank it is necessary to employ a trammel. This is usually constructed of timber, and should be as rigid as possible. It is secured upon a pivot fixed exactly in the centre of the tank, and should have a plumb line suspended from the end, so that the correct dimensions of the tank can be exactly adhered to. (Tanks have, however, been accurately set out and built to a true circle by the use of a steel tape, the end of which is secured to a stave driven in the centre of the excavation, from which all measurements are taken.) As soon as the tank wall is completed the excavation of the inside of the tank can be proceeded with. A portion of this, dependent on the angle of repose of the soil, is usually left in, this being known as the "cone" or "dumpling;" and it is necessary to place puddle up the sides and over the top of this "dumpling" in order to render the tank water-tight. Rest stones are bedded on the bottom of the tank for the purpose of resting the bottom curb of the holder when the latter is "down." Piers are formed at various points round the circumference of the tank for the purpose of taking the holding-down bolts of the gasholder columns, which are fixed and built in during the building of the tank. These should be bonded in with the rest of the brickwork. A stone coping is placed on the top of the piers on which the base of the gasholder columns rest. The thickness of a tank wall necessarily varies with the diameter of the tank. A common arrangement is to start with 3 feet thickness at the bottom, reducing to two-thirds the thickness some distance above and to one-third the thickness at the top. The reduction in thickness is made by "set offs" on the outside of the wall. The top of the tank is finished off with a brick or stone coping.

In concrete tanks the excavation for the concrete is an annular ring, rather wider than the width of the concrete sides, carried down as far as necessary and securely timbered. The bottom portion of the excavation should be made wider than the wall itself and left rough, so that when the inside of the tank is removed there may be a suitable surface for the new concrete forming the bottom of the tank to take hold of. The concrete employed consists of one part of Portland cement and seven of well-washed ballast, with a small quantity of clean, fine sand. The tank is rendered by applying first a coating of equal parts of Portland cement and washed sand from ½-inch to ¾-inch thick, followed by a finishing coat of neat cement about ¼-inch in thickness.

(133) Discuss the relative merits of trussed and untrussed gasholders, and give a sketch of an untrussed holder, showing the method by which it is supported when empty.

In large gasholders the expense of trussing is a serious item. The trussing also increases the weight, which, in turn, increases the pressure thrown. This was formerly considered a disadvantage, since any pressure in excess of that requisite for giving an adequate supply of gas to the district was thought to be wasteful. But oftentimes, in these days of high pressures, the inner lift of many gasholders is of insufficient weight to enable the top or peak load pressures to be worked, and boosting has to be resorted to. The system of erecting holders without trussing possesses the advantages of being simpler, cheaper, and more durable, since the weight of the holder can be spread over the sheeting in place of being in the trussing. As an illustration, a trussed gasholder, 100 feet in diameter and 25 feet deep, will weigh about 100 tons, 30 tons of which will be in the trussing, and it will throw a pressure of about 5½ inches.

If the trussing were dispensed with the holder would throw a pressure of only about 3 inches, which, in all probability, would be ample for supplying the district. It is in large holders, however, that the advantages of dispensing with the trussing are most marked, since the strength and weight of the trussing have to be increased as the square of the diameter of the holder. In untrussed holders the top curb is strengthened by the addition of an angle-iron ring and by increasing the thickness of the first rows of the side and crown sheets. The crown of an untrussed holder has usually a greater rise given to it than that of a trussed holder, in order to reduce the strain on the curb, which varies directly as the radius of a sphere of which the top is a segment.

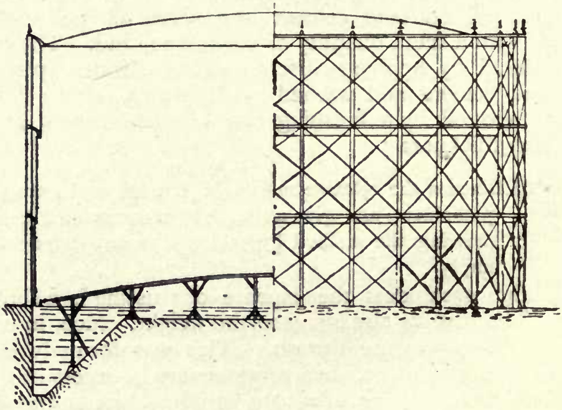


Fig. 35.

Fig. 35 shows the method of supporting an untrussed holder when empty.

(134) Give sketches of telescopic cups, and of one type of gasholder framing.

Fig. 36 shows a sketch of a flat cup and grip, Fig. 37 Piggott's circular cup and grip, and Fig. 38 a steel gasholder guide framing.

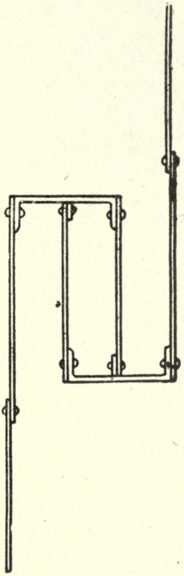


Fig. 36.

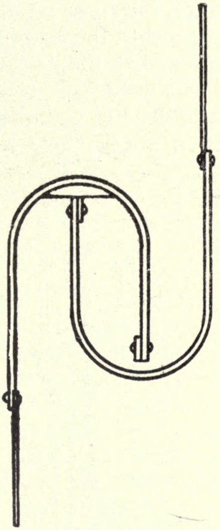


Fig. 37.

(135) **Briefly describe the Pease and the Gadd and Mason systems of gasholder construction.**

In the system of guiding gasholders patented by Mr. E. Lloyd Pease, there are a series of strong roller bearings on the level of the coping of the tank. These are securely fixed and arranged in pairs, with a space between in which a circular **H**-iron girder is placed, which is free to travel in either direction concentrically round the tank. In order to render the description clear it will be of advantage to assume that the holder is of the single-lift type and grounded. Upon the top curb of the holder a number of "goose necks" are fixed, to which are securely fastened one end of wire ropes as long as the holder is deep. The other ends of these ropes, after passing round guide pulleys, are attached to the upper side of the circular girder and lie along it. Other similar ropes are fixed to the under side of the girder, but pass in the opposite direction, and these are attached to the bottom curb of the holder. Now, when the holder is at the bottom of the tank, the upper guide ropes will be lying with most of their length on the top of, and in line with, the movable ring girder, while the under guide ropes are fully paid out and hanging their vertical length in the tank. If, now, the holder is raised, in ascending it takes up the top guide ropes, which, being fast to the girder, pull it round to the same extent horizontally and circularly. At the same time the under guide ropes are drawn out of the tank to the same extent and pass round with the girder until the holder is inflated, when the upper ropes are fully paid out. In the descent of the holder the reverse action

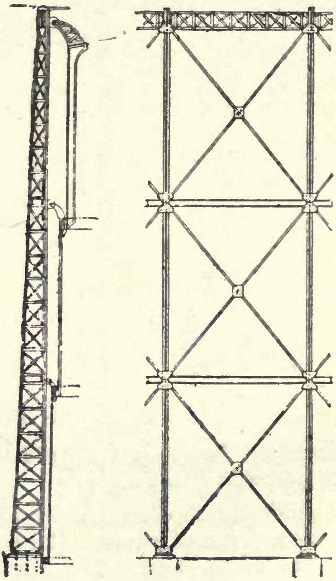


Fig 38.

takes place, the bottom ropes pulling the girder in the contrary direction, and the girder takes up the top guides as it travels. No rope can go faster than another, and so the holder is kept in a horizontal position at all heights and is tied with equal tension all round at the set points from top to bottom. The attachments of the ropes are so arranged that the ropes may be adjusted so that they are all equally strained. A modification of the foregoing consists in substituting a strong endless wire rope, running in grooved guide pulleys, to which the guide ropes are attached, for the circular girder. The advantages of this modification are that it is easier to fix to a telescopic holder, and it is cheaper.

The Gadd and Mason system consists in placing the channel guides in the gasholder tank at an angle, after the manner of the thread of a screw, instead of vertically, as is the usual manner. The guide rollers attached to the bottom curb of the holder are placed either radially or tangentially to the sides of the latter, and as they work in the channel or other guides a helical or screw-like motion is communicated to the holder as it rises and falls in the tank. The guides within the tank may be placed at any angle from 45° to something less than vertical. The effect of this is that so long as the rollers are free to move within the guides it is impossible that the holder can tilt, since the tendency of wind or other pressure exerted against the sides or on the roof of the holder will be to produce a kind of "locking action" which will sustain the holder in the vertical position, however great the strain, provided it is within the resisting strength of the rollers and their carriages. Although this locking action gives rigidity to the vessel, enabling it to resist the overturning force, the rollers are perfectly free to rise and fall within the guides.

(136) State the rule for arriving at the pressure thrown by a gasholder from its weight.

In order to calculate the pressure which will be thrown by a gasholder of a certain weight we make use of the following formula :—

$$P = \frac{W}{A \times 5{\cdot}21};$$

W being the weight of the holder in pounds,
A „ area „ „ „ feet, while 5·21 is the weight of a column of water 1 foot square and 1 inch high, or the twelfth part of a cubic foot of water, which weighs 62·5 pounds. As an example, suppose we wish to know the pressure which a gasholder 100 feet in diameter and weighing 73 tons will throw.

Then $73 \times 2{,}240 = 163{,}520$ pounds,
100 feet diameter = 7,854 feet area;

$$\frac{163{,}520}{7{,}854 \times 5{\cdot}21} = \frac{163{,}520}{40919{\cdot}34} = 4'' \text{ nearly.}$$

(137) How would you determine the capacity of a gasholder? What are the usual proportions of gasholders?

In order to arrive at the capacity of a gasholder we employ the following formula:—$D^2 \times 0{\cdot}7854 \times d$. Or diameter squared × 0·7854 = area; then the area multiplied by the depth in feet = capacity in cubic feet.

In calculating the capacity of a telescopic holder, the capacity of each lift must be taken separately, and the several capacities added together, deducting the space occupied by the cups.

In order to arrive at the capacity of the crown, we proceed as follows:—Radius squared × 3 + height squared × height × 0·5236.

The usual proportions of gasholders, that is, the relation of the height to the diameter, is:—$\frac{H}{D} = \frac{2}{3}$ to 1 and $\frac{H}{D} = \frac{1}{3}$ to 1; though many have been built where $\frac{H}{D} = \frac{1}{2}$ to 1.

CHAPTER XV.

POINTS IN MANAGEMENT.

(138) Explain fully how you would proceed to dry and bring up to carbonizing temperature a new bed of retorts fired by means of a generator and provided with regenerators. State the precautions you would take to avoid any explosion of gas within the setting

Before starting to dry the brickwork of a retort setting it is advisable to have all the flues, ports and nostril holes carefully examined and cleaned out, since the bad heating of a setting is frequently traceable to the presence of pieces of brick and clay which have been left behind by the retort setter, and which can only be removed when the setting is not at work. Assuming that everything is clear, all slides and dampers are closed, with the exception of the sight-holes and the charging and clinkering doors. A small fire is then made upon the grate bars, which is kept regularly filled up with clean coke or breeze, and as the brickwork dries the amount of fuel is increased. The charging and clinkering doors being open, sufficient air enters to ensure the complete combustion of the fuel. When steam ceases to issue from the top sight-hole the fire is increased, the dampers opened wide, and the top sight-hole plugged up so as to cause the products of combustion to be drawn over and pass through the regenerators and flues, so as to dry them also. As soon as all the brickwork has been thoroughly dried, the fire is further increased until the producer arch has attained a red, and the bottom retorts a dull-red, heat. The producer is next cleaned and filled with fuel. The secondary-air slides are then slightly opened, and afterwards the primary, to the extent of about double the area of the secondary. The charging and clinkering doors are then closed and the dampers adjusted so that they are open to the extent of about half an inch. The air slides and dampers are then gradually opened until the retorts are at a working temperature. To avoid local heating in the combustion chamber it is advisable to have only a slight excess of secondary air. In order to see if the correct amount of secondary air is being drawn in, the first waste-gas plug should be taken out and the secondary-air slide shut for a moment. A flame of unburned gas will now be seen in the spent-gas flue. The secondary-air slide should then be gradually opened until the flame can only just be seen, or just disappears. In order to prevent an explosion within the setting it is necessary to see that the combustion arch is sufficiently hot (as indicated by its colour) before closing up the generator and admitting the secondary air.

(139) State the precautions to be observed in getting rid of the air contained in a newly erected gasholder when filling it for the first time with gas.

In bringing a gasholder into use for the first time, or restarting one that has been emptied for repairs, there is a quantity of air to be got rid of, and in the getting rid of this air it is necessary to exercise great caution. One method of effecting its removal is to ascertain the quantity of air in the holder and allow gas to enter until there is an equal mixture of gas and air. Then the holder is shut off and allowed to remain so for from twelve to twenty-four hours. At the expiration of that time the man-hole plate, which should be fixed by two bolts until the mixture of air and gas is ready to be blown away, is swung round by removing one bolt, so as to allow of the rapid escape of the mixture. As soon as the holder is empty the man-hole is closed and the holder filled with gas and left for twenty-four hours to diffuse. The contents of the holder will then be fit for sending into the district. In every case, before blowing off, the contents of the holder should have time to diffuse and thoroughly mix, and at the time of performing the operation the inlet of the holder should be shut.

Another and more general way of getting rid of the air is to put a pipe through the crown of the gasholder, dipping down to within 2 to 3 inches of the water in the tank. The holder is then filled with gas at about the same rate as the discharge from the pipe, until there is a decided smell of gas at the outlet of the pipe. A sample can then be taken and tested, away from the holder, and if it burns quietly, without any explosion, we know that the gas is free from air; if it gives a decided "pop," then more gas must be passed into the holder until the test is satisfactory. An analysis may also be made to ascertain the percentage of oxygen and nitrogen present, which will show if the holder contents be of a satisfactory composition for putting on the district. In this method of eliminating the air, the gas, owing to its lightness, ascends to the top of the holder, where it presses down upon the air, forcing the latter up the pipe, whence it escapes into the atmosphere.

(140) What would you do in the case of a scrubber seal blowing?

Scrubbers are usually worked in pairs, and it is generally the first in the series which blows, since the first one has the combined resistance of the pair of scrubbers to overcome. The best thing to do in the event of the first scrubber "blowing" is to open the inlet valve of the second scrubber for the time being, and to shut the valve on the seal pipe of the first scrubber. This will permit of the seal-pot of the first scrubber being refilled, and give time to look round and discover the cause of the blow. After putting matters right (if the stoppage was only of a temporary nature, as would be the case if the rise of pressure was sudden), the valve on the seal of the first scrubber can be opened and the inlet of the second scrubber closed. Of course, if there is a reserve of plant, another pair of scrubbers can be put into action.

(141) How would you prevent the district being thrown into darkness owing to the shutting of wrong gasholder valves?

One of the most serious mishaps which can occur in the working of gasholders is the accidental shutting off of the gas supply to the district through the valve-man forgetting to open the outlet of a second gasholder before shutting off the first one. The method of preventing such an accident is by the employment of a safety governor, which is fixed between the outlet of the station meter and the inlet of the ordinary station governor. The safety governor is so arranged that it comes into action the instant the pressure falls below that given by the lightest holder. Fig. 39 shows one method of arranging the connections so as to utilise a safety governor, and shows the position of the safety governor in relation to the storage and distribution plant.

(142) How would you regulate the pressure in the event of the station governor being thrown out of action?

In the event of the station governor being thrown out of action, it would be necessary to open the by-pass valve and to control the pressure as well as possible by gradually opening and closing the valve, according to requirements.

(143) Supposing that the vacuum in the retort house was normal, but the gauge on the inlet of the exhauster suddenly read considerably higher than usual, what would this indicate, and how would you put matters right?

In the event of the gauge on the inlet of the exhauster showing a sudden and abnormally large vacuum, it will usually be found that owing to a sudden rush of tar and liquor from the retort house the liquor in the condenser seal-well has risen above the level of the mains leading to and from the condenser and temporarily logged them. The remedy is to by-pass the condenser for a time and to quickly pump out the seal-well. When that has been accomplished the by-pass can be shut and the gas allowed to take its ordinary course. If the obstruction is not at that point, the seals on the inlets to the exhausters must be looked to.

(144) Discuss the relative advantages and disadvantages of setting the retorts in a bed of eights in two or three vertical rows.

In setting eight retorts in four vertical rows of two in a tier there is an economy of space and more even heating of the retorts, since, however carefully a setting of eights in three tiers may be designed, it is difficult to prevent the middle retort from becoming overheated as compared with the remaining retorts. The disadvantages of the system are due to the additional height of the fourth tier, which renders it practically impossible to draw and charge the fourth tier without the employment of a travelling trolley,

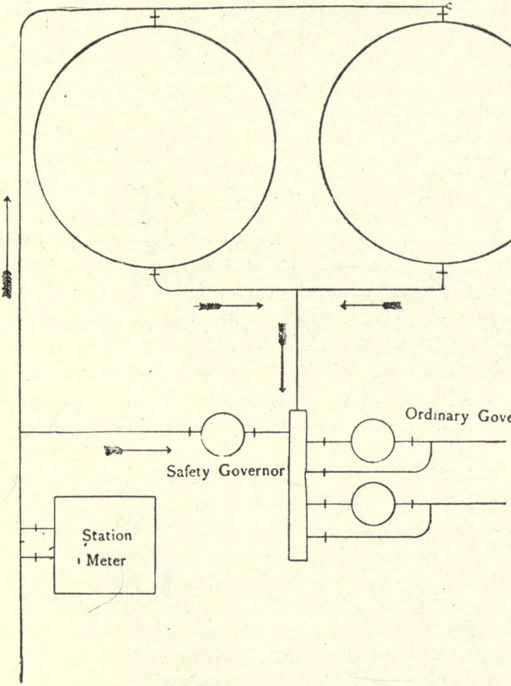


Fig. 39.

and also the extra fall given to the coke as it descends into the coke hole; but this last objection can be overcome by feeding the producer from the two top retorts. When stoking machinery is employed, these disadvantages disappear and by the use of a coke conveyor the coke has not so far to fall, and is, therefore, not broken to the same extent.

(145) State some points to be attended to in order to effect economy in the management of a gasworks.

The principal quarter in which economy can be effected in a gasworks is in the retort house. Some of the conditions for successful working are good and even heating of the retorts, tight retorts and lids, clear ascension pipes, dry coals, charges evenly spread and as heavy as can be well burned off, and always backed in from the front so that no part of the charge is nearer than 18 inches from the front of the mouthpiece. The retorts should be kept free from carbon and be heated by means of regenerative furnaces, which should be fed with hot coke, the fires "spiked" when clinkering, and the primary and secondary air accurately adjusted. The vacuum should be regular, and the hydraulic main should be supplied with ammoniacal liquor, so that the dip pipes have a liquor seal, the tar being taken off separately from the bottom of the hydraulic mains. Where coal elevators and conveyors are employed these should not be allowed to run empty. Where lime is used in purification, it should be well burned, should be thoroughly slaked before use, and should be quite cool before using. It should be placed in the purifiers as wet as possible, so that it does not fall into mortar, and should be well packed round the sides so as to avoid "creeps." In filling oxide vessels there should be an inch of space between each layer so as to leave room for expansion. The bottoms of purifiers and the purifier grids should be kept clean and free from spent material. The works mains should be cleaned out in the summer; also any scrubbers throwing pressure. Inlets and outlets of station meters should be examined and the meters cleaned and tested periodically. The pulling down of retort benches for renewals should be done at odd times when men can be spared, so as to avoid employing extra labour. All old bricks, whether whole or broken, should be cleaned and utilised again, especially in parts of the works in which the heat is not intense, such as the bottom of ashpits, filling in the fronts round retorts, top flues, etc. Gasholders should be prevented from blowing and the works kept in an orderly state.

