THE TECHNIQUE OF GAS MANUFACTURE.¹

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UNTIL the Seventeenth Century the store of human knowledge as to the aëriform substances, which are now named gases, was practically confined to that of the more striking physical properties of the atmosphere and its corroding effect upon metals, especially when they were heated.

Van Helmont (1577-1674) was probably the first to understand the existence of aëriform bodies distinct from ordinary air. These he called spirit and in his writings he mentions bodies almost entirely composed of spirit which was fixed and solidified in them. To this spirit he gave the name of "gaz." According to Priestley, Van Helmont derived this name from the German word "geist," meaning spirit, but a later writer claims to have found a statement of Van Helmont connecting the word with "chaos."

Apparently the first published assertion as to the composition of the atmosphere was made in 1665 by Hooke, who stated that air contains a principle similar to, if not identical with, that of nitre. He also seems to have recognized that only a certain portion of the atmosphere is required to support combustion and respiration. The precise experiments on respiration published by Mayow in 1670 greatly strengthened this conception of the complex nature of the atmosphere, but in spite of the incontestable facts he presented this truth was not fully recognized until more than a century afterwards.

Boyle extended the knowledge of the physical and chemical constitution of air by the work described in his treatises published between 1672 and 1692. About 1770 Rutherford demon-

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strated the existence in the atmosphere of nitrogen and shortly afterwards Priestley separated oxygen from red oxide of mercury, and the significance of this discovery, in relation to the constitution of air, was clearly demonstrated by Lavoisier, who by heating mercury in contact with a measured volume of air showed that about one-fifth of this volume was taken up, with the formation of the red oxide of mercury, and that the remaining four-fifths had all the properties of the "mephitic air," or nitrogen, of Rutherford.

Hydrogen was recognized as an individual gas by Cavendish in 1766 and its name was given to it by Lavoisier.

During the Seventeenth Century some progress was made in determining the identity of carbon dioxide as distinct from atmospheric air and in recognizing its various occurrences as the result of fermentation and combustion and as collected in subterranean and enclosed places at a low level, and as the cause of the sudden deaths known to occur in such places but previously ascribed to the acts of an evil spirit.

Van Helmont is stated by some authorities to have known the identity of the gases from these sources, but according to others these facts were not fully known until nearly the end of the Eighteenth Century. The composition of carbon dioxide was finally determined by Lavoisier.

The existence of fire damp, the name being obtained from the fact that this "damp" or vapor was inflammable, in connection with marshes and coal seams had been known at an earlier date, but Thomas Shirley seems to have been the first Englishman to examine carefully the properties of this important constituent of illuminating gas, now known chemically as methane, and generally as marsh gas, or carburetted hydrogen. In 1667 he published in the *Philosophical Transactions* an account of his investigation in 1659 of the phenomena occurring in a burning spring near Wigan in Lancashire. Shirley demonstrated that the combustible matter was a gas bubbling through the water, which gas he collected from the ground after the water had been diverted into another channel. After this publication many similar observations were made as to the formation of methane by the decomposition of vegetable matter.

One of the earliest observers of the fact that the distillation

of carbonaceous matter yielded a combustible gas was Boyle, who found that when distilled, wood yielded oil, spirit, phlegm (steam), and water. The Reverend John Clayton, in a letter written to Boyle and which, although only published in the *Philosophical Transactions* in 1739, must have been written before Boyle's death in 1691, describes experiments in distilling coal undertaken as a result of seeing gas escaping from a ditch near Wigan which was found to be underlain by coal. He used a retort and obtained first phlegm (steam), then black oil and then a "spirit" which could not be condensed and gradually accumulated until the pressure forced the lute and broke his glasses. The accidental ignition of the escaping gas proved that it was inflammable. By storing some of it in bladders he found that both it and its property of inflammability were permanent.

In 1726 Dr. Stephen Hales distilled wood and coal and noted the toxic effect upon animals of the "air" produced. He states that from Newcastle coal he obtained one-third of its weight of "air," but since this coal, even with improved methods of distillation, yields only one-fifth of its weight of permanent gas some condensable products must have been included in this amount.

In 1767 Dr. Watson published some essays in which he speaks of the giving off of "air" during the distillation of coal.