(146) Describe how you would test a 5-light wet meter and state the limit of error allowed.

In testing a 5-light wet meter, say at the gasworks, the following apparatus will be required—viz., a standard gasholder having a capacity of 10 cubic feet, a proving bench on which the meter under test stands, an overhead water cistern, a series of gas burners, known as a "float of lights," for burning the gas delivered from the meter, reliable thermometers for taking the temperature of the air and water, and a standard clock. Before testing the meter it must be properly charged with water, first taking off the cap and linings. It is then placed on the proving bench and the charging and syphon plugs removed. Water is then poured through the socket from which the charge plug has been removed until it flows freely from the meter at the syphon socket. The meter is then left until water ceases to drip, when the plugs are replaced. The meter is now ready for testing. Wet meters are usually tested for soundness and for percentage fast and percentage slow.

The gasholder is filled with gas and connected by suitable gas-tight connections to the inlet of the meter, the outlet of the latter being connected to the float of lights. The meter is now ready for testing for soundness, which is done by passing gas from the gasholder under a pressure of 3 inches, and, in the case of a 5-light meter, when it is passing one-twentieth of its measuring capacity per hour, which, being 30 cubic feet, would be about $\frac{3}{100}$ cubic foot per minute. The meter is first cleared of air. The gas is then shut off and the gasholder put under 3 inches pressure, as ascertained from the gauge attached to the holder. The outlet cock from the meter is then closed and the gas turned on to the meter from the gasholder. The cock connecting the outlet of the meter to the float of lights is then opened and the rate adjusted to $\frac{3}{100}$ of a cubic foot per minute. The meter case is then carefully examined for leaks, and if any are found the meter is rejected as unsound. If the index fails to record the passage of gas, the meter must in this case also be rejected.

The next operation is that of testing for "percentage fast." The pressure on the holder is now reduced to half an inch, by replacement of the necessary weights, the gas is turned off from the meter, and the outlet connection is removed. The charge and syphon plugs are taken out, and if any water flows out more is added and the excess is allowed to drain off. The outlet connection is then replaced, the gas turned on, and the rate of flow from the meter to the float of lights adjusted to the proper rate of flow for the capacity of the meter, which, for a 5-light meter, is 30 cubic feet per hour, the regulation of the rate of flow being made by adjustment of the cocks beyond the outlet of the meter. Observe the small metal drum above the index, and as soon as a figured division comes directly under the pointer turn off the gas. The holder is then refilled to a predetermined point and gas is passed through the meter until the index drum has made an entire revolution and the point from which it started is again brought under the pointer. The gas is then shut off and the amount of gas passed through the meter read off from the gasholder scale. If the reading on the gasholder scale and the quantity registered by the meter agree, then the meter is correct; but this rarely happens, the meter always registering an exact number of feet whilst something less than an exact number will be registered by the gasholder. It is necessary in such cases to obtain the percentage of error by proportion. This is usually obtained from tables; but it is advisable here to explain the principle on which the tables are constructed. If the gasholder reading be 9·8 cubic feet and the meter register 10 the percentage of error will be thus obtained

$$9{\cdot}8 : 10 :: 0{\cdot}2 : 0{\cdot}204 \text{ per cent. fast.}$$

In order to test for the percentage of error "slow," while the gasholder is still supplying gas to the meter and the outlet connected to the float of lights, sufficient water is syphoned off from the meter to cause the float to come down and thereby close the inlet valve, which will have the effect of extinguishing the flames in the float of lights.

With the gas still turned on water is very gently poured into the meter. While this is being done the meter should be tapped gently with the finger until the float rises and allows gas to pass freely, no more water being added than is absolutely necessary to lift the float. While effecting the last-mentioned operation a small flame should be applied to the float of lights so that the instant the meter passes gas it may be seen by the gas igniting. The operations described in connection with testing for percentage "fast" are then gone through and the results noted.

The limits of error allowed are 2 per cent. fast, or in favour of the company, and 3 per cent. slow, or in favour of the consumer. In order to avoid troublesome corrections it is important to secure uniformity in the temperature of the gas in the test holder, the water in the tank and the air in the room, but should a difference of temperature occur a correction may be made on the assumption that an increase or decrease of 4° Fahr. in the temperature of gas over water causes a difference of 1 per cent. in the volume of such gas. Thus, when the gas issues from the meter at a different temperature to that which it has in the gasholder, multiply the volume delivered from the gasholder by the number of degrees of difference in temperature and this result by 0·0025, and if the gas from the meter be higher in temperature add the product to the gasholder reading, and if the gas at the outlet of the meter be of a lower temperature subtract the product from the gasholder reading.

(147) Describe how you would test a station meter.

A station meter is tested by means of a standard test meter, which should be placed on a firm, level base as close to the station meter to be tested as possible. After being levelled it is filled with water and the water line adjusted. All the valves on the station meter are closed and must be quite tight. There is a connection below the inlet valve of the station meter to the inlet of the test meter for the purpose of supplying the latter with gas, and there is a connection between the outlet of the test meter and the inlet of the station meter above the valve. From the outlet of the station meter there is a pipe fitted with a cock for blowing gas away. Thermometers are fixed on the outlets of both meters. The station meter is charged with water, when open to the atmosphere, to the heights indicated by the water level gauges, which are subjected to the pressure of the outlet gas. The most convenient method for testing the registration of a station meter is to take off the index and solder a stout wire to the key wheel so that the end of the wire projects a short distance beyond the edge of the index pot, the starting or stopping point being defined by a fine chalk mark. The station meter must first be tested for soundness. Gas is passed through both meters until the air contained in them is expelled, and while this is being effected the speed of the test meter is adjusted by its outlet cock to the desired rate. The cock on the pipe leading from the outlet of the station meter is then closed. When the gas in both meters is compressed as much as the acting pressure will allow, the index of the test meter should remain stationary. If it remains so for a few minutes, the station meter and its connections may be said to be sound, but if the index of the test meter moves, it is a sign that there is a leakage, which must be sought for by the aid of a strong solution of soft soap and water. When the leak has been discovered and made tight, the station meter is tested for accuracy of registration. First close the cock on the pipe leading from the outlet of the station meter and allow gas to enter both meters, and set the index of the test meter to zero. The testing is effected by noting the difference between the reading of the test meter and one revolution of the station meter, represented by the height of the water line at the time of testing. In order to do this, some figure on the dial of the station meter in advance of the dial pointer is fixed upon and noted. The cock on the inlet of the test meter is then opened, which will cause both meters to commence working. The test meter should be run at the rate of about two revolutions per minute. As soon as the predetermined figure on the station meter is reached, the index of the test meter must be noted if not at zero, and gas is passed through until the station meter has made a complete revolution, when the cock of the test meter is instantly closed, and its index again noted. The difference in the readings before and after the test is equal to the capacity of the station meter, assuming that the temperature of both meters remains constant during the experiment. Thus, assuming that a station meter passed 100 cubic feet per revolution, and that the index of the test meter at the end of the experiment registered 101·4 feet and started at zero, this would show the capacity of the station meter to be, at the existing water line, 101·4 feet, and would indicate that the water line was low and the meter registering slow to the extent of 1·38 per cent. Should the temperature of the gas at the outlet of the meter vary, it will be necessary to correct the indicated volume for such difference, the necessary calculation being made on the volume registered by the test meter. Four degrees difference in temperature can be taken as causing a difference of 1 per cent. in volume, which should be added to the registration of the test meter if the gas passes from the station meter at a higher temperature and deducted from the registration of the test meter if the gas passes from the station meter at the lower temperature.

As an example :—

Temperature of gas at outlet of station meter . .	64°
,, ,, ,, test ,, . .	60°
Difference	4°

4° = 1 per cent. and 1 per cent. on 101·4 = 1·01, and this has to be added to 101·4 = 102·41 as the corrected capacity of the station meter.

(148) In testing a station meter it was found that with one revolution of the station meter = 100 cubic feet, the test meter registered 102·4 cubic feet. The temperature of the test meter being 68° Fahr. and that of the station meter 64° Fahr., work out from these particulars the percentage of error in the station meter.

From the data given the station meter is slow, and in place of registering 100 cubic feet it only registers 97·6 feet. In order to find the percentage we say, As 100 : 97·6 : : 2·4 : 2·34 = percentage of error.

In order to correct for temperature :—

Temperature at outlet of test meter = 68° Fahr.
,, ,, station ,, = 64° ,,

A difference of 4° in temperature = 1 per cent., and 1 per cent. on 102·4 = 1·02 and 102·4 − 1·02 = 101·38 = capacity of station meter. Then to obtain the percentage,

As 100 : 98·62 : : 1·38 : 1·36.

(149) Give sketches *(a)* of a direct loaded retort house governor, *(b)* of a counterbalanced governor. What advantages are obtained by employing such apparatus?

Fig. 40 illustrates a direct loaded retort house governor and Fig. 41 a retort house governor of the counterbalanced type. The latter, according to tests carried out by Dr. W. B. Davidson, is the most sensitive and reliable governor

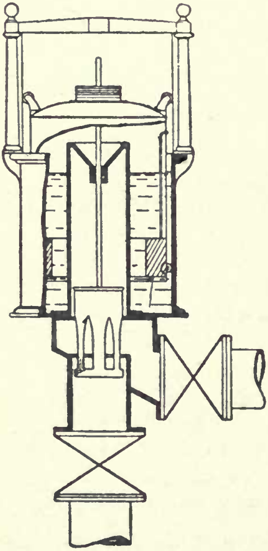


Fig. 40.

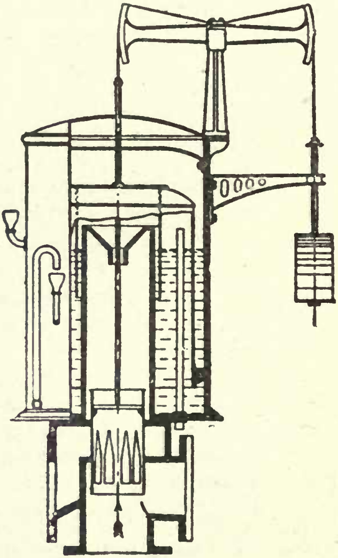


Fig. 41.

(see paper by Dr. Davidson and Mr. Pearson before the Midland Junior Gas Association, THE GAS WORLD, 29th April 1911). By the use of a retort house governor, lighter seals may be safely worked on the dip pipes, which results in less pressure in the retorts, less oscillation of the liquor in the hydraulic mains, and, consequently, less stopped pipes, with an increased yield of gas from the coal. The best position for the governor is on the foul main, at the point where it leaves the retort bench. Here, the gas being at a fairly high temperature, the tar is of a liquid nature and will be less likely to block up the governor valve. The pull of the exhauster at the governor outlet varies at different works from 2 inches to 5 inches, which is reduced on the inlet side by adjusting the governor with the necessary weights to give the desired pull or vacuum in the foul or hydraulic main, usually worked at from level gauge to one-tenth of vacuum.

(150) In designing a gasworks, give in detail (approximately) the amount of plant you would allow for each portion of the works, and give the basis of your estimate.

In answering this question it is assumed that the gasworks is capable of making 1,000,000 cubic feet per day, or carbonizing 100 tons of coal in December, usually the period of heaviest demand. The first item is that of land, a fair figure to allow being $2\frac{1}{4}$ acres per million. The next item is that of retort house, coal stores and retort benches. We will assume that the house is of the stage type, having accommodation for storing three weeks' average consumption of coal on the stage floor. A fair allowance is 6,000 cubic feet of house capacity per ton of coals carbonized daily, or 6,000 × 100 tons = 600,000 cubic feet, arrived at by taking the outside dimensions of the building in feet at the ground line and mutiplying this by the height from the ground line to half-way up the roof. The floor area should be equal to 100 superficial feet per ton, inside the walls, or 100 × 100 = 10,000 superficial feet. The next item is that of condensers, a fair allowance for which is 50 superficial feet of surface per ton, or 50 × 100 = 5,000 superficial feet. We next have the item of boiler house and plant, for which we should allow 120 cubic feet for the building to contain the boilers, having a floor area of 4 superficial feet per ton. The boilers should be of the Lancashire type, and their total cubical contents should be 10 cubic feet per ton of coal carbonized per day. Following the boilers, we have the exhauster house, with its accompanying plant, for which we should allow 130 cubic feet of building, to contain the exhausters, engines and connections, and a floor area of 4 superficial feet per ton per day. For the washers and scrubbers, we may allow 100 cubic feet of internal capacity per ton per day.

If a covered-in purifying house is adopted it should have 1,600 cubic feet of structure and a floor area of 50 superficial feet per ton per day. For the purifiers we may allow a total capacity of 130 cubic feet, and for the sieve area enclosed in the vessels 100 superficial feet per ton per day. Where the purifiers are not provided with an upper floor it is necessary to provide lime and oxide sheds for the purpose of storing and preparing the lime and oxide required in purification. For this we may allow 800 cubic feet of building, having a floor area of 25 superficial feet per ton. Speaking generally, the total area of the lime and oxide shed should be one-half that of the adjoining purifying house. We next have the item of meter house and the meters contained therein, for which we may allow 170 cubic feet of building, having a floor area of 3·80 superficial feet per ton per day. For gasholder tanks we may allow 5,000 cubic feet per ton per day, measured inside the walls, and for gasholders 12,000 cubic feet of capacity per ton per day. For tar and liquor tanks, we may allow 150 cubic feet, measured inside the walls. For workshops, offices, etc., we may allow 400 cubic feet of building per ton per day.

(151) Give the approximate cost of constructing a new gasworks, giving the data on which your estimate is based.

The following gives the approximate cost of the different portions of a gasworks plant per ton of coal carbonized per day on the basis of a maximum production of 2,500,000 cubic feet of gas per day :—

	Cost Per Ton of Coal Carbonized per Twenty-Four Hours. £	s.	d.
Retort House—			
House, roof, walls, etc.	29	0	0
Stage floors	9	0	0
Horizontal retort bench and ironwork complete	53	10	0
Stoking machinery and coal plant	28	0	0
Coke conveying and screening plant	10	0	0
Total	£129	10	0
Condensers	7	0	0
Boilers and boiler house complete	9	10	0
Exhausters and exhauster house complete	7	10	0
Washer, with foundations	1	5	0
Rotary scrubbers	9	0	0
Tar and liquor wells	7	0	0
Purifiers and oxide sheds	15	0	0
Station meter and house, with station governor	13	10	0
Works mains, valves and sundries	6	0	0

A gasholder having a capacity of 3,000,000 cubic feet will cost approximately £5, 10s. per thousand cubic feet capacity and the tank for the holder about £4, 10s., or a total of £10 per thousand cubic feet capacity—a total of £30,000.

It will be understood, of course, that the foregoing figures are only approximate, and are simply intended to serve as a rough guide to the probable cost.

(152) Give a list of some available data which a gas engineer should always have ready for use.

The following data will always be of service to a gas engineer :—The weight of a cubic foot of hydrogen is an exceedingly useful number to remember, since by multiplying the atomic weight for a simple gas, or half the molecular weight of a compound gas by the number, we obtain the weight of a cubic foot of the gas required. The weight of a cubic foot of hydrogen may be taken for all practical purposes as 37 grains. Supposing we wish to obtain the weight of a cubic foot of, say, oxygen, whose atomic weight is 16, then $16 \times 37 = 592$ grains ; or, in the case of a compound gas, such as sulphuretted hydrogen, where we have

$$\begin{array}{lr} \mathrm{S} & 32 \\ \mathrm{H_2} & 2 \\ \hline \end{array}$$

$34 \div 2 = 17$ = half molecular weight, then $17 \times 37 = 629$ grains.

42·5 cubic feet = 1 ton of ordinary gas coal.

Weight of bog ore, 54 lbs. per cubic foot.

" " spent oxide containing 50 per cent. sulphur, 57 lbs. per cubic foot.

New lime in lumps weighs about 56 lbs. per cubic foot.

To obtain pounds of sperm per ton yielded by a coal, multiply the make per ton by the illuminating power, and this by ·00343.

Weight of a cubic foot of cast-iron = 451 lbs.
" " " wrought " = 485 "
" " " steel = 499 "

A bar of wrought-iron 1-inch square and 1 yard long weighs 10 lbs., and a square foot of wrought-iron $\frac{1}{4}$-inch thick also weighs 10 lbs.

A difference of 4° in the temperature of gas stored over water is equal to an increase or decrease of 1 per cent. in volume.

A rod of brickwork laid four courses to 12 inches requires 4,360 stocks and weighs approximately 15 tons.

1 cubic foot of water = 6·235 gallons; 1 gallon of water weighs 10 lbs. ∴ 1 cubic foot of water weighs 62·355 lbs.

To reduce the pressure in inches of water on a pressure gauge to the equivalent of pounds per square inch, multiply the number of inches on the water gauge by 15 and divide by 408. To find the weight of a gasholder in pounds, multiply the area of the top in feet by the weight corresponding to a column of water corresponding to its pressure (a column of water 1 foot square and 1 inch high = 5·21 lbs.). To find the pressure capable of being thrown by a holder, divide its weight in pounds by the area multiplied by 5·21.

(153) Draw up a statement showing how you would arrive at the coke made and used for fuel in a regenerative retort setting.

(The answer is on page 181.)

EXPERIMENT ON THE AMOUNT OF FUEL REQUIRED TO HEAT NO. 5 RETORT SETTING, NO. 2 RETORT HOUSE.

1911. Date.	Time.	Coke Weighed into Furnace.	Breeze Dried and Weighed into Furnace.	Coal Carbonized.	Coke made. Commenced at 12 noon June 1.	Breeze made. Commenced at 12 noon June 1.
		c. lbs.	c. lbs.	t. c.	c. lbs.	c. lbs.
June 1	6 a.m. to 6 p.m.	8 13	2 8	4 5	0 14 24 0 14 24	2 108
June 2	6 a.m.	8 23	2 0	4 10	1 7 54 1 7 54	3 92
	6 p.m.	11 56	1 77	4 0	1 7 22 1 7 22	6 4
June 3	6 a.m.	10 56	2 0	4 0	1 6 33 1 6 33	3 36
	6 p.m.	10 0	2 0	4 0	1 6 86 1 6 86	4 68
June 4	6 a.m.	10 0	2 0	10	1 6 59 1 6 59	3 32
	6 p.m.	8 67	2 14	4 5	1 7 101 1 7 101	5 8
June 5	6 a.m.	8 0	2 56	4 5	1 6 5 1 6 5	4 40
	6 p.m.	10 28	1 77	4 0	1 6 86 1 6 86	5 4
June 6	6 a.m.	10 0	2 56	4 5	1 6 23 1 6 23	3 56
	6 p.m.	10 48	3 14	4 5	1 8 44 1 8 44	5 24
June 7	6 a.m.	9 0	3 56	4 5	1 7 82 1 7 82	3 42
	6 p.m.	10 50	2 56	4 5	1 9 32 1 9 32	5 12
June 8	6 a.m.	8 0	3 56	3 0½	1 6 89 1 6 89	3 56
	12 noon.	..	..	..	0 14 60 0 14 60	2 36
		t. c. l. 6 13 5	t. c. l. 1 13 22 10°/. water 0 3 35 1 9 59	t. c. l. 57 15 56	t. c. l. 38 4 42	t. c. l. 3 1 58

Remarks.

Commenced observation of coke and breeze made 12 noon, June 1.
Coals used, Newcastle.
The furnace breeze was dried, freed from clinker, and weighed.
The unscreened breeze dried at 212° Fahr. lost 10 per cent in moisture.

The scraps and residue amounted to:—

	Cwts.	Lbs.
Coke - - - - - - - - - - - -	5	28
Rough furnace breeze, containing 31 per cent. water -	15	0
Clinker breeze, containing 24 per cent. water - - -	40	84
Clinker proper - - - - - - - - - -	2	39

Summary of seven days' working, from June 1 to 8, 1905:—

	Tons.	Cwts.	Lbs.	Tons.	Cwts.	Lbs.
Coal carbonized	57	15	56 =	4	2	60 per mouthpiece.
Coke made -	38	4	42			
Breeze - -	3	1	58			

	Cwts.	Lbs.
Coke and breeze together (weighed) made per ton of coal	14	68
Coke only - - - - - - - - - - -	13	35

	Tons.	Cwts.	Lbs.
Coke used for fuel - - - - - - - -	6	13	5
Less scrap coke, 31 per cent. deducted for moisture - - - - - - - -	0	3	70
	6	9	47

	Tons.	Cwts.	Lbs.
Breeze used for fuel - - - - - - -	1	9	99
Less scrap rough breeze, 25 per cent. deducted for moisture - - - - - - - -	0	11	28
	0	18	71
Making a total of fuel used - - - - - -	7	7	118

	Tons.	Cwts.	Lbs.	
Coke weighed into furnace	6	9	47 =	11·2 lbs. per 100 lbs. coal carbonized.
Breeze, dried - - - -	0	18	71 =	1·6 „ „ „
Total - -				12·8 „ „ „

(154) What is suction gas? Describe how it is made and state how it compares with coal gas.

Suction gas is a form of producer gas obtained by passing air and steam through carbonaceous fuel contained in a generator, but in place of forcing the air through the apparatus it is sucked in by the outward stroke of the piston of a gas engine which it supplies, the amount of gas delivered being governed by the requirements of the engine.

The apparatus consists of a generator, having within it a small boiler known as the evaporator, which is the source of the steam required in the production of the producer gas. This boiler or evaporator does not, under ordinary conditions, work under high pressure, and frequently air is drawn over the surface of the water and becomes mixed with the steam, and since the evaporator is usually heated by the sensible heat of the gas produced, in the event of an interruption of the production of gas the supply of heat to the evaporator ceases, and consequently the production of steam stops, so that, in the event of a stoppage of the gas engine, this will stop the production of gas, by interrupting the supply of steam to the producer. Suction plants do not require a gasholder, but it has been found advantageous to satisfactory working to insert a small storage chamber between the gas engine and the gas-producing plant, to serve the purpose of an anti-fluctuator. Before the gas enters the cylinder of the engine it is necessary that it should be deprived of solid particles, and this is effected by passing the gas, after leaving the generator, through a tall scrubber filled with coke and supplied with a water spray. The starting of a suction plant when cold is effected by forcing air through the generator by means of a hand driven fan until the fuel bed is raised to incandescence and sufficient gas is being produced to start the gas engine, and thus induce the necessary suction for making the production of gas continuous.

The following is an analysis of suction gas :—

Nitrogen . . .	55·3 per cent.
Carbonic oxide . .	20·3 ,,
Hydrogen . . .	1·55 ,,
Carbonic acid . . .	7·2 ,,
Marsh gas . . .	1·2 ,,
Oxygen	0·5 ,,

Calorific value, 136 B.Th.U. per cubic foot, as against, say, 640 B.Th.U. from 16-candle coal gas.

(155) How would you obtain the specific gravity of a sample of gas?

The simplest method of determining the specific gravity of gas is by means of Schilling's effusion test, which is based on the fact that gases issuing under similar conditions of pressure from a minute orifice in a metal plate flow through it at rates which vary inversely as the square roots of their densities. The apparatus employed in Schilling's test consists of a cylindrical glass vessel within which is placed a glass tube. This is fitted at the top with a metal cap, while its lower end is inserted into a metal base, which serves as a foot and also as a weight to keep the tube immersed in water. The upper cap carries two cocks, one at the side and the other on a short upright pipe. The last-mentioned cock is really a three-way one, and is provided with a pointer and an index, which is marked "on," "off," and "vent." The glass tube has two marks engraved upon it, one near to the base and the other near to the metal cap at the top. The specific gravity is determined by ascertaining the time in seconds which it takes equal volumes of air and gas, under equal pressures, to escape from a minute opening in a thin disc of platinum, which is fixed in the nozzle of the three-way cock. When the latter is in the position of "on" the only opening for the passage of air or gas is through this minute opening. The specific gravity is obtained by dividing the square of the time taken for the gas to escape by the square of the time taken for the air to escape. In making a test the tube is immersed in the vessel containing water, and is charged with air by raising it and letting air enter through a by-pass in the top stop-cock. The cock is then closed and the tube re-immersed. The plug of the cock is then so turned as to allow the air to escape through the hole in the disc, and as soon as the water reaches the lower mark on the tube a minute clock or stop-watch is started, and stopped immediately the water reaches the upper mark, the time in seconds being noted. The tube is next charged in a similar manner with gas; it is necessary in this case to connect the side cock to a gas supply by means of indiarubber tubing. When filled with gas the time occupied in emptying is noted as before. Then assuming that the time taken for the air to escape was 200 seconds and for the gas 135 seconds, $200^2 = 40{,}000$ and $135^2 = 18{,}225$, and $18{,}225 \div 40{,}000 = \cdot 455$ = specific gravity of the gas.

CHAPTER XVI.

DELIVERY OF GAS THROUGH MAINS.

(156) Calculate the quantity of gas in cubic feet, of the specific gravity 0·45, which will be discharged in one hour from a pipe 9 inches in diameter, under a pressure of 1 inch, and 1,000 yards in length, and show the necessary calculations.

The rule for obtaining the volume of gas capable of being discharged per hour through a pipe of a certain size and under a given pressure is as follows. Multiply the pressure in inches of water by the diameter of the pipe in inches. Divide the product by the specific gravity of the gas multiplied by the length of the pipe in yards. Extract the square root of the quotient and multiply this by the constant 1,350 and by the square of the diameter of the pipe in inches. The product will be the number of cubic feet discharged per hour. This may be more shortly expressed in the shape of a formula, as follows :—

$$Q = 1350\, d^2 \sqrt{\frac{h\, d}{s\, l}}$$

where Q = quantity of gas in cubic feet per hour,
l = length of pipe in yards,
d = diameter of pipe in inches,
h = pressure in inches of water,
s = specific gravity of gas, air = 1.

Applying this formula to the data given in the question, we have—

$$\frac{9 \times 1}{0·45 \times 1000} = 0·020, \text{ the square root} = 0·143,$$

and $1350 \times 81 \times 0·143 = 15{,}637$ cubic feet.

(157) If an 18-inch pipe 1,000 yards in length discharges 65,600 cubic feet of gas per hour when the specific gravity is 0·400 and pressure 0·5 inch, how much will the same pipe discharge when the specific gravity is 0·520?

In order to obtain the quantity under the altered specific gravity, multiply the quantity delivered under the original specific gravity by the square root of the latter (= 0·6325) and divide by the square root of the altered specific gravity. Thus—

$$\frac{65{,}600 \times 0{\cdot}6325}{0{\cdot}7212} = 57{,}532 \text{ cubic feet.}$$

(158) If 26,000 cubic feet is discharged per hour from a certain main under the pressure of 6-tenths of an inch and a specific gravity of 0·4, what quantity would be discharged under a pressure of 1·2 inches?

In order to obtain the quantity delivered under the different pressure of 1·2 inches, multiply the quantity delivered by the square root of that pressure and divide by the square root of the original pressure. Thus—

$$\frac{26{,}000 \times 1{\cdot}0954}{0{\cdot}7745} = \frac{28{,}480{\cdot}4000}{0{\cdot}7745} = 36{,}798 \text{ cubic feet.}$$

(159) What will be the pressure required to discharge 33,000 cubic feet per hour through a pipe 12 inches in diameter and 1,000 yards long, the specific gravity being 0·4.

In order to find the pressure required to deliver a certain volume of gas of a given specific gravity per hour through a pipe whose dimensions are given, the rule is to multiply the square of the feet of gas to be delivered in one hour by the specific gravity of the gas and to multiply the product by the length of the pipe in yards. This product is divided by the square of the constant 1,350 multiplied by the fifth power of the diameter of the pipe in inches. The quotient will be the pressure. In the example given

$$33{,}000^2 = 1{,}089{,}000{,}000$$

$$\frac{1{,}089{,}000{,}000 \times 0{\cdot}4 \times 1{,}000}{1{,}822{,}500 \times 248{,}832} = \frac{435{,}600{,}000{,}000}{453{,}496{,}320{,}000} = 0{\cdot}96,$$

or nearly 1 inch.

APPENDIX.

ANSWERS TO 1909 HONOURS GRADE QUESTIONS SET IN THE EXAMINATION IN GAS ENGINEERING.

By "Mentor."

(1*a*) Name the chief points of difference in and the special advantages claimed for (1) Woodall-Duckham vertical retort system; (2) Dessau vertical retort system; (3) Munich chamber system; (4) Love's 45° inclined system.

(1) The Woodall-Duckham vertical retort system is continuous, the coal being fed in at the top and the coke discharged simultaneously at the bottom. The retorts are elliptical in shape, roughly 25 inches by 12 inches, and each retort carbonizes 2½ tons per twenty-four hours. The advantages claimed for this system are:—The retorts are not opened either for charging or discharging, hence the usual dust and smoke of the retort houses is done away with. The retorts are not subjected to sudden changes of temperature. The hottest part of the bench is at the top, and, if that should be burnt out, it can be replaced without disturbing the greater part of the setting below. The advantages claimed for this system are:—Increased make of gas; increased yield of tar; increased yield of ammonia; freedom of the gas from naphthalene; coke made from any kind of coal is relatively

better; the hydraulic main and ascension pipe, with all their attendant disadvantages, are done away with; and improved labour conditions at reduced cost.

(2) The Dessau retorts are set vertically, the carbonization is intermittent, the retorts are quite full, and a limited amount of steam is admitted. At Dessau, the retorts are 13 feet 1½ inches high. The section of the retort is an oblong with rounded corners. The retort tapers from bottom to top, the top portion being 22½ inches by 9 inches and the bottom 27¼ inches by 13¾ inches. They are emptied and filled every twelve hours.

The advantages claimed for the Dessau system are:—Low labour charges; low cost of repairs; high quality and superior density of the coke and almost entire absence of breeze; the satisfactory average yield of gas; the purity and the good lighting and heating value of the gas; increased yield of ammonia; and the thinness of tar and consequent avoidance of retort house troubles.

(3) In the Munich chamber setting, the retorts or ovens are made of great depth, as compared with ordinary horizontal or inclined retorts. In one installation the bench is 12 feet 4 inches wide between centres, and consists of three chambers, each 20 inches wide, 6 feet high and 13 feet 9 inches long, inclined at an angle of about 35°. In another installation, at Hamburg, the chambers are 24 feet 6 inches long and 7 feet 4 inches high, three chambers in each bench. The outside chambers are 20 inches and the inside one 24 inches wide. These chambers are also set at an angle of 35°, and they are charged intermittently every twenty-four hours, the charge per bench being nearly 18 tons.

The advantages claimed for the chamber system are the reduced labour costs, due to the heavy charges employed, a higher yield of both gas and by-products, and the production of a high-class coke, resembling oven coke, and suitable for metallurgical purposes.

(4) In Love's 45° inclined system the retorts are of the same length and the same sectional area as the horizonal retorts usually employed, but set at an angle of 45°. The retorts are filled with coal, and the charging and discharging

are intermittent, but the duration of the charge is longer, one charge of 8 cwts. being left in for twelve hours, in place of the usual charge of 3 cwts. in six hours.

The advantages claimed for Love's 45° setting are:—Simplicity of design; carbonizing charges 45 per cent. less than with horizontals; greater yield of gas; increased value of coke; 25 per cent. more ammonia; more liquid tar; and no stopped pipes.

(1*b*) Assuming that a single section of coal gas plant be required to turn out 1,000,000 cubic feet per twenty-four hours, what would be the approximate figures (*a*) length and breadth in feet of retort house, inside sizes, ignoring coal store, and for hand stoking; (*b*) number and size of horizontal retorts; (*c*) square feet of condensing surface (atmospheric); (*d*) cubic feet in tower scrubbers (no washers of any kind to be used); (*e*) square feet of single sieve area in purifiers each containing four tiers of sieves (oxide to be used); (*f*) sizes of gas main connections throughout the works. State the approximate costs for (*g*) retort house and retorts complete (without coal store or machinery, but with horizontal retorts for hand charging, regenerator furnaces and stage floor); (*h*) atmospheric condensers and foundations; (*k*) exhausters and boilers (without houses, chimneys or stand-by plant); (*l*) scrubbers, pumps and foundations (no washers to be employed); (*m*) purifiers and connections on ground level, with house to cover purifiers, and, in addition, as much extra space for materials as purifiers themselves will occupy.

Before one can arrive at the length and breadth of the retort house, it is necessary to know how many retorts will be required to produce 1,000,000 cubic feet per day. Assuming that each mouthpiece will make 7,000 cubic feet, six-hour charges, this will equal, in round numbers, 142 mouthpieces, and adding 10 per cent. for contingencies gives a total number of 156 mouthpieces. Supposing they are set in sevens, we will require twenty-two beds.

Assuming they are set back to back, or as throughs, and the arches are 9 feet 6 inches centre to centre, and to have a passage 8 feet wide at each end, this will give a length of about 125 feet. Allowing a width of 20 feet on each side for the charging stage, plus 20 feet length of retort, we obtain a breadth of 60 feet. The retorts required (including contingencies) would be 156, single ⌓'s, say 22 inches by 15 inches. Allowing 10 square feet of condensing surface per thousand cubic feet made per day, we have 10,000 feet. Cubic feet in tower scrubbers, say 9 cubic feet per thousand feet made per day = 9,000. Sieve area of one purifier = 5 superficial feet per ton = 100 × 5 = 500 feet. Say four purifiers = 2,000 feet total (single) sieve area. For gas connections throughout the works, the rule is to allow 1½ square inches per ton of coal carbonized per day. 100 × 1·5 = 150, which would give the size of mains as 14 inches. But to allow for corrosion, etc., it would be advisable to have 18-inch mains, or even 24-inch.

The cost for retort house and accessories would be, roughly, £9,000; condensers, £800; exhausters and boilers, £1,000; scrubbers, etc., £1,500; purifiers, etc., £4,500.

(2*a*) If a bed of retorts heated by gas from a regenerative furnace is first heated well and evenly, and afterwards unevenly, what steps would you take to ascertain the cause of this bad working?

It may occur that retorts which at one time were heated evenly may become heated unevenly by (*a*) the heat having gone to the bottom, or (*b*) to the top retort, or (*c*) there is a very high temperature in the combustion chamber and very low heats in the rest of the setting. In the case of transference of heat to the bottom retorts, a remedy is to check the secondary air, which will cause the flame in the combustion chamber to become larger, and thus produce more heat higher up in the setting. The shortening of the flame may be due to an excess of ash in the fuel; this causes the grate bars to become clinkered over more quickly, which will prevent the free passage of primary air into the fuel, and this will result in a deficiency of producer gas for the quantity of secondary air for which the slides were originally set. Another cause of bottom heating is not keeping the furnace full, thus preventing the proper reduction of the carbonic acid to carbonic oxide, $CO_2 + C = 2CO$. Yet another cause may be that the primary air has too free a passage through the fuel, and the latter is, in consequence, converted principally into CO_2, as in an ordinary direct-fired furnace. An excess of heat travelling to the top of the setting may be due to short circuiting, as this causes the flame in the combustion chamber to be too long for even heating. This is due to insufficient air entering the combustion chamber to enable the producer gas to burn within the required limits. This may be tested for by suddenly withdrawing one of the top plugs in the waste gas flue from its sight hole, and carefully watching for any unburned gas, the presence of which is shown by a blue flame as soon as the gas reaches the air. To remedy matters in this case, it will be necessary to admit more secondary air.

If not due to short circuiting, the increased length of flame may be due to an excess of producer gas for the quantity of secondary air, due to the fuel containing less ash than that which was in the fuel when the slides were first set. In this case the primary air slides should be checked until the gas burns with a normal length of flame. In the case of the temperature being very high in and around the combustion chamber, this may also be caused by an excess of secondary air, which can be proved by an analysis of the waste gases, which should show, when things are working normally, about 18 per cent. of CO_2 and 2 per cent. of oxygen, whereas if there is an excess of secondary air, the CO_2 will be found to be lower and the O_2 higher. The remedy is to keep the furnace well filled and to examine the nostrils in the producer arch, to see that they are clear. If they are partially choked, the volume of producer gas made will decrease in proportion to the decrease in the area of the nostrils, and the secondary air will be increased, owing to the pull being greater, and this would cause the symptoms referred to.

(2*b*) What are the effects of temperature (1) on the volume and the quantity of the produced tar, (2) on the production of ammonia, (3) on the impurities in coal gas which have to be removed (CO_2, SH_2, CS_2)?

For answers, see pages 14 to 19.

(3*a*) How do variations in (1) quantity of air blown in, (2) quantity of steam blown in, (3) temperature of carburettor and superheater, affect the quantity and quality of carburetted water gas? How would you proceed to test the oil used in carburettor by fractional distillation?

A deficiency of air will result in the generator not being hot enough to produce the maximum amount of CO, but will produce an excess of CO_2, and also a deficiency of producer gas for heating the carburettor and superheater. An excess of steam will cause a large percentage of CO_2 in the gas, while a deficiency of steam will cause a reduction in the make of gas. A low temperature in the carburettor and superheater will result in the oil not being properly gasified, causing tar to be deposited, while an excessive temperature will cause carbon to be deposited, in the form of lampblack, on the checkerwork of the carburettor and superheater, and will prejudicially affect their efficiency.

The testing of the oil is accomplished by distilling a litre of the oil in a globular thermometer flask, provided with side tubulere, connected to a water-cooled Liebig's condenser. The oil should be weighed after being placed in the flask, and the distillates should be collected in quantities of about 10 per cent. on the original sample. The temperature at which each fraction comes over should be noted and recorded, also the volume, weight and nature of the fraction (colour, etc.). When all the volatile matter has been driven off, the residue, in the form of pitch, should be weighed, and should not amount to more than 1 per cent. of the original quantity. The amount of water, which should be small, should also be noted. Each fraction should be tested for sulphuretted hydrogen, by means of lead paper. The neck of the flask should be lagged with asbestos twine, protected from draught, and the heat applied gradually, and so adjusted as to cause the distillates to fall from the condenser into the graduated measuring glass in drops. The sum of the various fractions, plus the pitch, should total up to within 1 per cent. of the original quantity taken for distillation.

(3*b*) Compare concisely the claimed advantages and disadvantages of high and low grade gases.

The claimed advantages of high grade gas are that you get a better light from flat-flame and argand burners, also a higher heating effect. But these claimed advantages are more than counteracted by the extra cost, and by the fact that the gas cannot be burned economically, or, in other words, it is burned wastefully, and, therefore, the advantage of the extra quality is not obtained. Further, since the greater proportion of gas is now burned in incandescent burners, there is no need for high grade gas. In order to increase sales, gas must be cheap, and high grade gas is dear.