Even at this comparatively late date, gases were thus spoken of as "air," and although the name "gas" suggested by Van Helmont for these bodies was defined in Macquer's Chemical Dictionary published in 1771 as the "name given by chemists to invisible parts which escape from certain bodies," this name was not used generally until some time after it was adopted by Lavoisier in 1786.

The discovery that the distillation of coal and other carbonaceous substances produced an inflammable and more or less luminous gas was thus made prior to 1690, but it was not until nearly one hundred years later that the idea of using this gas for illuminating purposes was conceived. Then this use seems to have been thought of independently by several persons in different countries at about the same time, and consequently there is a dispute as to who should be accredited as having been the originator of the use of coal gas as an illuminant.

Apparently J. P. Minckelers, a professor in the University of Louvain, in Belgium, in 1784, distilled powdered coal, for the production of inflammable air which he used to fill balloons. In a report advocating the use of coal gas for aeronautical purposes, in which he was particularly interested, he is said to have mentioned the fact that the gas might be purified by being passed through lime water and could then be used for illuminating purposes. It is also claimed that records in the archives of Louvain show that in 1785 Minckelers lighted his lecture room with inflammable air produced by the distillation of coal.

Phillippe Lebon distilled wood and coal in 1786 and in 1799 took out a patent for "a new method of employing fuel with greater utility either for heating or lighting and to obtain certain products therefrom." The apparatus described in this patent was not very practicable and in 1801 he obtained a certificate of additions. In this certificate he calls the apparatus a "thermo-lampe" and apparently his main idea was to obtain inflammable gas with the object of producing motive power by means of its explosion and little importance was attached to the gas as a means of lighting. For lighting purposes he described a means of consuming the gas inside a glass globe into which gas and air were led by separate pipes and from which the products of combustion escaped by a third pipe. Such a complicated apparatus was not suitable for ordinary use, but his exhibition of lighting by this method, given in Paris in 1802, was written up in glowing terms by the Parisian newspapers and in this way attracted attention all over the Continent of Europe.

The earliest patent taken out in England, in connection with the distillation of coal, was that of Lord Dundonald, for the production of different substances from the distillation of coal, obtained in 1785. His object, however, was the production of tar and while he is said to have lighted the hall of Culross Abbey with crude coal gas in 1787 he apparently did nothing further along the lines of illumination by means of coal gas.

William Murdoch, who is credited in Great Britain and among English speaking countries as being the originator of the use of gas for illuminating purposes, apparently began experimenting along this line at Redruth, Cornwall, in 1792. In that year he distilled coal, peat, wood and other carbonaceous

bodies and, being impressed by the quantities of gas given off during the distillation and the facility with which a brilliant light was produced by this means, he made experiments to determine the relative costs of light so obtained and that obtained from oils and tallow. In 1797 he lighted his own premises in Old Cumnock, Ayrshire, with coal gas. Becoming connected with the firm of Boulton and Watt, quite prominently identified with the development of the steam engine, he lighted with coal gas in 1789 one of the principal buildings of their plant at Soho, Birmingham, and in 1802, in celebration of the Peace of Amiens, the Soho works were strikingly and, for the period, brilliantly illuminated by means of that gas.

Apparently Minckelers and Lebon while working with other objects in view preceded Murdoch in their experiments with, and demonstrations of, illumination by means of coal gas, but the latter was the first to work with illumination as the main object.

Through Lebon, however, the man who probably was the greatest factor in hastening the introduction of the public supply of gas became interested in the subject. This man, Frederick A. Winsor, seeing, in one of the European newspapers, a description of Lebon's exhibition was struck by the possibilities of the process and, going at once to Paris, saw the light and tried to obtain from Lebon information as to the method of producing it. It was, however, impossible for him to pay the high price asked and Winsor left Paris disappointed but determined to find out the causes of such important effects and results.

By the next year he had obtained a certain amount of knowledge on the subject and gave in Brunswick exhibitions of the lighting effect of gas produced by the distillation of wood. At this time he was seized with great force with the idea that England was the most favorable field for the exploitation of the process and, acting promptly on this thought, went to London and there gave, in 1804, at the Lyceum Theatre, lectures and exhibitions on gas lighting. Although working under difficulties, and at first without much success, partly because of his extravagant claims, Winsor persisted in his efforts to promote and finance a National Light and Heat Company, and was finally reported to have obtained nearly £50,000, all of which was expended in the furtherance of his plans. In 1809 he lighted

with gas a portion of one side of Pall Mall, this being the first public street lighted by means of coal gas.