The advantages of low grade gas are its cheapness, due to the fact that more gas can be obtained from a ton of coal than in the case of high grade gas, and this can be obtained from common coal without aid of enrichment, and its suitability for incandescent burners and heating appliances. It has been shown that the thermal efficiency of a gas from a coal yielding 10,120 cubic feet per ton was 628 B.Th.U., and when the make was increased to 12,500, it was 577 B.Th.U.; an increase of 25 per cent. in the amount of gas produced resulting in a loss of heating power of only 51 B.Th.U., or 8 per cent. Professor Lewes has shown that a reduction from 20 candles to 12 candles, or 40 per cent., resulted in a loss of heat efficiency of only 25 per cent. Other observers have shown that as between a 16 candle-gas of 573 B.Th.U. and an 11-candle gas of 460 B.Th.U. there is no difference on the light of an incandescent burner.

(4*a*) What proposals have been made and what processes have been tried to revivify spent lime to enable it to be again used for coal gas purification?

There are two methods for the reburning of spent lime which have stood the test of practical experience—Hislop's and Stoke's. Hislop's, which is the older process, consists of a series of small kilns or ovens, set in one bench, heated by means of producer gas. The upper portion of the bench is used as a drying chamber, where the spent lime remains for about eight hours. At the expiration of this period the charge of the top retort or chamber is raked down and distributed on the shelves of the three lower retorts, in layers of 3 or 4 inches thick; the top retort being immediately recharged with spent material. The lower retorts are at a much higher temperature than the upper one, and the lime readily parts with its CO_2, which, on its way to the chimney, passes over the charge contained in the upper retort, and displaces the sulphur compounds contained in the lime. The charges of the three lower retorts are at the end of six hours withdrawn as quicklime, which should be at once slaked, and stocked as hydrate, ready for the purifiers.

Stoke's plant consists of a cylinder about 50 feet long and 5 feet diameter, lined with firebrick, and set at a slight inclination. The cylinder revolves on rollers at the rate of about one revolution per minute. It is heated by means of producer gas, which enters at the lower end, where it meets the air required for its combustion. The spent lime is elevated to the upper end of the cylinder, and is fed into it automatically. The upper 8 feet of the cylinder is of a larger diameter than the remainder, and forms a chamber in which the lime is retained until it has been deprived of the greater part of its moisture. As the cylinder revolves, the lime automatically falls out of the chamber and down to the lower end of the cylinder, where it meets the flame of the producer gas, which raises the lime and the firebrick of the cylinder lining to a high temperature. It takes from half an hour to an hour for the lime to travel down the cylinder, the time depending upon the rate of revolution, which is proportionate to the rate at which the lime is fed in and to the character of the lime to be burned. The lime drops from the calcining cylinder into the upper end of a similar inclined cylinder, up which the air for the combustion of the producer gas passes. This lower cylinder, in which the lime is cooled, also revolves.

The heat given up from the lime serves to heat the air passing in for the combustion of the gas in the upper cylinder. The cooled lime is discharged at the lower end of the cylinder into trucks or barrows. The plant may be worked by a small gas engine, which elevates the lime and turns the cylinders.

(4*b*) Describe any method for determining the amount of cyanogen present in purified coal gas and in spent ammoniacal liquor. Why is it necessary, in the latter case, to reduce this quantity as much as possible when the spent liquor has to be run into a sewer or river?

The amount of hydrocyanic acid in coal gas is determined by passing a measured quantity of the gas through a strong solution of an alkali (potash) to which a small quantity of ferrous sulphate has been added. The hydrocyanic acid in the gas then forms ferrocyanide of potassium, which is afterwards converted into prussian blue, and from the weight of this the amount of HCN in the gas is calculated. The apparatus employed consists of three small Woulff's bottles, containing a mixture of caustic potash and sulphate of iron. The gas is measured by an experimental meter at the rate of from 1 to 2 cubic feet per hour, about 5 feet being passed through during the experiment. At the end of a test, the solution in the Woulff's bottles is washed out into a flask, boiled for about fifteen minutes, allowed to cool, and filtered, the filter being washed two or three times with cold water. A slight excess of hydrochloric acid is added to the filtrate, which produces a precipitate of impure prussian blue. The latter is collected on a filter, re-dissolved in caustic potash, and reprecipitated as prussian blue, by adding a boiling solution of ferric chloride. The precipitated prussian blue is allowed to settle, washed first by decantation, and collected on a filter and washed on the filter with hot water until the filtrate is free from ferric chloride. It is then ignited in a platinum crucible until nothing but ferric oxide remains. 560 parts of ferric oxide correspond to 860 parts of prussian blue, and since prussian blue contains 468 parts of CN, the amount of HCN in the gas passed, also per 100 cubic feet, is easily calculated.

The cyanogen in the spent liquors from the manufacture of sulphate of ammonia is usually present in the form of sulphocyanide (thiocyanate). The most modern method for the estimation of sulphocyanide is that of Linder. 50 c.c. of the gas liquor is boiled. To the warm solution (50° to 60° C.) add perchloride of iron, to precipitate any ferrocyanide, and filter. Acidify the filtrate with sulphuric acid; add an excess of solution of sodium bisulphite, with 5 c.c. of a cold saturated solution of copper sulphate; boil for two minutes; warm on a water bath for two hours; allow to cool; filter; wash the precipitate three times with water containing sodium sulphate. Transfer the precipitate to a beaker; boil for five minutes with excess of a 20 per cent. solution of sodium carbonate; filter; wash the residue three times with a strong, hot solution of sodium sulphate, and allow to cool. Acidify the filtrate with nitric acid, free from nitrogen oxides; add a measured excess of N/10 silver nitrate solution and titrate back with a N/10 solution of ammonium sulphocyanide, using iron alum as an indicator.

It is necessary to reduce the amount of NH_4CNS as much as possible before the spent liquor is run into a sewer on account of its interfering with the bacteriological treatment to which most sewage is now subjected, in order to purify it; while if run into a river, spent liquors containing cyanide would destroy any fish in the river.

(5*a*) **How can the amount of NH_3 in a sample of sulphate of ammonia be accurately determined? If a sample contains 24·75 per cent. of ammonia, what percentage of nitrogen does it contain?**

In testing sulphate of ammonia, the moisture is first determined by heating a weighed quantity of the salt on a flat dish for several hours, and then reweighing. The loss of weight gives the amount of water contained in the original salt. A portion of the sample is well ground up, and passed through a sieve of 10 holes to the inch. Twenty grammes of the material which has passed through the sieve are weighed out and dissolved in 500 c.c. of distilled water, and 25 c.c. of the resulting solution (equal to 1 gramme), together with an excess of caustic soda, are placed in a flask provided with a funnel, with stopcock and leading tube, which is connected to an absorption apparatus containing 20 c.c. of normal sulphuric acid, previously diluted with distilled water, into which the ammonia disengaged is led. At the end of the distillation, the acid is titrated with normal caustic soda solution, using methyl orange as indicator. The percentage of ammonia in the sulphate is obtained by multiplying the number of c.c. of acid neutralized by the ammonia in the sulphate by 0·017 and moving the decimal point two places to the right.

The molecular weight of ammonia, NH_3, is 17, and this contains 14 parts of nitrogen. Consequently,

$$17 : 14 :: 24·75 : 20·38.$$

20·38 = percentage of nitrogen corresponding to 24·75 of ammonia.

(5*b*) If a closed saturator be used in the manufacture of sulphate of ammonia, how can the arsenic which may be contained in the acid be removed so that a good grey salt can be produced ?

The method for removing the arsenic in the acid when using a "closed" saturator is governed principally by the amount of arsenic present in the acid. When the amount of arsenic is small, it has been found that a small quantity of green oil added when the salt is precipitating will have the effect of producing a good grey colour in the salt. Some saturators are provided with what is known as a scumming pipe, which dips just below the surface of the acid in the saturator. The scum finds its way up this pipe, and escapes at the top. Another plan is to bubble SH_2 gas, or gases containing SH_2, such as the spent gases from the saturator, through the acid. This will precipitate arsenious sulphide, which must be filtered off.

(6*a*) Describe fully the process employed for determining the amount of naphthalene in coal gas.

The amount of naphthalene in gas is usually determined by the method of Dr. H. G. Colman and Mr. J. F. Smith, and is based upon the fact that picric acid combines with naphthalene to form naphthalene picrate, $C_{10}H_8C_6H_3N_3O_7$, a substance which is sparingly soluble in aqueous picric acid. In making a test, a solution of picric acid is employed of such a strength that it is nearly saturated at ordinary temperatures. The strength of the solution is determined by titrating it with N/10 baryta water, the indicator employed being lacmoid, which changes in colour, in the presence of an excess of alkali, from brownish yellow to green. The test is performed by bubbling from 10 to 15 cubic feet of gas, at the rate of from 0·5 to 1 cubic foot per hour, through a train of four Woulff's bottles, three containing picric acid and the fourth one empty. The first bottle has a capacity of about 300 c.c., and contains 100 c.c. of picric acid solution; the second and third bottles contain 50 c.c. of the solution, while the empty bottle serves to retain any splashings of the acid which may be carried over from the other bottles. The outlet of the last bottle is connected to the inlet of an experimental meter.

When the required amount of gas has passed through, the gas is shut off, the bottles disconnected from one another, and the contents of the second and third bottles added to those of the first bottle. The latter, which now contains the whole of the solutions, is then closed with an indiarubber cork, having a glass tube passing through it. This is closed at the lower end, but has a small hole blown in at the side, about an inch from the bottom, and the tube is so arranged that this hole comes just below the bottom of the cork. The bottle is then exhausted by means of a vacuum pump, and while it is being exhausted the glass tube is raised so that the small hole in the side comes well above the bottom of the indiarubber cork, with the object of ensuring the bottle being sealed. The bottle is then placed in a water bath, so that the water in the bath covers it. The water in the bath is then raised to the boiling point, and maintained in that condition until the liquid in the bottle becomes quite clear. After this, the bottle is removed from the bath, and allowed to cool. While cooling, it should be occasionally shaken, in order to carry down into the solution any naphthalene which may have sublimed on the upper portion of the bottle.

After standing for some time, it will be found that the naphthalene picrate separates out completely; when it should be filtered off, and washed with a small quantity of water. The combined filtrate and washings are then made up to 500 c.c., and well mixed. 100 c.c. are taken and titrated with decinormal baryta water. From these data the quantity of picric acid which has combined with the naphthalene can be calculated. Since in naphthalene picrate 229 parts of picric acid are united with 128 parts of naphthalene, the quantity of picric acid found multiplied by 0·559 (128 ÷ 229) gives the amount of naphthalene in the quantity of gas passed through the bottles.

(6*b*) Describe fully the method you would adopt for determining the amount of CO present in a town's supply (containing from 10 to 20 per cent. of carburetted water gas).

There are various apparatus employed in gas analysis, Orsat's being one of the simplest and easiest to manipulate. Although the results are not quite accurate, they are sufficiently so for all practical purposes. The apparatus (which is contained in a wooden case) comprises a measuring tube holding 100 c.c., and graduated into $\frac{1}{10}$ c.c. This tube, which is surrounded by a water jacket, for maintaining a constant temperature, is connected at the bottom, by means of indiarubber tubing, with a levelling bottle, which should be about two-thirds filled with water. The upper capillary end of the measuring tube is connected by thick-walled tubing with a horizontal tube furnished at the end with a three-way stopcock. This horizontal tube has, in addition, four branch taps connecting it to four absorption pipettes, containing glass tubes. The first pipette is filled with a 50 per cent. solution of caustic potash, for removing CO_2; the second with a mixture of two parts by volume of a 50 per cent. solution of caustic potash and one part of a 20 per cent. solution of pyrogallic acid, for the absorption of oxygen. It is necessary to protect the pyrogallate solution from air. The third pipette contains Nordhausen sulphuric acid, for the purpose of removing illuminants (benzene, ethylene, etc.). The fourth pipette is filled with a strong solution of cuprous chloride in hydrochloric acid, for absorbing CO. The pipette containing cuprous chloride should be filled with copper wire spirals, instead of glass tubes, and the liquid should be protected from contact with the atmosphere. The absorbents should just reach to the under parts of the stopcocks, with the exception of the Nordhausen acid, which should stand in the capillary tube of the pipette at a mark made a short distance below the connecting tube.

To fill the measuring tube with the gas to be analyzed, the levelling bottle is placed on the top of the case, and the stop cock turned so as to put the measuring tube in communication with the atmosphere. As soon as the water reaches the top of the measuring tube, the communication should be cut off. Then, if the gas to be examined is under pressure, connect the end of the horizontal tube with the source of supply, and allow the gas to blow through the side opening of the cock, in order to displace the air in the connecting tube. Then turn the stopcock so as to put the gas supply in communication with the measuring tube, lower the levelling bottle until the gas fills the tube to a little below the zero mark, and then close stopcock. The levelling bottle should then be raised until the gas is compressed, and rises in the measuring tube to a little above the zero mark. A pinchcock should now be placed on the connecting tube, the levelling bottle placed on the laboratory bench, and the pinchcock cautiously opened until the bottom of the meniscus of the water just touches the zero mark. Then momentarily draw out and replace the plug of the stopcock; and there will remain in the measuring tube exactly 100 c.c. of the gas at the atmospheric pressure prevailing at the time of the experiment.

The analysis is made by placing the levelling bottle on the top of the case, removing the pinchcock from the connecting tube, opening the cock of the final absorption pipette containing KHO, when the gas will pass into the latter. When it has all passed in, the levelling bottle is lowered until the absorbing liquid in the pipette nearly reaches the stopcock. The levelling bottle is then placed again on the top of the case, in order to force the gas once more into the pipette. After this, the levelling bottle is cautiously lowered with the right hand, and the stopcock shut with the left as soon as the absorbent reaches the underside of the cock. The levelling bottle is next held at the back of the measuring tube, so that the water is at the same level in both. There will now be found a diminution in volume corresponding to the amount of CO_2 in the gas, which can be read off and noted.

The same operations are gone through with the remaining pipettes in succession, passing the gas into each pipette three times, with the exception of the cuprous chloride pipette, since CO requires more prolonged contact. After finally passing into the pipettes containing cuprous chloride and Nordhausen acid, the gas should be passed, before measurement, once or twice into the pipette containing caustic potash, in order to remove acid fumes, which would exert a pressure and tend to give erroneous readings.

(7*a*) **What is meant by ammoniacal liquor being 10-oz. strength? What percentage weight of NH_3 does such a liquor contain, and what does this amount to in grains per gallon? State method of accurately determining the amount of NH_3 contained. Why does the ordinary hydrometer test only give very approximate results?**

By 10-oz. liquor is meant that a gallon of such liquor requires 10 ozs. of pure strong sulphuric acid to neutralize the ammonia contained therein. From the equation

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4,$$

we find that 34 parts of ammonia are equal to 98 of sulphuric acid. Consequently, 10 ozs. of acid are equivalent to 3·47 ozs. of ammonia, and as a gallon is equal to 160 ozs., as 160 : 100 : : 3·47 : 2·168 = percentage of ammonia.

Since a gallon of 10-oz. liquor contains 3·47 ozs. of ammonia, 3·47 × 437·5 = 1,520 grains per gallon.

The most accurate method of determining the amount of ammonia contained in liquor is that known as the distillation test. A glass flask, provided with a cork fitted with stoppered funnel and leading tube which dips into a smaller flask, is placed on a sand bath. A solution of sulphuric acid, made by adding 1 lb. of pure sulphuric acid to distilled water, and the contents made up to a gallon, and having a specific gravity of 1,064·4, and a solution of caustic soda which exactly matches the acid are required. 2 ozs. of the liquor are placed in the large flask, followed by an excess of caustic soda solution and 2 ozs. of the standard acid placed in the small flask into which the leading tube dips. Heat is then applied to the large flask, and after all the ammonia has been driven off, the small flask is taken away and allowed to cool. When cold, 2 ozs. of the standard alkali solution are placed in a burette which is divided into 32 parts, and the acid is titrated, using cochineal as the indicator. The strength of the liquor is indicated by the quantity of test alkali left in the burette, which represents the quantity of ammonia given off from the liquor and absorbed by the acid in the small flask. Thus, if 8 divisions of the standard alkali be left in the burette, the liquor will contain sufficient ammonia per gallon to neutralize 8 ozs. of sulphuric acid. The hydrometer is a measure of density only, and the density of liquor is not constant for equal strengths, but varies according to the different kinds of coals employed, conditions of carbonizing, and treatment to which the gas is subjected in the washers and scrubbers. A solution of "free" ammonia and water has a lesser density than water, while a liquor heavily charged with CO_2 has a greater density than water, and thus conditions are set up which make the indications of the hydrometer as a guide to the strength of liquor unreliable.

(7*b*) Explain, with sketches, a standard calorimeter, and describe the process of making a test of gas with this. Explain clearly the difference between "gross" and "net" calorific values.

For answers, see pages 75 and 83.

(8*a*) Give a brief description of the different systems employed for transporting coal in a gasworks.

The transporting of coal in gasworks is principally effected by inclined elevators, gravity bucket conveyors, horizontal push-plate conveyors, horizontal band conveyors and Temperley transporters, while it is lifted out of barges, and from heaps, etc., by means of Hone's grabs. Elevators are used for the purpose of raising coal from the crushers into overhead hoppers or on to horizontal conveyors. The apparatus consists of a series of buckets holding from 15 to 28 lbs. of coal (Fig. 1). These buckets are attached to a jointed steel chain which works over sprocket wheels fixed at the top and bottom of the elevator. The buckets are attached to arms, which serve as guides, and travel along steel rubbing strips fixed in angle irons, which form the framing of the machine. Such conveyors are frequently fixed at an angle of 50°. Gravity bucket conveyors are connected to roller chains which pass over rollers at each end. Push-plate conveyors are employed to receive the coal delivered from the inclined elevator and to carry it forward along the top of the overhead hoppers. The push-plates, which are made

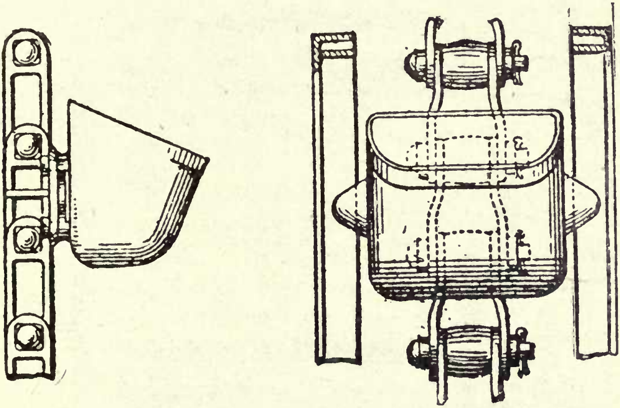


FIG. 1.

of steel, are carried on rollers running on an angle iron track, and, as the name implies, they push the coal along. The plates are usually spaced about 18 inches apart, and they work in a steel trough, furnished with sliding doors in the bottom for dropping the coal at any particular point. Band or belt conveyors are used for conveying coal across the retort stack from the head of the elevator to the overhead hopper on the opposite side. The working part of such a conveyor is shown in Fig. 2. The belt itself is usually made of stout canvas, 18 inches to 20 inches wide, and runs on the cast-iron rollers shown in the sketch

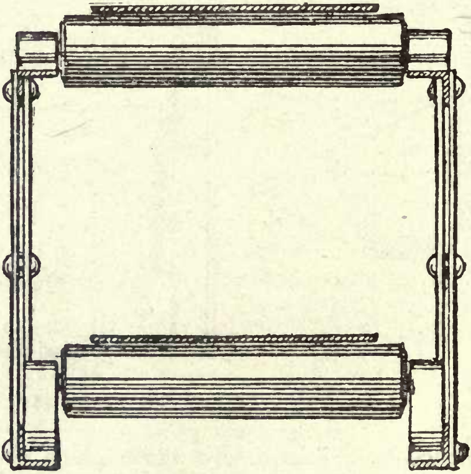


FIG. 2.

Perhaps the most usual method of transporting coal in a gas works where there is railway communication is by means of inclined railways rising to 20 feet or so above the yard level. Hydraulic hoists for lifting coal waggons to the height required for economically utilizing the force of gravity have also been used in many works. To facilitate the automatic emptying of coal waggons, Mr. Charles Hunt, in conjunction with Mr. A. L. Shockelford, has designed special hopper waggons.

(8*b*) Explain why different gases, when burned at the same rate, through the same burner, give different lengths of flame.

The different lengths of flame of various gases when burning at the same rate, through the same burner, are due to differences in the composition of the gas. Thus, hydrogen and carbon monoxide produce very short flames, since they require only one-half their own volume of oxygen for their complete combustion, and they are able to obtain this a very short distance from the point of ignition. Marsh gas (CH_4) requires twice its volume of oxygen, and burns with a flame nearly four times the height of the flames of the gases previously mentioned, when consumed at the same rate. Thus, ordinary 16-candle coal gas enriched by cannel will give a flame of about 3 inches when burned in the London argand, the height of the flame being principally due to methane, which will represent about 35 to 40 per cent. of the volume; while in the case of carburetted water gas, the flame will be only about 2 to 2½ inches, owing to its containing more carbon monoxide and hydrogen and less methane.

(9*a*) A concrete tank is required for a large gasholder. What ingredients and in what quantities would you make the concrete work? What precautions would you take to ensure firm binding between the horizontal joints and between the vertical joints of the different batches of concrete employed? What special precautions would you take if it were to be specified that the concrete was to be thrown from a height, and what are your objections to this practice? What specification would you give for the cement to be employed, and how would you test the cement when delivered?

The materials employed in the construction of a concrete tank are portland cement, and either gravel, shingle, broken stone, bricks, or old retorts, and clean, sharp sand, the proportions commonly employed being from 3 to 5 parts of ballast gravel or other material to

1 of clean, sharp sand and 1 of portland cement. In order to ensure firm binding, after one batch of concrete has been laid, before the next one is placed on top of it, the upper portion of the last batch laid should be swept and plentifully watered. In order to effect satisfactory and complete union of the old material with the new, the watering should be done just prior to the laying of the next batch of fresh concrete. Hoop iron is sometimes used to assist the bonding. The precaution to be taken when throwing concrete from a height is to run it down a tunnel or wooden shoot on to the spot where it is required. The objection to tipping it from a height is that it tends to disintegrate the materials composing it. The following embrace some of the leading points which should be included in the drawing up of a specification for portland cement. The whole of the cement shall be fine portland cement, and shall conform to the following tests :—To be of such a degree of fineness that when sifted through a standard sieve, having 50 holes per square inch, there shall not be more than ½ per cent. by weight of residue; when sifted through a sieve having 76 holes per square inch, there shall not be more than 5 per cent. of residue; and when sifted through a sieve having 100 holes per square inch, there shall be not more than 12 per cent. of residue. A pat of neat cement, gauged with the minimum of water at the normal temperature of 60° Fahr., and placed on a glass or other non-porous slab, shall not commence to set in less than eight minutes or take longer than five hours to set hard. Briquettes of neat cement gauged with the minimum of water on a non-porous bed, and placed in water twenty-four hours after gauging, shall carry an average tensile strain of not less than 350 lbs. per square inch after three days, 450 lbs. after seven days, and 550 lbs. after twenty-eight days from the time of gauging. Briquettes composed of three parts of standard sand to one part of cement by weight, treated as above, shall carry an average tensile strain of not less than 150 lbs. per square inch at seven days, and 250 lbs. at twenty-eight days, from the time of gauging, but no matter how much greater strength may be developed at the earliest dates, both neat

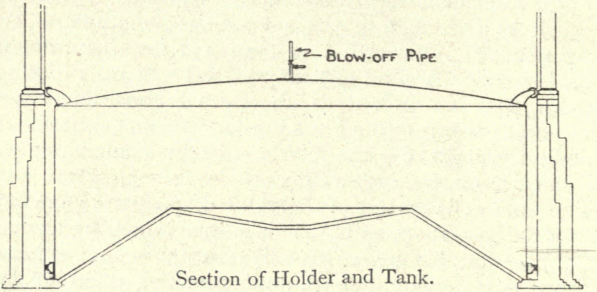
and sand briquettes must develop an increase of at least 50 lbs. between each date.

Portland cement may be tested for fineness, which should be such as is stated in the preceding paragraph. The cement should not weigh less than 112 lbs. per imperial striked bushel. A good test for portland cement is to gauge a small pat (*i.e.*, mix it to the proper consistency with water) and pack it into a glass bottle. When set, it should be found still to fill the bottle, neither cracking it nor becoming loose, so as to rattle.

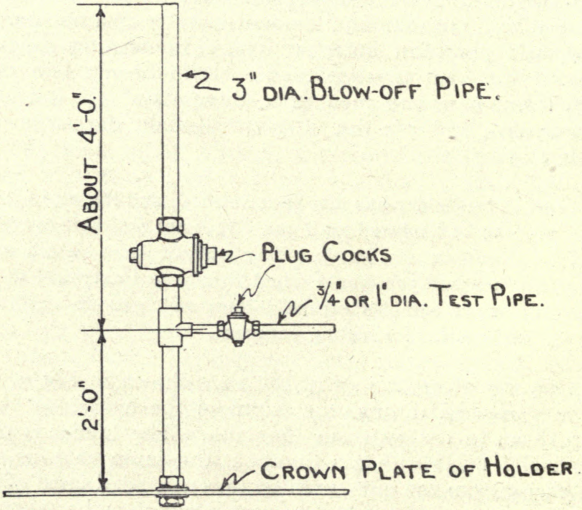
The most reliable test of the value of portland cement is that of the tensile strength. This is ascertained by forming the cement into briquettes (usually of a minimum section of $1\frac{1}{2}$ by $1\frac{1}{2} = 2\frac{1}{4}$ square inches), and subjecting them to slow tension in a cement testing machine. Such briquettes, gauged with the minimum amount of water on a non-porous bed, and placed in water twenty-four hours after gauging, should carry an average tensile strain of not less than 350 lbs. per square inch after three days, 450 lbs. after seven days, and 550 lbs. after twenty-eight days from the time of gauging.

(9*b*) **A gasholder has just been finished, and the air in it has to be displaced with gas. It is not desirable to "blow off" in any careless way. Show by a sketch what method you would adopt to ensure safety and to get such samples of the "blow-off" gas as might be required for testing purposes.**

One way of getting rid of the air is shown in Fig. 3. A pipe is inserted through the crown of the holder so as to dip down to the water in the tank. The holder is then gradually filled with gas at about the same rate as the discharge from the pipe, until there is a decided smell of gas at the outlet of the pipe. A sample can then be taken at the test cock shown, and tested away from the holder, either by estimating the amount of oxygen by means of a Bünte burette, or by filling a test tube and observing how the gas burns. If it burns quietly, without any explosion, we know that it is free from air, whereas if it gives a decided "pop," it will then be necessary to pass more gas into the holder, until a sample ceases to "pop." In this method of getting rid of



Section of Holder and Tank.



Detail of Blow-off Pipe.

FIG. 3.

the air, the gas, owing to its lower specific gravity, ascends to the top of the holder, where it exerts its pressure upon the air, forcing the latter up the pipe, whence it escapes into the atmosphere.

(10*a*) **Describe, with sketches, an efficient apparatus for keeping the lutes of a tank of a three-lift gasholder free from ice, steam being available for this purpose.**

Fig. 4 shows a method for preventing freezing of the cups of a three-lift telescopic gasholder. In America, where the cold is frequently very intense, it has been found that the best method of supplying the steam to the tank is by the use of ejectors, which pull the water from the bottom or any desired part of the tank and send it along in a current round the surface. The number of ejectors to be employed and their position will depend upon local conditions. In holders of a capacity of between 1,000,000 and 3,000,000 cubic feet, eight ejectors may be employed, four of which draw from the bottom and discharge half way up, while the other four draw half way up and discharge just below the surface. Those round the tank may be placed at equal distances apart, but if the holder is in a very exposed situation and the cold is felt more in one position than another, then the majority may be placed on the weather side. An ejector which has been found to be very suitable for the purpose mentioned is shown in Fig. 4, A being the steam orifice, which is made of brass. Messrs. S. Cutler and Sons, of Millwall, have patented an arrangement for preventing the freezing of

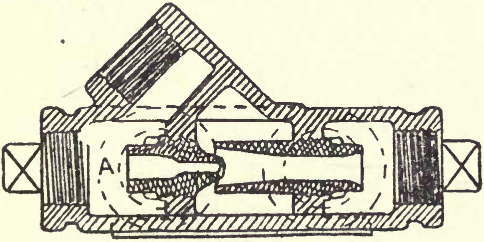


FIG. 4.

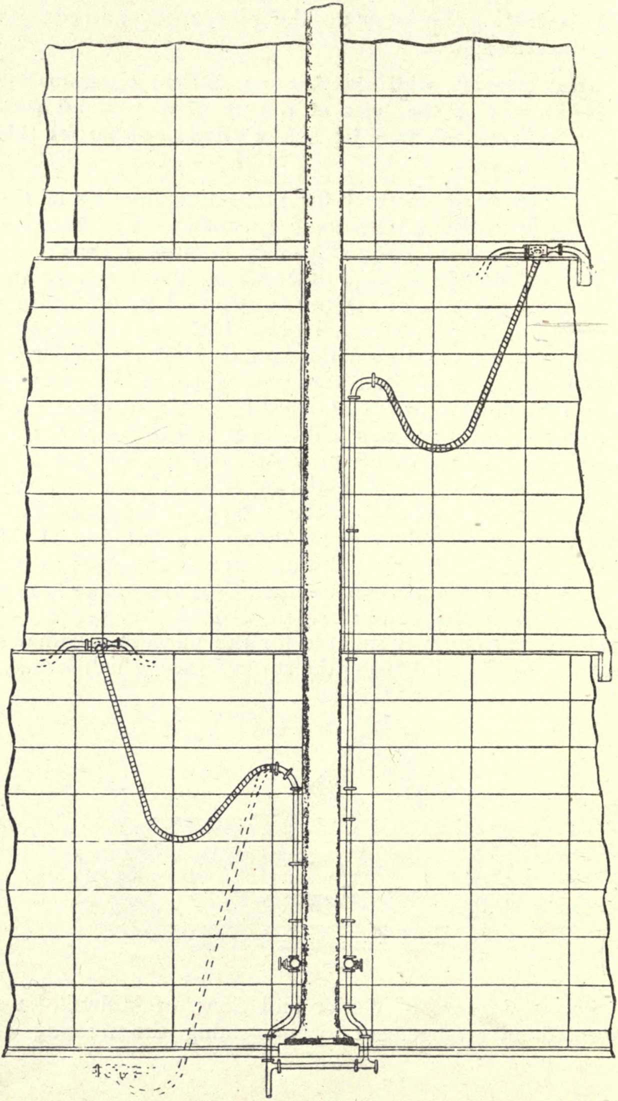


FIG. 5.

gasholder cups which is also very effective. This arrangement consists of a series of flexible hoses passing over pulleys which are counterbalanced so as to take up the slack of the hose pipes (Fig. 5).

(10*b*) **A single-lift gasholder, 137 feet diameter, is open to the air when the tank is quite filled with water, the tank being 140 feet diameter and the depth of water in tank from bottom till it just overflows 42 feet. A pressure of 5 inches is required to lift the holder. When the holder is shut off from the air, and gas forced in, how many gallons of water will have passed through the overflows by the time the holder is just commencing to rise?**

This is an example of the action of a U-tube pressure gauge. The reading of the gauge, which indicates the pressure thrown by the holder, is a reproduction of the two water levels in the tank, the one inside and the other outside the holder. This gives us the block of water inside which is displaced by the pressure and will find its way to the outside of the holder, and will force an equivalent quantity of water over the overflows. The diameter of the holder being 137 feet, this is equal to an area of 14,741 square feet, and the pressure required to lift the holder being 5 inches, the displacement will be 6,043 cubic feet of water; and as a cubic foot of water is equal to $6\frac{1}{4}$ gallons, on multiplying 6,043 by $6\frac{1}{4}$ we get 37,768 gallons as the quantity of water which will pass over the overflows.

ANSWERS TO 1910 HONOURS GRADE QUESTIONS SET IN THE EXAMINATION IN GAS ENGINEERING.

By Ernest M. Myers (Silver Medallist).

(1) Describe any modern method, and name the principle on which the method is based, for preparing a coal, inferior as regards purity, for gas and coke-making.

Coal which contains a high percentage of ash—or, as it is technically termed, "dirty coal"—can be utilized for gas and coke-making by subjecting it to a suitable washing process.

The principle on which this coal-washing process is based—and, in fact, all coal-washing plants, of which there are a great variety in existence—is, that if particles of the same size, but of different weights, be allowed to fall through water, the heaviest particles will fall the quickest.

The specific gravity of coal averages about 1·3, whilst dirt, such as fire-clay, shale, sandstone, etc., will average about 2·5, and pyrites as high as 5. The rate of fall of these particles has been investigated by Rittinger, who gives the following formula as expressing the rate at which a body will fall in still water:—

$V = 1{\cdot}28\sqrt{D\,(d-1)}$, where
V = Velocity in feet per second.
D = Diameter of holes in screen through which substance has passed.
d = Specific gravity of substance.
$1{\cdot}28$ = A constant, obtained experimentally.

The majority of coal-washing plants deal only with coal which has passed through a 2-inch screen, although there are installations in existence which are designed to deal with pieces as big as 4 inches or 5 inches. Usually, big coal can be dealt with by removing the dirtier pieces on a hand-picking belt.

The coal to be treated is elevated into a screening appliance, consisting of a set of concentric screens, and by this means it is sorted into several sizes—nuts, peas, fine coal and dust. From this screen the different sizes are conveyed, by means of shoots—down which water is travelling—into their respective washers, each size being apportioned to at least one washer.

A typical washer is shown in the accompanying sketch (Fig. 1).

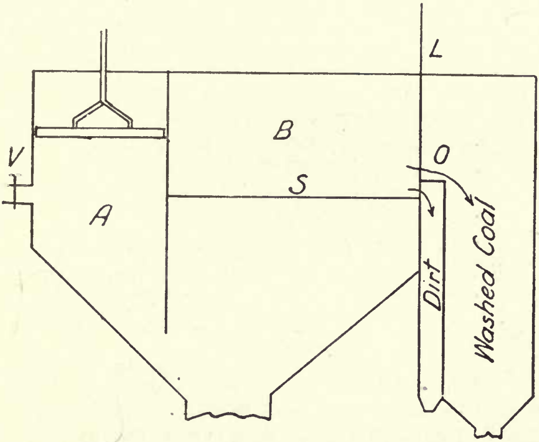


Fig. 1.

It may be described as a vessel divided into two unequal parts by a vertical division nearly reaching to the bottom. Across the larger part, B, is fixed a horizontal screen, S, on to which the coal to be washed is shot. In the smaller part, A, a piston is fitted, and suitably geared to allow of its moving up and down. When the piston descends, the water (which is supplied through the valve, V, in addition to that fed with the coal) is forced up through the coal lying on the screen, and returns again when the piston rises. This pulsating motion of the water causes the lighter particles—which are clean coal—to flow over the opening, O, whilst the heavier particles—the dirt—work their way downwards, on to the screen, and are removed every few minutes through a slotted division plate, which can be opened and closed by the lever, L.

In the washers for the smaller sizes, a layer of felspar is put on the screen, S, and the dirt gradually works its way through this layer, and finally through the screen, whilst the clean coal is washed over in the usual way. Suitable arrangements are made for collecting the different sizes of the washed coal, which, if necessary, are mixed together, sometimes in a disintegrator, and then elevated into bunkers, to be stored ready for use. The water is kept in constant circulation, and arrangements are made for using it over and over again.

(2) Name some possible disadvantages which may follow the use of very small coal in the process of carbonization. How may these disadvantages be minimized? What would be the effect *(a)* on the gas, *(b)* on the residuals, and *(c)* on some parts of the carbonizing plant, of endeavouring to reduce, by the use of high temperatures, the period of carbonization whilst retaining heavy charges of very small coal?

Small coal can only be used successfully where stoking machinery is installed. Where hand-stoking is employed, it will be found to be extremely difficult to obtain an even layer in the retorts, and consequently decomposition of the light-giving hydrocarbons will take place. Very small coal cannot be employed in "slopers," owing to the difficulty experienced by the coal "banking up." Another disadvantage of using very small coal is the amount which is lost in charging.

The best way to use "small coal" is by employing chamber retorts, or simply filling up the ordinary ⌓ retort with a heavy charge.

It is bad practice to force the speed of carbonization by the use of excessive temperatures. If this is done, the percentage of fuel used for the furnace rises considerably, and the quality of the gas is impaired, owing to the decomposition of the heavy hydrocarbons. The gas will be found to contain more impurities :—CS_2, H_2S, CN, and CO_2, and there will be an increase in the percentage of nitrogen and hydrogen. The by-products will be reduced. The ammonia will tend to become decomposed into cyanogen and nitrogen and hydrogen, whilst the tar will be thicker, and contain more free carbon. The coke will not suffer in the same way, although it may appear more friable.

Troubles on the plant will arise through increased scurf in the retorts, stopped ascension pipes, and the formation of pitch in the hydraulic main. The brickwork of the setting will also suffer, on account of the excessive temperature.

(3) **How do the chemical and physical properties of a coal influence the method adopted for its safe storage? Where a coal store is limited in area for the quantity it is desired to store, what precautions would you consider it advisable to adopt when storing coal to a depth of 20 to 30 feet?**

Coal, like all other carbonaceous matter, has the property of oxidizing, and so generating heat. Two reasons are generally assigned for this spontaneous combustion.

(1) The iron pyrites (FeS, FeS_2), which all coals contain in greater or lesser quantities, undergoes slow oxidation, and gives rise to a steady accumulative rise in temperature.

(2) When coal is "freshly wrought," it contains comparatively large quantities of gases imprisoned in the fissures and cracks. These gases are chiefly composed of a mixture of methane and carbon dioxide (CH_4 and CO_2) and are termed "occluded gases." As the coal becomes broken up, these gases escape, and expand. At the same time the methane undergoes oxidation, and so sets up a rise in temperature.

Large masses of coal are more liable to spontaneously ignite than small ones, and large heaps hold heat much better than smaller masses.

Therefore, under the above conditions :—

(1) It will be advisable to store the coal in as large lumps as possible.

(2) As moisture assists nearly all kinds of chemical action, and especially the spontaneous combustion of coal, the coal should be stored as dry as possible.

(3) The coal should not be stored in close proximity to sources of external heat, *e.g.*, steam pipes.