While Winsor was thus working to interest capital in a company to exploit gas lighting over the whole area of Great Britain, attention was also being called to this means of lighting by the lectures of various chemists, and practical applications of the process were being made in various cotton mills by Murdoch, and by Samuel Clegg. Even with the crude apparatus employed, lighting by coal gas was found to be much cheaper and more brilliant than that obtained, according to the general practice of the day, by the use of candles.

In 1809 Winsor and his associates applied to Parliament for a charter for a company to supply gas over the whole of Great Britain. Murdoch, who claimed that priority of invention entitled him to the charter if any were granted, opposed this application and it was denied, but another, made in 1810 by Winsor and his associates, resulted in the passing of an Act authorizing the king to grant, within three years, to the London and Westminster Chartered Gas Light and Coke Company, a charter covering London, Westminster, Southwark and the adjacent suburbs. The capital was fixed at £200,000 to be raised in full within three years after the granting of the charter, while £100,000 had to be raised before the company could commence operations.

The company finally obtained its charter on April 30, 1812. Its operations were not successful at first, but in 1813 progress began to be made, and by 1815 the company had installed three manufacturing plants and fifteen miles of street mains. Other companies were soon organized and the business of supplying gas progressed so rapidly in Great Britain that by 1829 more than two hundred gas companies had been formed.

The first use of coal gas as an illuminant in the United States is said to have been made in Philadelphia in 1796, but the first definite record of such use in this country is the lighting in 1806 by David Melville of his house in Newport, R. I., with gas made by himself. In 1810 he obtained a patent for "a gas lamp for lighting manufactories, mills, theatres, etc., with hydrogen gas, or inflammable air produced from pit coal," and in 1813 he lighted with gas some mills in the vicinity of Newport.

The first gas company in the United States was organized in Baltimore in 1817 and this was followed by the organization of companies in Boston and New York, but because of the comparative cheapness of other illuminants progress was slow and up to 1830 these were the only cities that had gas works.

I have been unable to find any description of manufacturing apparatus specifically stated to be that employed in the first works of the Chartered Gas Light and Coke Company. It is probable, however, that the apparatus described in "A Practical Treatise on Gas Light," published by Frederick Accum in 1815, as being calculated for lighting towns or large districts of streets and houses, is, even if not exactly the same, very similar to that which was installed in these works, because Accum was the first engineer of the Chartered Company and refers throughout this book to information obtained from Samuel Clegg, who was his successor.

In this apparatus the coal was distilled in cast iron retorts about 15 inches in diameter and 3 or 4 feet long, placed in sets of two in the flues of fireplaces, built under the backs of the retorts, in which coal fires were maintained. The fronts of the retorts opened into a chamber shut off from the operating floor by means of a brick wall through openings in which the work of drawing and charging was done, the coke falling, as it was drawn, through a hole in the bottom of this chamber into a space below the operating floor. The gas leaving the retorts passed through so-called syphon tubes, with a diameter of probably less than 3 inches, into the horizontal condenser, or hydraulic main. The lower end of the syphon tube, or of the dip pipe, was sealed by the accumulation of the liquids condensed from the gas in the hydraulic main until they passed off over the top edge of a partition plate set at a level above that of the bottom of the syphon tube. From this condenser the gas was carried by a take-off pipe to a pipe coil placed in the water in the space between the holder and the tank. After being cooled in this coil, the gas was led into a lime machine while the condensed liquids ran into a tar cistern. In the lime machine the gas was caused to bubble through lime water by which the sulphur compounds were removed. Upon leaving the lime machine the gas was passed through a small washing apparatus placed inside

of the holder, from which it escaped into the interior of the latter.

The holder bell probably had a capacity of about 14,000 cubic feet and was made of light sheet iron fastened to a rectangular frame formed of wooden struts and iron bars, while the tank was apparently made by lining with wrought iron the foundation walls of the building in which the holder was enclosed.

The street mains were made of cast iron spigot and faucet, or bell and spigot, pipes, the joints being made with either iron cement or lead.

Service pipes up to a diameter of $1\frac{1}{4}$ inches were made of tubes of welded wrought iron in 3-foot lengths with wrought iron fittings and screwed joints.