(4) Arrangements should be made for the ventilation of the stack of coal, by the insertion of perforated pipes at intervals. A better method still would be to insert at different points in the store bombs of liquid carbon dioxide. These cylinders should be closed with a nozzle, fitted with a plug made of fusible alloy, and melting about 100° C. Whenever the temperature of the heap rises above the melting point of the plug, the escaping CO_2 would (*a*) smother the fire, and (*b*) owing to the extremely low temperature which would be produced by the escaping gas, the mass of coal would be materially cooled.

(4a) Retorting plant is required for a maximum daily output of 2,500,000 cubic feet, and it has been decided to instal horizontally set retorts and stoking machinery. State what number of settings of eight retorts you would consider it advisable to provide, and what saving in ground space, in square feet, could be effected by the adoption of four-tiered settings in place of three-tiered settings. State what you consider to be the advantages and disadvantages of both types of setting.

Number of retorts required (20 feet by 22 inches by 16 inches) at, say, 7,500 cubic feet per mouthpiece per day

$$= \frac{2,500,000}{7,500 \times 2} = 167.$$

Number of settings of 8's $= \frac{167}{8} = 21.$

For four-tiered settings there would be 8 feet between each division wall; for three-tiered settings, 10 feet between division walls. Therefore, if the former type were introduced, there would be a saving in each setting of 2 feet of width; so that for twenty-one settings there would be 2 feet × 21 = 42 feet.

Allowing 25 feet on each side of the bench, the total area saved would be :—

$$(2 \times 25 + 20) \times 42 \text{ feet} = 70 \times 42 = 2{,}940 \text{ square feet.}$$

The advantages of four tiered settings are :—(1) Saving in ground space, (2) more retorts on same area, (3) more evenly heated retorts. The disadvantages are :—(1) Extra height of fourth tier necessitates extra expenditure on charging and discharging machinery, (2) extra fall which coke has on being discharged from fourth tier retorts (this can be obviated by using this coke for the furnaces, (3) owing to the division walls of each setting being nearer together, there is a difficulty in arranging the ascension pipes.

In the three-tiered settings, it is difficult to prevent the middle retorts from being overheated, and the advantages lie decidedly on the side of four tiers.

(4b) Discuss the relative methods of retorts constructed vertically and worked intermittently and those worked with a continuous feed and a continuous withdrawal of coke. What theoretical and practical considerations are favourable to the continuous method of working?

Continuously worked vertical retorts more nearly approach the ideal method of carbonization than any other system, on account of the natural and regular way in which the coal is distilled and the gas given off, and also the manner in which the coke is withdrawn. The advantages claimed for both systems are similar, viz., increased make of gas of better quality; increased yield of coke, tar and ammonia; improved labour conditions at reduced cost; economy in first cost of land and buildings; no naphthalene difficulties, etc. It will, therefore, be seen that to compare the two types and their relative merits, the actual settings themselves must be taken into consideration.

In the continuous system, there is no sudden cooling of the retort, by introducing a fresh and cold charge of coal, as in the intermittent system. This will prevent that wear and tear on the retort that is bound to take place when it suddenly contracts owing to the latter method of charging The coke is withdrawn from an intermittent retort at the end of the carbonizing period, and the quenching of this large mass gives rise to large volumes of steam, besides affecting the silvery appearance of the coke. In the continuous system, owing to the gradual withdrawal of the coke, there is only a small mass to be dealt with at a time, and even this has been made to give up most of its heat to the secondary air, before being finally discharged.

Then, again, by a very simple contrivance, the speed of carbonization in the continuous system can be easily controlled, by varying the amount of coal entering the retort in a given time. This fact obviates the difficulty (which is bound to arise from time to time in the best regulated settings) of varying heats.

In the continuous system, the hydraulic main and ascension pipes, with their attendant disadvantages, are dispensed with, there being no necessity for sealing the retorts from this point. In the intermittent system, the hydraulic main is still in use.

Trouble is apt to arise, at first, in intermittent retorts from the heavy gas pressure which is encountered at the bottom. This rises as high as 8 inches, especially where fine coal is used.

The continuous working vertical retort seems to lend itself more to absolute control than the intermittent retort, and the highest temperature being at the top of the setting renders it possible to drive off the gas as soon as is consistent with good working, and also reduces the travel of the gas, over hot material, to the shortest possible space.

(5a) Give the approximate evaporative value, in lbs. of water per lb., of the following fuels :—

(*a*) Coke breeze	containing	12	p.c.	of ash	and	10	p.c.	of water.
(*b*) Coke	,,	8	,,	,,	,,	4	,,	,,
(*c*) Coal slack	,,	15	,,	,,	,,	2	,,	,,
(*d*) Oil tar	,,	0·2	,,	,,	,,	2	,,	,,
(*e*) Creosote oil	,,	0	,,	,,	,,	0	,,	,,

Gmelin's formula for obtaining the calorific power of fuels—coal and coke—approximately, is

$$\text{C.P.} = [100 - (w + a)]\,80 - c \times 6w,$$

where w = percentage of water,
a = percentage of ash,
c = constant, varying with the amount of water.

The result is given in calories.

The values of c with the percentages of water specified below are:—

	$c=$		$c=$
(1) Less than 3 p.c. . .	4	(5) Between 12 and 20 p.c.	8
(2) Between 3 and 4·5 p.c.	6	(6) ,, 20 and 28 p.c.	6
(3) ,, 4·5 and 8·5 p.c.	12	(7) Over 28 p.c. . .	4
(4) ,, 8·5 and 12 p.c.	10		

So that for the fuels mentioned in the question we get—

	C. P.	Evap. Power.
(*a*)	$5{,}640 = \frac{5{,}640}{537}$	10·5 lbs. of water per lb.
(*b*)	$7{,}040 = \frac{7{,}040}{537}$	12·8 ,, ,, ,,
(*c*)	$6{,}592 = \frac{6{,}592}{537}$	12·2 ,, ,, ,,

(*d*) Oil tar has an evaporative power of 14·9 lbs. of water per lb.

(*e*) Creosote oil ,, ,, ,, 20·5 ,, ,, ,,

(5b) Give a description, with sketches (if possible), of any apparatus designed to consume heavy fluid hydrocarbons, smokelessly, for steam raising.

The accompanying sketch (Fig. 2) shows a water-tube boiler fitted with burners suitably arranged to burn tar. The boiler is partly heated by waste gases, but the combustion of the tar is completed thoroughly before the products of combustion mix with the waste heat. It will be noticed that there is an extensive space provided for the purpose of ensuring that the tar is thoroughly atomized and burned.

Fig. 3 shows one of the tar burners (of which there are four to each boiler) known as the Field and Kirby. Tar,

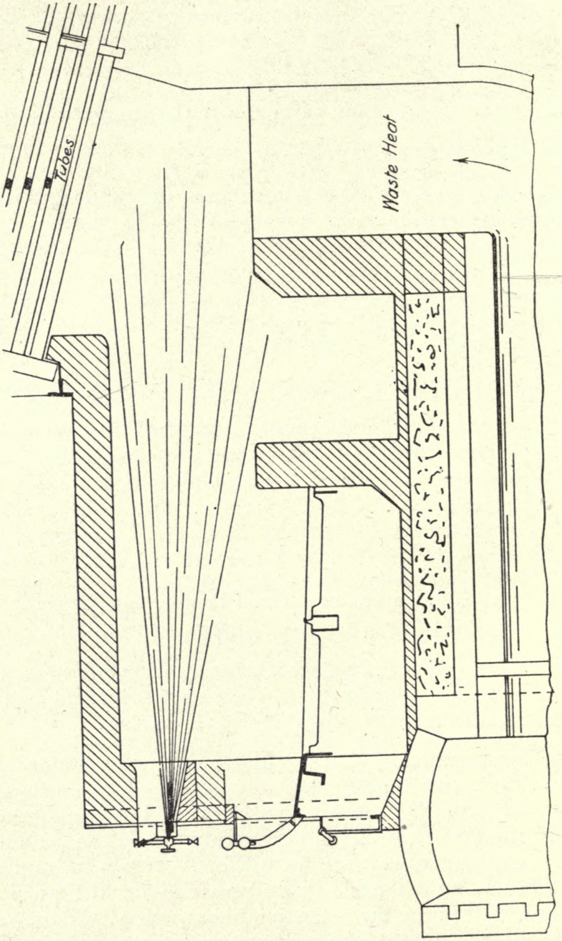


FIG. 2.

steam and air are injected by means of this burner. The tar is supplied to the inner chamber, in which works a cross-head valve, and by means of which the number of holes through which the tar escapes can be increased or diminished at will.

Steam, entering at V, fills the chambers, E, F, H, and escapes at F^1 and H^1, and at the same time draws in a current of air to the chamber, I, and discharges it at I_1. The tar in the chamber, C, flows through the holes, G, and into the boiler furnace. The steam jets cross each other, and so break up the tar into a very fine state of division. The tar supply is preheated by a steam coil, to make it of the requisite fluidity.

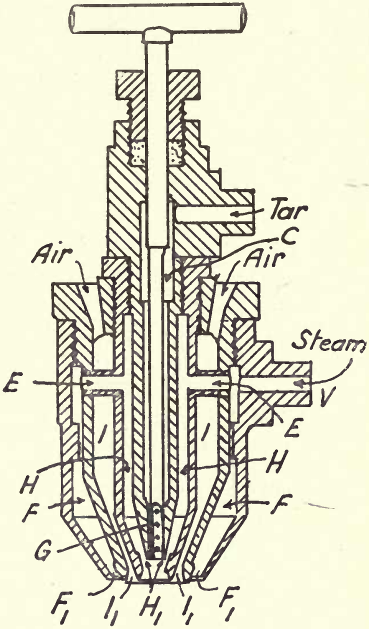


FIG. 3.

(6) **What would be the result, on the quality of the producer gas, on the temperature of a setting, and on the brickwork lining of a furnace, of the following practice :—**

(*a*) Feeding at too infrequent intervals.
(*b*) Omitting to spread the fuel evenly over the area of the grate.
(*c*) Omitting to clean the front of the furnace door of accumulated refuse.
(*d*) Using a fractured feeding door or frame.
(*e*) Using too much chimney draught.

	Quality of Producer Gas.	Temperature of Setting.	Brickwork Lining of Furnace.
(*a*)	Increase of CO_2 and nitrogen.	Alternating high and low.	High temperature in furnace and short life of lining.
(*b*)	Increase of CO_2 and nitrogen owing to air taking easiest course.	Reduced temperature of setting.	High temperature in furnace and short life of lining.
(*c*)	Reduction in quantity and increase in clinker.	Reduced temperature.	No effect.
(*d*)	Increase of CO_2 and nitrogen. Air tends to pass up "face" of fuel bed close to inner surface of front brickwork.	Reduced temperature.	Rapid destruction of lining.
(*e*)	Increase of CO_2, nitrogen and oxygen.	High in waste gas flue.	High temperature and destruction of lining.

(7) A carburetted water gas plant, designed for the production of high-grade gas, is required to produce a large volume of low-grade gas containing a small percentage of non-combustibles. State as fully as possible what alterations in the arrangement of the plant and operating conditions would be favourable to efficient working under the new requirements.

In order to make a high grade carburetted water gas, the chequer work in the carburettor and superheater would have to be heated to a sufficiently high temperature to properly crack from 3 to 4 gallons of oil per thousand cubic feet, and in order to bring about this result it would be necessary to make sufficient combustible gas during the blow to heat up the chequer work to the desired degree.

Under the new requirements, it would not be necessary to make such a large quantity of producer gas during the blow, and, therefore, a great saving in coke would be effected.

The alterations to the plant which would be necessary to bring about this result would be :—

(1) Increase the area of the generator.
(2) Decrease the depth of fuel in proportion to the quality of gas required.
(3) Increase the pressure of blast.
(4) Reduce period of blow.

Working in this manner, the plant could be used either to make blue water gas, by slightly modifying the plant, or a low-grade carburetted water gas having a low percentage of non-combustibles.

(8) Discoloured sulphate can be produced in several ways. Enumerate all the wrong conditions you know which lead to the production of coloured sulphate, and state what alterations in the method of working would remedy the defects enumerated.

The chief discolourations of sulphate are blue, black and yellow. If the temperature of the still gases falls below 100° C., so that condensation can take place, the subsequent chilling of the saturator liquor will cause the formation of blue salt. At the same time, the acid bath will be considerably less agitated, thus setting up a local alkalinity and the separation of FeS. Immediately this compound is precipitated, it reacts with the ammonium cyanide from the still gases, with the formation of ammonium ferrocyanide, thus :—

$$6NH_4CN + FeS = (NH_4)_4Fe(CN)_6 + (NH_4)_2S.$$

As soon as normal working is resumed, the soluble ammonium ferrocyanide will be converted into ferrous ferocyanide (which is insoluble) by the ferrous sulphate always present in commercial acid, thus :—

$$(NH_4)_4Fe(CN)_6 + 2FeSO_4 = Fe_2[Fe(CN)_6] + 2(NH_4)_2SO_4.$$

This ferrous compound is a white flocculent body, and will be ejected with the sulphate, which will often appear remarkably white. However, on exposure to the atmoshere for a few days it gradually assumes a blue colour, owing to the ferrous compound oxidizing first to ferrous ferricyanide—Turnbull's blue—$Fe_3[Fe(CN)_6]_2$, and finally to ferric ferrocyanide—prussian blue—$Fe_4[Fe(CN)_6]_3$.

Although priming may cause blue salt, unless the saturator has a reduced boil, or agitation, the effect of priming is practically neutralized.

Black salt is formed when the saturator liquor becomes what is technically termed "burnt." This condition is due to an insufficient amount of acid, or, in other words, the saturator becomes alkaline. The ammonium sulphide then reacts with the ferrous sulphate in the saturator, precipitating ferrous sulphide, which is black.

$$(NH_4)_2S + FeSO_4 = FeS + (NH_4)_2,SO_4.$$

Yellow salt is only formed when arsenical acid is used. Arsenical acid is produced from pyrites, which nearly always contains arsenic sulphide. When such pyrites is roasted to form SO_2, the arsenic sulphide becomes converted into As_4O_6, and dissolves in the sulphuric acid. As soon as any H_2S comes in contact with such acid, As_2S_3 (arsenious sulphide) is precipitated. The sulphide is yellow, and imparts a characteristic tinge to the resulting sulphate.

All the above wrong conditions may be avoided by:—

(*a*) Keeping the still chambers as free as possible from incrustation, thus assuring ample space for the full force of steam to blow through all the trays, and, incidentally, keep the temperature of the still gases well over 100° C. The use of a thermometer in the top chamber of the still, besides the periodical cleaning of the still chambers, is highly essential.

(*b*) Keeping a sufficient supply of acid in the saturator. This can easily be followed by never allowing the density of the saturator liquor to fall below 56° Twaddel.

(*c*) Ensuring that the incoming liquor to the still is sufficiently pre-heated, thus avoiding the chilling of the still.

(*d*) Periodical examination of the ammonia distributing pipes in the saturator, with a view to keeping the outlets as small as is consistent with efficient working.

(*e*) If arsenical acid is used, tar admitted to the saturator will cause the arsenious sulphide to rise to the surface as a scum, which can be skimmed off at will.

(9) Describe any details of design and method of governing a gas engine intended to overcome fluctuations in voltage, where an engine is used for generating electric current.

There are two methods of governing a gas engine, apart from the hit and miss principle:—(1) By varying the quality of the mixture of gas and air admitted to the cylinder, and (2) by varying the quantity of the mixture admitted. Both methods are supposed to give an explosion every second revolution, but the quantity regulation is far more certain in its action than the quality regulation.

Fig. 4 shows a section of a quantity governor made by Messrs. Crossley Bros., Limited, whereby the quality of the mixture remains the same at all loads, but the quantity is automatically controlled by the governor. A cut-off valve, worked by an eccentric from the side shaft, is placed between the air and gas suction valves and the admission

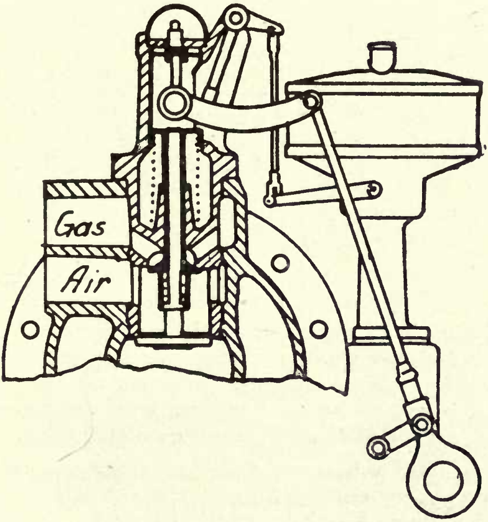


FIG. 4.

valve. The induction valve is opened and closed in the ordinary way, and at the same points of the stroke at all loads ; the setting of the cut-off valve, however, is altered by the governor. The governor determines the position of the fulcrum of the lever to which the valve spindle is attached. By this means, a strong explosion is obtained with full load and a weak explosion with a light load.

This efficient governor can be augmented by using a fairly heavy fly-wheel and by the insertion of a medial pulley between the engine and the dynamo, as shown in the sketch (Fig. 4A). The pulley considerably minimizes the jerking action, and, besides reducing the variation in voltage to 1 per cent., also gives a longer life to the belts.

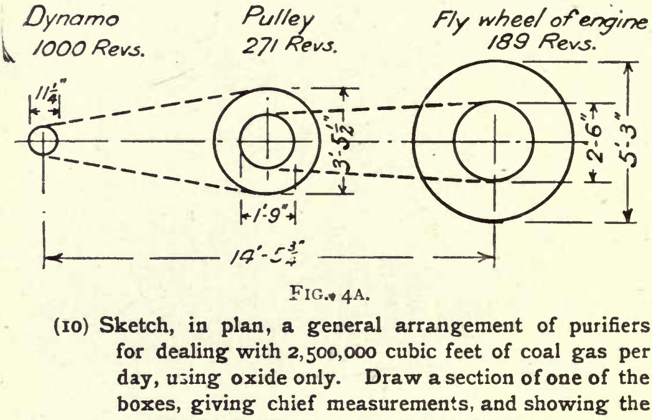


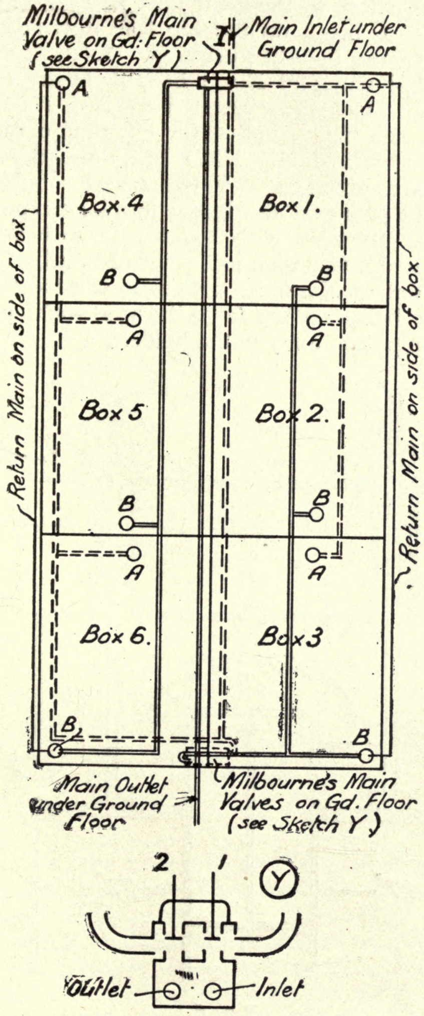
FIG. 4A.