For house piping tubing made either of sheet iron brazed, of lead or of copper with lap-over joints was used. Copper with brass fittings was recommended by Peckston for interior work, with wrought iron tubing for pipe exposed to the weather. The burners were either cockspur, consisting of three round jets, a single round jet, batswing or Argand.

In the 1819 edition of Peckston's "Theory and Practice of Gas Lighting" it is stated that the general mode of charging customers for light was at a certain sum per annum for burners of given dimensions burning from sunset until a stipulated hour, but that this was not satisfactory and that meters for measuring the actual amount of gas used were being gradually introduced, a suitable meter having been brought out in 1817.

In a modern coal gas plant the retorts in which the coal is carbonized are made of clay, are D-shaped with a height of about 16 inches, a width of 24 to 28 inches and a length of 9 to 10 feet for what are known as single retorts, or from 11 to 20 feet for what are known as through retorts. They are set in groups of from six to twelve, each group or bench being heated by means of a generator furnace equipped with recuperators. As a rule the long axis of the retort is horizontal, but that of through retorts is sometimes inclined about 32° from the horizontal and during the last five years the practice of having this axis vertical has been quite largely adopted. In smaller works the coal is charged into, and the coke drawn from, the retorts by hand, but in larger works these operations are performed by

machinery. The stand, bridge and dip pipes, through which the gas passes from the retorts to the hydraulic main, have a diameter of 7 or 8 inches. Except for details of construction adopted to insure the sealing of the dip pipes in ammoniacal liquor the hydraulic main remains much the same as in the early works.

The amount of apparatus between the hydraulic main and the holder has been greatly increased from that in the original plants, in order that the removal of tar, the cooling of the gas and the removal of ammonia and of the sulphur compounds may all be efficiently effected.

In the United States the first piece of this apparatus is often a primary condenser, or cooling vessel, employing air as the cooling medium. Either following this condenser or being itself first in the series is an exhaustor or gas pump, which relieves the retorts of the pressure thrown by the holders and the friction developed as the gas passes through the apparatus between the exhaustor and the holder. From the exhaustor the gas passes into a frictional tar extractor, then to the secondary condensers, which are usually water cooled, and then to the washers or scrubbers for the removal of ammonia by solution in water, a washer being a vessel in which the gas is caused to pass through water in small bubbles, while a scrubber is one in which the gas passes in thin streams over surfaces kept wet with water. Leaving the scrubbers the gas goes to the purifiers, where it is freed from sulphuretted hydrogen by means of the chemical affinity between this substance and the oxide of iron which forms the active portion of the purifying material customarily used. After passing the purifiers the gas is measured by large wet meters and then passes to the holders, which, **except in the smallest plants**, are made with more than one lift and for large plants vary in capacity from 1,000,000 cubic feet to the 15,000,000 cubic feet of the largest holder in the world, that at the works of the Astoria (L. I.) Light, Heat and Power Company.

In some of the larger works rotary scrubbers for the removal of cyanogen and naphthalene are also provided.

The change from the simple plant described in Accum's Treatise to the more complete modern one was made gradually as knowledge was gained concerning the principles involved in the distillation of coal and the subsequent treatment of the

volatile products of such distillation. These principles are treated of later.

About 1850 clay retorts began to replace iron ones because of their ability to withstand a much higher temperature, and so make possible a much larger production of gas from a given quantity of coal. The temperature to which the retorts could be heated was increased and economy of fuel obtained by improvements in the design of the furnaces and in the method of setting the retorts. The greatest advance, however, in securing both intensity of heat and economy of fuel came with the introduction of generator firing and the preheating of the air used for combustion by means of the heat contained in the waste gases passing to the chimney. While one of the earliest experiments with gaseous firing for heating retorts was made in 1862 when a Siemens regenerative furnace was used for the purpose at one of the gas works in London, this method of heating was developed on the continent of Europe. The Siemens furnace was too elaborate for general use, but simpler generators and recuperators were soon devised and by 1874 had been adopted in about twenty works. After that time the progress was rapid on the Continent, but up to 1878 there was practically no gaseous firing in either England or the United States. In that year Dieterich furnaces were installed in one of the gas works in Baltimore and experiments, apparently not very successful, were made in several places with other furnaces, but success was obtained in the early eighties and after 1885 the use of generator furnaces and recuperators became general in the larger coal gas plants.