(10) Sketch, in plan, a general arrangement of purifiers for dealing with 2,500,000 cubic feet of coal gas per day, using oxide only. Draw a section of one of the boxes, giving chief measurements, and showing the method of fastening a rubber-jointed cover.

The area of the boxes to deal with 2,500,000 cubic feet would be 950 square feet for each box. The boxes should be 25 feet by 38 feet by 6 feet, and six boxes should be put down. The mains would have to be 27 inches diameter.

Fig. 5 shows an arrangement of six purifiers on Milbourne's principle. Suppose it is desired to work

$$\text{Boxes } \overbrace{2 — 3 — 1 —}^{\text{Right-hand Section}} \overbrace{4 — 5 — 6.}^{\text{Left-hand Section.}}$$



Inlet mains thus = = =. Outlet mains thus ═══

FIG. 5.

Then the gas enters by the main inlet at I into the main valve. Valve 1 being on the top face, this admits the gas to inlet of the right-hand section. Inlet, A, of No. 2 box open, and outlet of No. 1 box, B, open; all other valves closed. Gas then passes into No. 2 box—over bridge pipe into No. 3 box—over bridge into the return main, over the bridge into No. 1 box, through outlet, B, to main valve at outlet end. Valves 1 and 2 being down, the gas would pass over the bridge into inlet pipe of left-hand section. Inlet No. 4 open and outlet to No. 6 open; all others closed. Gas then passes into No. 4 box, through No. 5 and out of No. 6, back to main valve at inlet end, I. Valve 2 being on top face, the gas would pass into main outlet pipe and away to the holders.

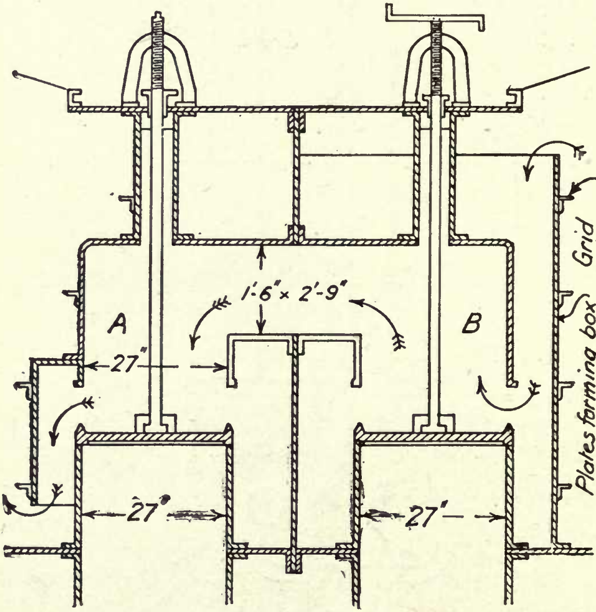


FIG. 6.

Fig. 6 shows a section of two adjacent boxes, fitted with Milbourne's valves. When both valves are closed, as shown, the gas flows from one box to the next, as indicated by the arrows.

Fig. 7 shows the working of Milbourne's rapid fastener. In the drawing, the cover is shown fastened down to the box. By turning the square shaft in the direction indicated by the arrow, the eccentric disc lowers the shackle, and releases the grip at D. The end of the slot then engages the stud, E, and the square shaft, eccentric and shackle move together, throwing the shackle right over on to the cover. The shackles are spaced about 4 feet apart, and the turning movement of the shaft is communicated round the cover by mitre wheels at each corner.

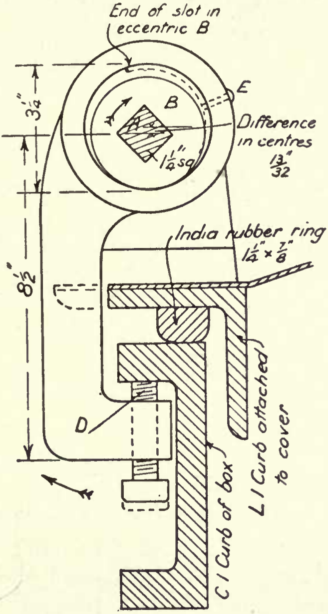


FIG. 7.

ANSWERS TO 1911 HONOURS GRADE QUESTIONS SET IN THE EXAMINATION IN GAS ENGINEERING.

BY FRANK L. BASSETT, B.SC., A.I.C.
(SILVER MEDALLIST).

(1) In what forms of combination is sulphur usually found in coal? Give an approximate balance-sheet, showing the distribution of sulphur in the gas and in each of the residuals after carbonizing an ordinary gas coal containing an average quantity of sulphur.

Sulphur is found in coal in three forms of combination :—

(1) As pyrites ("brasses"), FeS_2.
(2) Combined with carbon, hydrogen, nitrogen and oxygen in the complex organic substance of the coal.
(3) As sulphates, chiefly sulphate of lime, $CaSO_4$.

When the coal is carbonized, most of the "organic sulphur" goes into the gas as H_2S and CS_2. A small amount also forms complex sulphur compounds in the tar. The sulphate of lime remains in the coke, and would ultimately be found unchanged in the ash of the latter. The pyrites is decomposed by the reducing action of the hydrogen or hydrocarbons of the gas at the high temperature of the retorts, in accordance with the equation :—

$$FeS_2 + H_2 = FeS + H_2S.$$

The H_2S, of course, goes forward with the gas, while the iron sulphide remains in the coke.

A different reaction may take place if much moisture is present in the coal, and all the sulphur may be eliminated, thus :—

$$2\ FeS_2 + H_2 + 3H_2O = Fe_2O_3 + 4H_2S.$$

However, ordinary gas coke contains at least 1 per cent. of sulphur.

In framing the balance-sheet for sulphur, an ordinary gas coal may be considered, containing, say, 1·3 per cent. of sulphur. One ton of such coal carbonized at a moderately high temperature would yield approximately :—

11,000 cubic feet of crude gas, containing 1·5 per cent. by volume of H_2S and 0·03 per cent. of CS_2.

10 gallons of tar, weighing, say, 115 lbs., and containing about 0·4 per cent. of sulphur.

11 gallons of ammoniacal liquor, which holds altogether about 1·5 lbs. of sulphur.

13 cwts. of coke, with 1 per cent. of sulphur.

The balance-sheet is therefore as follows :—

	Lbs. of Sulphur.		Lbs. of Sulphur
1 ton of coal with 1·3 per cent. of sulphur . .	29	11,000 cubic feet of gas .	13·0
		10 gallons of tar . .	0·5
		11 gallons of liquor .	1·5
		13 cwts. of coke . .	14·0
	29		29

(2) Describe by the aid of sketches any efficient form of "regenerator" used in conjunction with a producer or "generator" for heating a retort setting. Give the approximate area of air heating surface per ton of fuel consumed per diem and the temperature of the gases entering the regenerator and entering the main flue.

The regenerators are two in number, and are arranged one on each side of the producer or generator. Each occupies a space of about 18 feet × 6 feet × 2 feet 6 inches, and the most efficient form consists of three flues or passages, the central one conveying air, which is gradually heated in its passage to the top of the regenerator by the hot gases in the two outside passages. Both the air and waste gases pass several times to and fro across the width of the setting, in an upward and downward course, respectively, and the air current in the central channel is always moving in the direction opposite to the gas currents in the adjacent flues.

The efficiency of such a regenerator depends on three factors, viz., the area of heating surface exposed to the action of the hot gases, the thickness of the walls, through which all the heat must pass, and the conductivity of the fire-brick employed. With this end only in view, the heating surface should be as large as possible, the walls as thin as possible, and the fire-brick of the densest and best conducting variety.

But one other consideration is of great importance, namely, the necessity of avoiding all liability to short-circuiting between the air and gas flues. The drawing in of furnace gases with the secondary air will at once lower the temperature of the setting. Therefore, the regenerator should be constructed so that the chances of cracks appearing between the air and gas channels, owing to the strains caused by expansion and contraction, or by any slight settlement of the setting, are reduced to a minimum. Regenerators have been built with double walls, formed of fire-clay tiles overlapping at the joints, so that there is little chance of short-circuiting. Some of the more complicated forms, however, are so expensive that it is doubtful whether any commercial advantage accrues from them.

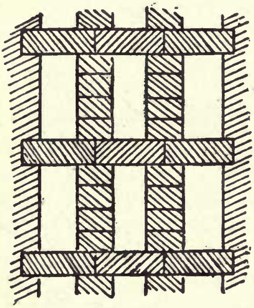


FIG. 1.

A form of construction which has the merit of simplicity combined with durability and a reasonable freedom from derangement is shown in Fig. 1. The division walls are formed of fire-clay bricks, laid on the face, the four bricks giving a height of 1 foot for the flues. The top and bottom of the passages are formed of 3-inch bricks or tiles, built in as shown. Fire-clay is used for all joints. There is not much chance of short-circuiting from gas to air flue or *vice versa.* A leak from one channel to the one immediately above would not be so serious, and thus there is little need for the double floors to the channels which are sometimes met with.

The area of air heating surface per ton of coke consumed per day is about 320 square feet. The temperature of the gases entering the regenerator would probably be 1,050° C., and of those leaving the regenerator and entering the main flue, 650° C.

(3) Give a description of the Fiddes-Aldridge stoking machine, with detailed sketches of that portion of the mechanism which enters the retorts.

Or,

Describe, by the aid of sketches, the discharge ends and discharging mechanism of two forms of continuously worked vertical retorts.

(*a*) The Fiddes-Aldridge machine consists of an outer frame of steel angles and channels, running on a trolley, with the usual propelling gear. A steel inner frame can be raised and lowered by steel wire ropes.

From the measuring chamber, which is fed by a hopper, the coal falls through a shoot, under which passes a push-plate conveyor, usually called the chain. It consists of vertical parallel plates, held in position by arched stays, and hinged at the upper edges, so that when withdrawn from the retort they can wind round a wheel.

From the arched stays are suspended push-plates, so that when the chain enters the retort the plates are held in a vertical position, but when withdrawing, they swing back over the fresh charge of coal, and level it in the retort. The front push-plate is of heavier construction, and pushes out the coke during charging. Thus one stroke of the machine discharges and recharges the retort.

A hinged apron plate is lowered on to the mouth of the retort, and forms, with the floor of the retort, a temporary floor for the conveyor. Two movable plates at the bottom of the shoot regulate the flow of coal into the chain.

The outer frame carries the measuring chamber and shoot and part of the travelling gear. The inner frame carries the chain wheel and electrical gear. Series wound motors are used, with a tramway controller, and the current is collected from overhead rails by flexible conductors. The driver controls everything from one position on the frame.

An automatic hopper door is used with the machine, with a double ended lever, which is opened and closed by two upright pins on the machine, as the latter travels from one retort to another. The doors of the hoppers are placed between the vertical rows of retorts, so that the machine receives its coal while getting into position.

The chain wheel and conveyor are shown in Figs. 2 and 3.

(*b*) Sketches are given of the discharge ends of Woodall-Duckham and Glover-West continuously worked vertical retorts.

The Woodall-Duckham arrangement is a hopper of the curious shape shown in Fig. 4. The weight of the charge is taken up by the curved back plate, A, so that the extracting wheel, B, can work freely. By the revolution of this wheel, the coke is extracted in small quantities at a time and drops into the bottom portion of the hopper. From time to time it is allowed to fall out by swinging back the curved door, D, which gives the actual exit from the retort. It can be seen that this door gives a complete seal, and, as it is balanced, it is very easily operated. The heavy swinging plate, C, prevents crushing of the coke during extraction, and also prevents the coke from discharging except at the predetermined rate.

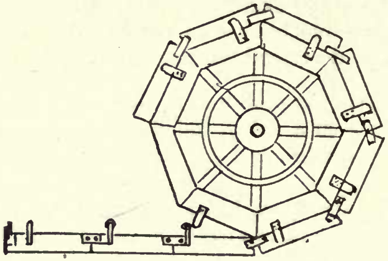


FIG. 2.

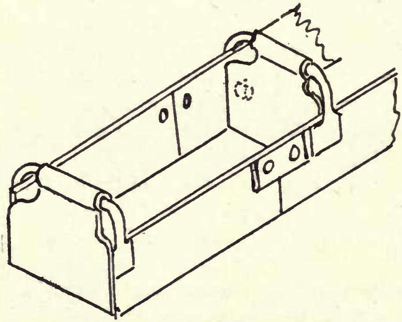


FIG. 3.

The Glover-West discharging arrangement is also primarily a hopper, in the narrow upper part of which is a worm, or helix, held vertically by two guides, as shown. This forms practically a short spiral conveyor, which, when revolved, extracts the coke continuously. The coke drops into a hopper, sealed by a dish-shaped door, containing water. The arrangement is indicated in Fig. 5. The hopper is shown separately, as the view is at right angles to that of the helix. One large hopper generally receives the coke from four retorts.

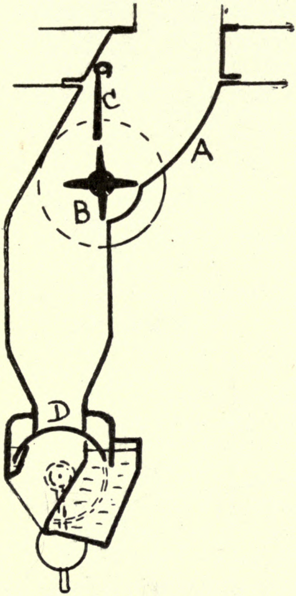


FIG. 4.

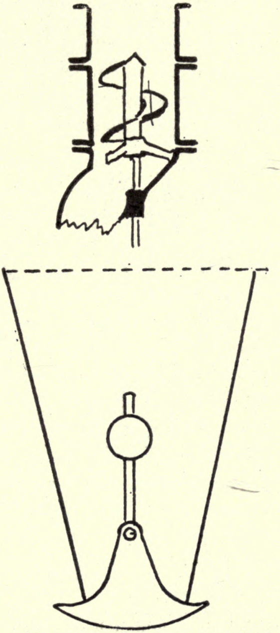


FIG. 5.

(4) Explain, by the aid of sketches, the principle of the Dillamore tar column and its application to the adjustment of seals in hydraulic mains. Enumerate the advantages and disadvantages of this method of adjusting seals, and state what precautions in designing and working it is necessary to observe.

Most modern retort houses have a tar tower into which the tar and liquor are run from the hydraulic main, there being, in addition, some device for maintaining a constant level of liquor while allowing both tar and liquor to be drawn off. The Dillamore column is shown in outline in Fig. 6. It is not of recent date, and has been used in Salford, Birmingham, and other important works for many years.

The hydraulic main is preferably divided into sections, each with its own tar column, so that any one section may be shut out if required. The tar has a free outlet from the main to the tar column, so that as little tar as possible remains in the main the seal being maintained with liquor, which has a free way to the column by the same pipe as the tar.

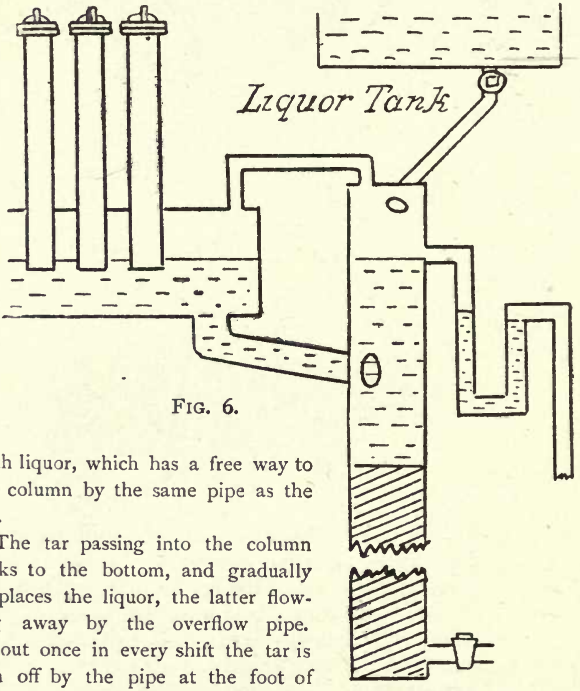


FIG. 6.

The tar passing into the column sinks to the bottom, and gradually displaces the liquor, the latter flowing away by the overflow pipe. About once in every shift the tar is run off by the pipe at the foot of the column, liquor being run in from an overhead tank, to maintain the level during this operation. Thus, the column is again full of liquor, which is gradually displaced by tar, as before. The important thing is that the level in the tower should be constant, for on this depends the level in the main. This is ensured if liquor is always trickling from the overflow.

It is a great advantage to maintain constant seals in the hydraulic main, and, further, to know exactly what these seals are. The desirability of absence of pressure (and also absence of vacuum) in the retort is too well known to need any mention. One or two precautions in designing and working these towers are necessary, however, in order to attain the desired end.

In the first place, when the exhauster is working, there will always be a difference of level in the column and the main, if the former is open to the atmosphere. If the exhauster is giving ½ inch of vacuum in the hydraulic, the level there will be ½ inch higher than that in the tower, which is fixed by the overflow. If the exhauster from any cause ceases to give the ½-inch vacuum, the level in the main will fall (the excess of water passing into the tower and out of the overflow), and thus the seal is reduced. Supposing the seals were only ½ inch and the exhauster were stopped, the dips would then be on the point of unsealing. It can, therefore, be seen that the seals depend on the pull of the exhauster, instead of being constant and independent of it. The important conclusion is that it is impossible to vary the pressure or vacuum on the retorts, as it is desirable to do, by means of the exhauster. Thus, suppose the exhauster is pulling ½ inch, and the seal of the dips is ¾ inch, there is obviously ¼ inch pressure in the retorts. It is found that the gas is not getting away freely, and the pull is increased to 1 inch. The seal immediately rises (*i.e.*, as soon as the main can fill up) to 1¼ inches. Pressure in the retorts, still ¼ inch. Or, again, with a pull of ¾ inch and a seal of ½ inch, it is discovered that furnace gases are being drawn in. The pull is lowered to ½ inch, but the seal immediately falls to ¼ inch, so the vacuum on the retorts is still ¼ inch.

The top of the tower must, therefore, be covered in, and a pipe carried from it to the top of the hydraulic, so that the two are under the same vacuum. The seal of the dips then becomes independent of the pull of the exhauster.

The overflow from the tower can, obviously, be no longer a plain pipe; it must be a syphon, as shown. The level of the outer bend must be below the connection to the column, so that the latter may determine the level of the liquor. This connecting pipe may seem to be an obvious necessity, but it has before now been proposed to leave it out, "and allow for the difference in the levels."

The tower may be 20 feet high, if desired. It depends on the extent of main with which it is connected and the frequency with which the tar is to be run off. The tar should not be allowed to get thick in the column.

An important point in running off the tar is to keep up the supply of liquor, or else the dips will soon be unsealed and the hydraulic main emptied. Liquor must flow from the overflow throughout the operation.

(5) Draw a cross section of a Pelouze and Audouin apparatus; explain its function, its action, and its position relative to the other apparatus used for cleansing the crude gas.

The Pelouze and Audouin apparatus consists essentially of a bell suspended by means of a counterbalance weight in a liquor seal. The top of the bell is a flat plate, and its sides are composed of a number of thin cylinders, either of wire gauze or of plate perforated with small rectangular holes. There may be four or six of these concentric cylinders, with a very small distance between the walls of each.