The exhauster, first introduced in 1841, came into general use at the same time as clay retorts. Its use is required because a high pressure on the hydraulic main coupled with the bubbling of the gas through the hydraulic seal on the dip pipes produces in the retorts great fluctuations in pressure and a consequent pulsation of the gas passing off from the coal, which increases very greatly the extent of its contact with the hot walls of the retorts and the destructive breaking down of valuable hydrocarbons by reason of this contact.

The change from the condensing coil placed in the gas holder tank to the form consisting of vertical pipes connected at the top

in pairs by return bends and at the bottom into a cast iron box with suitable partitions came before 1841. This form, while still commonly used in Great Britain, has been superseded in the United States by condensers in which the gas passes through an enclosed space traversed by tubes or pipes, the cooling medium being either water or air flowing through these tubes.

It is uncertain when washers and scrubbers were first introduced for the purpose of absorbing ammonia. Washers, apparently placed ahead of the condensers, were used at some works before 1841, but they were tar extractors rather than ammonia extractors. By 1853 tower scrubbers filled with coke were being used but also seem to have been intended more for the removal of tar than for that of ammonia. By 1868, however, the use of tower scrubbers for the removal of ammonia from the gas before it entered the purifiers seems to have been thoroughly established. Rotary scrubbers were introduced shortly after 1880 and have been adopted in the larger plants.

The change from wet to dry methods for the removal of sulphuretted hydrogen and other sulphur compounds, advocated as early as 1817, had not become general in 1841, but the use of dry lime was generally adopted soon after that year and from 1850 on the use of oxide of iron as a purifying material became quite common and in recent years it has been almost the only material employed for this purpose.

The use of station meters began soon after 1815.

The increase in the amount of gas sold and the difficulty of securing ground space in the crowded neighborhoods in which the early gas works were built gradually led to the use of holders of more than one lift and the capabilities of the older methods of guiding holders, that is of providing against their being upset, were soon outgrown. At first holders were guided either by the sliding along a central post of an open pipe with its lower end sealed in water or by means of chains attached at different points around the circumference of the crown and led over grooved wheels to be fastened to a single weight which descended as the holder was raised. Later the guiding was by means of wheels or rollers fastened at points equally distant around the outer edge of the crown and the bottom curb and working against rails or plates attached to the tank wall and to

columns, each composed at first either of a single cast iron cylinder, or in some cases of groups of cast iron columns joined together by struts, and later of a single wrought iron cylinder, the columns whatever their form of construction being joined at the top by means of wrought iron girders. The latest style of guide framing, which came in use with the adoption of holders of more than two lifts, consists of structural steel columns joined to each other by several series of horizontal struts and diagonal ties in such a way that the whole frame may be considered as forming a rigid cylindrical cantilever.

At about the same time that the modern system of guide framing was adopted the use of steel tanks built largely above ground in place of the brick tanks built below the level of the ground also began to become general in the United States.

Until recently the comparatively small retorts employed in gas works formed the sole source of coal gas, but now the by-product, or retort, coke oven used in the manufacture of coke also affords a supply of such gas for illuminating purposes. When first introduced all the gas produced by these ovens was consumed in the plant itself, but shortly after 1896 the sale of surplus gas for illuminating and heating purposes was begun in Glassport, Pa., and in 1899 this sale on a large scale was entered into by the New England Gas and Coke Company with a plant at Everett, Mass., supplying gas to Boston and its suburbs. Since that time other plants have entered this field until there are now eleven coke oven plants selling illuminating gas in the United States.

When the surplus gas is to be sold two separate sets of hydraulic mains and condensing and scrubbing apparatus are provided, one handling the rich gas made during the early, and the other the poorer gas made during the latter part of the charge. The rich gas is distributed, while the poorer gas, after being freed from ammonia, tar and benzol, is used for heating the ovens. In one or two plants the ovens are heated with producer gas made from part of the coke and all the coal gas is sold.

Apart from the use of retort ovens, instead of retorts, the treatment in a coke oven plant of the gas which is to be sold does not differ materially from that in an ordinary coal gas plant.