The gas pressure, acting on the interior of the bell, causes the latter to rise or fall, and thereby expose a greater or lesser area of its perforated sides above the level of the liquor. Thus, the area of escape for the gas is proportional to the amount of gas passing, and the frictional resistance for a given volume of gas is constant. Every perforation of a plate is opposite a blank on the next plate, so that the gas, on taking a zig-zag course through the walls, is constantly impinging in fine streams on blank surfaces. This results in a deposition of the tar held in suspension by the gas. The tarry drops run down into the trough, and the tar thus collected passes away by a syphon pipe.

Thus the essential function of the apparatus is that of a tar extractor, particularly for the heavier tars which would otherwise come down in the condensers. The lighter tars go forward, and will more readily dissolve out naphthalene than when mixed with heavier tars. The tar extractor is, therefore, placed before the condensers, and is the first piece of apparatus entered by the gas on leaving the foul main.

A good deal of naphthalene is also removed from the gas by friction in this apparatus, so that a special naphthalene washer may be unnecessary.

The apparatus is shown in Fig. 7.

(6) How do the results obtained from the carbonization of heavy charges in long periods vary from those obtained when light charges are carbonized in short periods? What classes of coals are most advantageously carbonized by each of the two systems, and why?

One of the most notable changes in carbonizing practice of recent years has been the introduction of the heavy charge, and consequent long period of carbonization. Mr. Chas. Carpenter was one of the first to try the experiment of filling the retorts full, and the practice has now become general in all large works. In view of the results obtained, it seems almost extraordinary that for so many years gas engineers were content with a thin layer of coal on the floor of the retort.

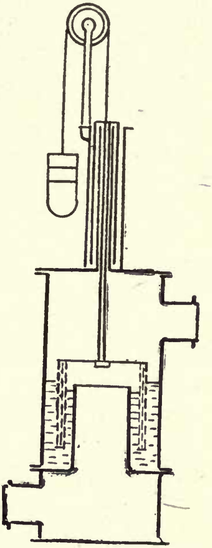


FIG. 7.

The almost universal testimony is that the yield of gas is increased by the 12-cwt. 12-hour charge. A slight decrease in illuminating power is generally admitted, but this is not of very great importance, and will be of even less in the future. The calorific value of the gas is not impaired. Turning to the impurities, sulphuretted hydrogen and sulphur compounds are decreased. Carbonic acid is not much affected. The tar is thinner, and exerts a greater solvent action on the naphthalene, of which, therefore, there is less in the purified gas. The yield of ammonia is increased by the heavy charge; and the coke is large, and of good quality.

These results are generally accepted without question for any class of coal at present carbonized for gas making, so that it is difficult to find gas engineers who deny the merits of the heavy charge.

However, Dr. Davidson, on the results of his experiments at Birmingham, maintains that the heavy charge has no advantage over light, short period charges. Dr. Davidson is known as an accurate worker, and the whole question must be left there. It would be of great interest to have his results confirmed at other large works. At present it can only be said that the heavy, long period charge is accepted by the gas industry as constituting the best carbonizing practice.

With reference to the class of coal, cannel coals and certain Midland coals would seem to be the only kinds that could be just as advantageously carbonized on the old lines, and cannel is not now in use to any extent. Coals which yield their gas very freely, as cannel does, would obviously be less advantageous to carbonize in large bulk and long period than ordinary bituminous coal. Again, the cannels generally decrepitate in the retort, and this, again, would throw the advantage more on the side of the light charge.

(7) Describe any well-known gas calorimeter and the methods of testing. Show by figures what would be the effect on the calorific value of (*a*) drawing in, by over exhausting, 8 per cent. of furnace gases, or (*b*) adding 15 per cent. of blue water gas to a high-grade coal gas.

[Mr. Bassett described the Boys' calorimeter, already described on pages 79 to 83.]

(*a*) The effect of drawing in, by over exhausting, 8 per cent. of furnace gases.

If this is taken to mean 8 per cent. on the mixed gas (or total volume of gas passing through the exhauster), the calorific value is simply reduced 8 per cent. For the furnace gases have neither heating nor cooling effect, and are simply diluents, so that 92 volumes of pure gas have become 100 volumes of mixed gas, having only the heating value of the 92.

Thus, if the gross calorific power of the original gas was 150 calories, it is now $\frac{92}{100} \times 150$, or 138 calories per cubic foot.

(*b*) In this case the mixed gas is 85 per cent. coal gas, calorific value, say, 150, and 15 per cent. blue water gas, calorific value, say, 75.

Thus, 100 volumes of the mixture possesses $(85 \times 150) + (15 \times 75)$ heat units $= 12{,}750 + 1{,}125 = 13{,}875$ units.

Thus, the calorific power of the mixture is 138·75 calories per cubic foot.

(8) State how the quality of the coal and the carbonizing conditions affect the production of naphthalene. Give a brief description of the methods usually employed to reduce the quantity contained as vapour in the gas or to prevent its deposition in a solid form in the distributing mains.

It may be stated at the outset that very little information has been published as to the effect of the quality of the coal on the production of naphthalene. Isolated statements can sometimes be found in text-books, such as, "Newcastle coals produce a great deal of naphthalene, whereas Wigan coals give rise to benzol and phenol." These statements, however, are not of much value. Contradictory results are sometimes found for the same coal, said to be carbonized under the same conditions, while in a few cases in which comparative experiments have been made with various classes of coal, the names and descriptions of the coal have been withheld from the published results.

There is no doubt, however, that while any ordinary bituminous coal carbonized at a high temperature will give rise to a high proportion of naphthalene in the gas, cannel coals and those bituminous coals which resemble cannel in their properties (certain Midland coals, for instance) will not originate naphthalene troubles. The greater the ease with which a coal will yield its gas, the less naphthalene is produced. Moreover, the tar from these coals is of a thin nature, with a comparatively high proportion of solvent hydrocarbons, which, in the process of condensation, effectually dissolve out the naphthalene. Thus, not only is the total quantity of naphthalene in gas and tar very much less than with bituminous coals, but what there is will be found almost entirely in the tar, owing to the solvent nature of the latter.

Of far more importance for the production of naphthalene are the carbonizing conditions, of which the most important is the temperature of the retort. High heats, together with the superheating of the gas, are responsible for the naphthalene troubles of recent years. In the days of direct-fired settings and yields of 9,000 to 10,000 cubic feet per ton, very little was heard of naphthalene stoppages. The benzenoid hydrocarbons tend to associate at the high temperatures now attained. Thus, we get more naphthalene and more "free carbon" in the tar. Contact with the red-hot retort walls accelerates the process, and for this reason a coal which gives off its gas very freely in the first two hours of carbonization will give rise to less naphthalene than one that evolves gas more slowly for a longer period. For the same reason, pressure within the retort is conducive to naphthalene formation. Heavy charges undoubtedly reduce naphthalene, and this is due to the smaller area of white-hot surface per ton of coal, and possibly to the cooling effect for the first hour or two of the heavier charge.

Naphthalene may either be eliminated from the gas at the works (which is nearly always done, as far as possible), or the gas may be rendered capable of carrying it forward to the point of consumption. Since naphthalene deposits are generally periodical in character (for they chiefly occur in summer, when the warm gas comes in contact with comparatively cool mains) many works keep a carburetting plant as a "stand by," with which to carburet the gas when naphthalene troubles arise. Many devices have been used, but it will, perhaps, be sufficient to mention one that has given very good results, namely, the Botley carburettor. This apparatus consists of a short length of large diameter main, through which the gas passes (entering and leaving at the side), and fitted with small inspection windows near one end.

On a level with these is a row of small jets, four or five in number, through which ordinary kerosene or burning oil is forced under a high pressure. The jets are so shaped as to give a whirl to the spray of vapour, so that the carburetting chamber is filled with a very fine mist of the oil. Very little oil is used. About 0·2 gallon per 10,000 cubic feet of gas is found to be effective in a well-known London works, so that the cost is about 1d. per 10,000 cubic feet.

The pressure is put on the surface of the oil, contained in a steel tank, by means of an air pump.

The removal of naphthalene from the gas can generally be effected in two ways, either by careful condensation and scrubbing, or, when this fails, by the use of a washer and a suitable solvent. A good deal, however, can be done with the condensers and tar extractors. Although a high-grade gas suffers considerably in value on sudden cooling, this treatment does not do much harm to the lower grade gas now made, and it is to a great extent effective in reducing naphthalene. The heaviers tars are quickly separated by sudden cooling, leaving the lighter tars to go forward, and bring down the naphthalene. This they do more readily than when mixed with the heavier tars. Similarly, the tar extractors, such as the Pelouze and Audouin apparatus, Dr. Colman's "Cyclone," or Everitt's tar screens, if placed before the condensers, will effect by friction the removal of the heavier tars, leaving the lighter tars to go forward to the condensers and dissolve the naphthalene. Apart from this, some naphthalene is removed by friction in the tar extractors themselves.

The washing of the gas is frequently resorted to, either a rotary washer or a Livesey or Walker washer being employed. There is a great variety of solvents in use. Coal tar (heavy) naphtha, petroleum naphtha, "green oil," light coal tar, water gas tar, and many other solvents are used. Sometimes the gas is washed with warm tar, and then with naphtha. In other cases various patent mixtures have been employed. The total cost of this washing should never exceed 1d. per ton of coal carbonized.

(9) What is the function of a safety governor? In what position, and under what conditions, is it usually fixed, relative to the gasholder valves and the ordinary station governors?

A safety governor is employed in order to prevent the district being thrown into darkness through the valve man forgetting to open the outlet of a second gasholder before shutting down the first one. It is fixed between the outlet of the station meter and the inlet of the ordinary station governor, and is arranged so that it comes into action and opens a way from the station meter to the district the moment the pressure falls below that given by the lightest of the holders in use The arrangement is shown in Fig. 8.

(10) Explain the construction of the London No. 1 standard test burner. State the nature of its defects as a "standard," and how these have been overcome in designing the No. 2 Metropolitan burner.

The London argand No. 1 burner, which was used until 1906 for gas testing in the metropolis, consists of an annular steatite chamber perforated on the crown with twenty-four holes, 0·045 of an inch in diameter. This is supplied with gas by three supply pipes, 0·08 of an inch in diameter, which spring from a common base, as shown in the sketch (Fig. 9). Around the steatite chamber is the cone which

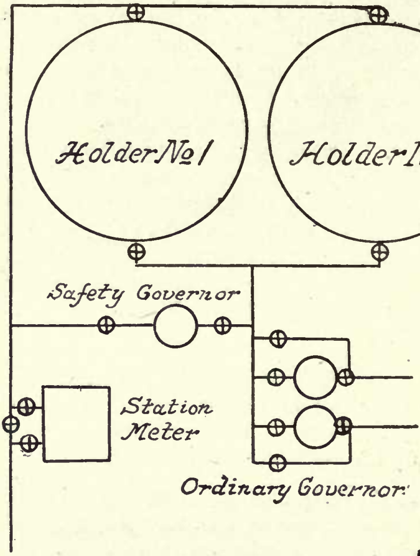


FIG. 8.

directs the external air supply on to the outside of the flame. Beneath and around this, again, is the gallery for the glass chimney, the latter being 6 inches high and $1\frac{7}{8}$ inches internal diameter. The flame has thus an internal and an external air supply. The gas is burned at the standard rate of 5 cubic feet per hour, except for very rich gases, which should be burned at a reduced rate. Such gases, however, are generally tested with a flat-flame burner.

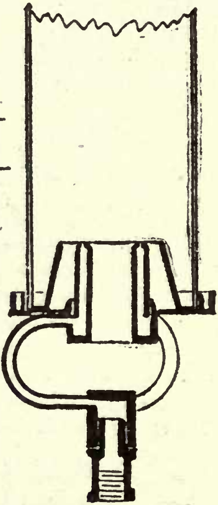


FIG. 9.

The burner does not really give uniform and comparative results for gases of different candle-power (say 14-candle gas and 18-candle gas). The air supply is not adjustable to suit the particular gas to be tested (supposing it to be burned at the fixed rate). Therefore, to get the maximum effect, the rate must be increased for a poorer gas. But a greater proportion of the total heat now generated is conducted away, or rapidly radiated from the flame, so that the carbon particles are not raised to the same temperature of incandescence. This is unfair to the poorer gas.

The remedy lies in the provision of an adjustable air supply, and this was done in the Metropolitan argand No. 2, designed by Mr. Charles Carpenter, and introduced in 1906. This burner is shown in the sketch (Fig. 10). It hardly needs any description. The air adjustment is effected by turning the milled nut on the screwed stem. This burner gives good results with all grades of gases now in use.

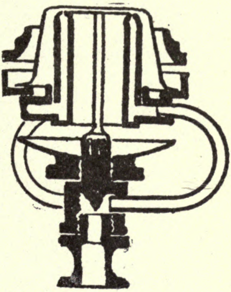
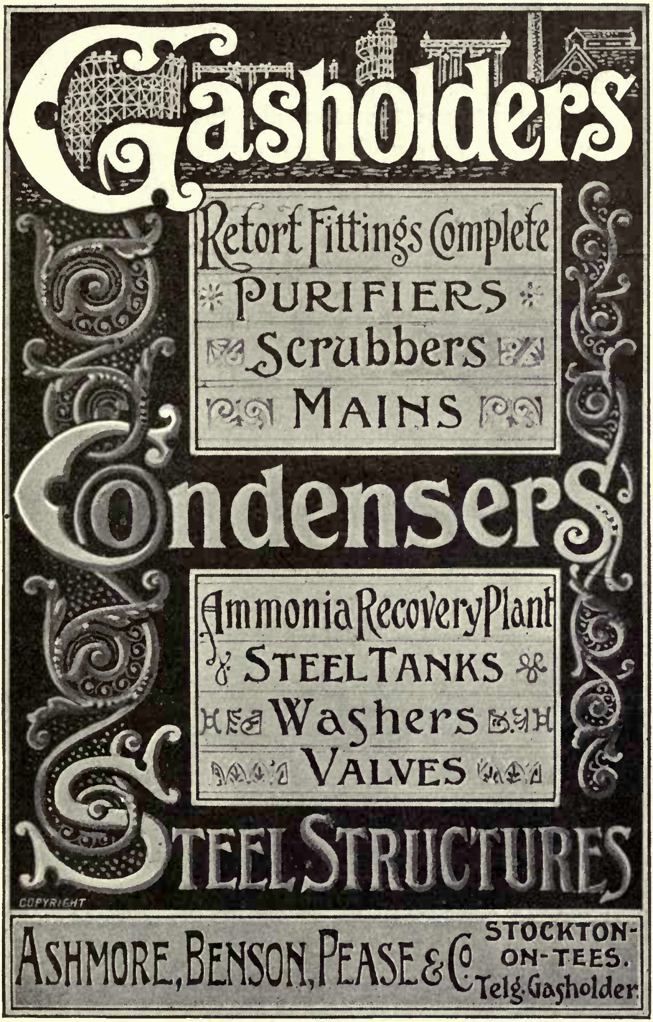
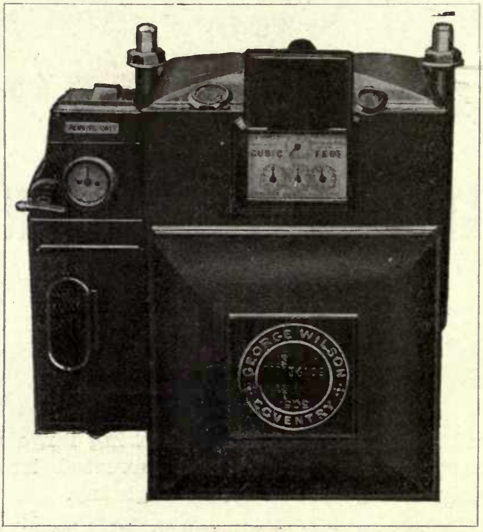


FIG. 10.

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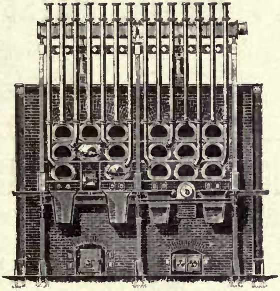

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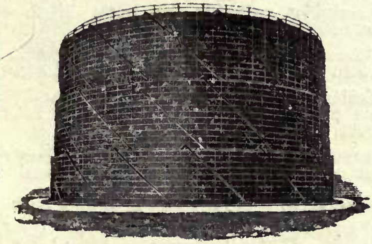

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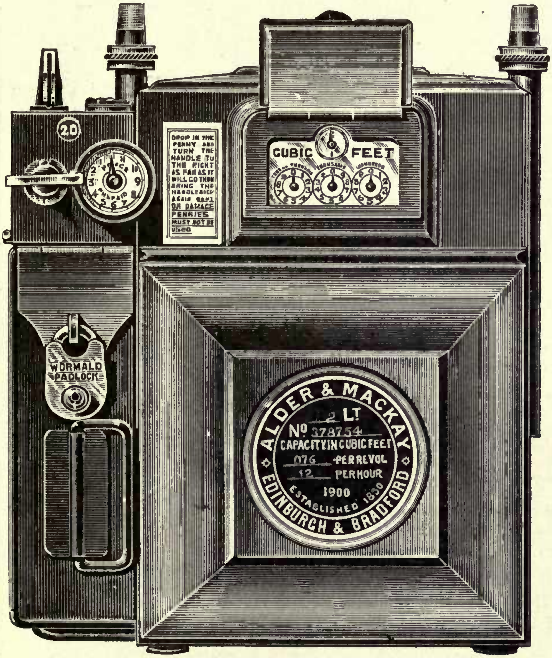
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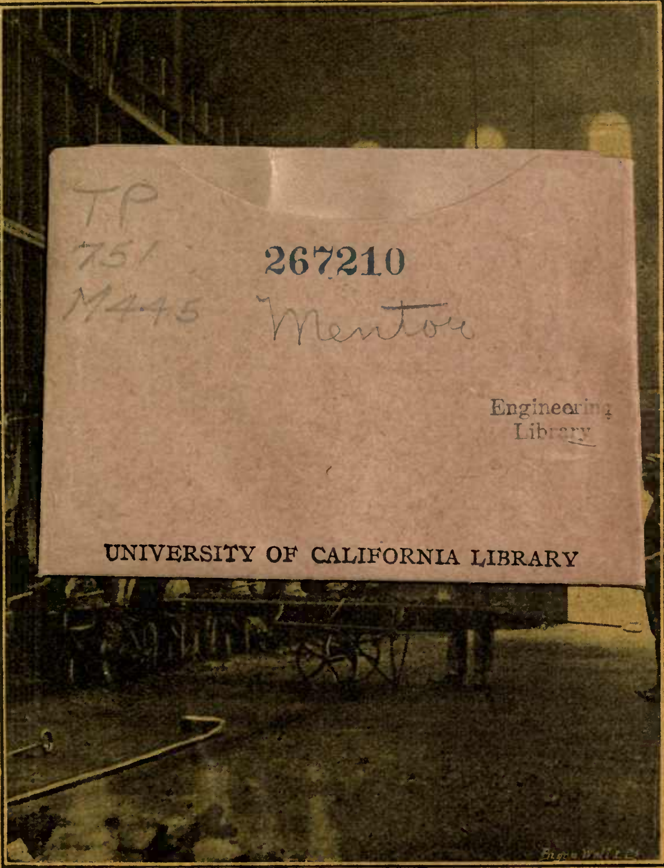

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