The advantages claimed for coke ovens as producers of coal

gas are low labor costs, because of the large weights of coal used in one charge, and the production of a quality of coke which in many localities commands a better market than does ordinary gas coke.

While in Europe the carbonization of coal furnished up to about 1894 practically the sole source of illuminating gas and is still by far the largest source of such gas, in the United States it is second in this field to carburetted water gas. The latter gas is produced by mixing with non-luminous water gas a sufficient amount of oil gas to give the mixture the desired illuminating value.

The decomposition of steam by means of highly heated carbon, with the formation of water gas, was known before the coming into use of coal gas and was experimented upon by Fontana in 1780. After the introduction of coal gas efforts to carburet water gas were begun and in 1847 a patent was taken out in England by Stephen White for the production of a combined coal and water gas. The process covered by this patent was widely discussed by gas engineers of that time and was favorably regarded by some of them, but it proved to be incapable of control and therefore to give very variable results and was not a commercial success. Other processes for the production of carburetted water gas were presented but none of them were successful until in the early seventies T. S. C. Lowe devised in this country the apparatus which, although greatly modified and much improved by other men, still bears his name. The success of this apparatus is due to the principle, first employed in it, of the internal heating of the vessels required for the manufacture of the oil gas needed to carburet water gas, by the combustion in them of the combustible portion of the producer gas formed while the fuel in the water gas generator is being brought up to the temperature necessary for the decomposition of steam.

The Lowe apparatus, in which the water gas and oil gas are made practically in one operation, while the conditions suitable for the manufacture of each can be separately obtained and controlled, in connection with the supply of cheap and suitable carburetting materials afforded by the large production of petroleum and its distillates, made the manufacture of carburetted water gas commercially practicable and economical in the United States

and after the installation of the first apparatus in Pennsylvania in 1873 it was rapidly adopted until at the present time it furnishes slightly more than two-thirds of the total amount of illuminating gas made and sold in this country.

The generating apparatus employed in the manufacture of this gas consists of three suitably connected cylindrical vessels constructed of steel plates and lined with fire-clay blocks. The first vessel, called the generator, contains the fuel and furnishes both the producer gas and the water gas required. The other two vessels, in which the oil gas is made, are called respectively the carburetter and superheater and are filled with fire-brick piled in rows from 2 to 3 inches apart, the rows in one tier being at right angles to those in the tiers next above and below. The necessary blast, steam and oil connections are provided and at the top of the superheater there is a take-off pipe with its lower end sealed in water in an auxiliary vessel and having an opening to the atmosphere that can be closed by a self-sealing lid.

A fire having been started in the generator it is gradually filled with coal or coke and this fuel is brought up to a state of incandescence by air blown in under pressure. Because of the deep fuel bed producer gas is formed, the combustion of which in the carburetter and superheater heats the checker brick in these vessels to the temperature required for the gasification of oil. When the proper temperature has been reached in all three vessels the blast is shut off, and the opening into the air from the take-off on the superheater is closed. Steam is admitted to the generator and passing through the fire is decomposed by the combination of its oxygen with the hot carbon and the gas thus formed, consisting principally of carbon monoxide and hydrogen, passes to the carburetter. Oil sprayed in at the top of this vessel is vaporized by the heat and the vapors travel with the water gas through the carburetter and superheater, being converted during this travel into a permanent oil gas. The carburetted water gas thus produced must be cooled and purified as in the case of coal gas except that since it contains practically no ammonia it is not necessary to pass it through apparatus for the removal of that substance.

In the larger gas works the manufacture of both coal and carburetted water gas in conjunction is advantageous. The fluctuations in demand and the seasonal peak requirements can

be cared for much more economically with a carburetted water gas plant than with a coal gas one, because of the smaller investment required by the former for a given generating capacity and the greater ease and economy with which it can be put into and taken out of action. In many cases it has been found that even when the cost of carburetted water gas is greater, the cost of a properly proportioned mixture of the two will be less than the average cost of coal gas alone.

A combination plant has also the advantage of giving the company possessing it a better control of the market for coke, the main residual of coal gas manufacture, and placing it in a position to take advantage of fluctuations in the prices of coal and of petroleum because of its ability to vary the amount of gas made from either of these raw materials. Owing to these advantages of the combination plant almost all of the companies in the United States manufacturing more than 50,000,000 cubic feet of gas per year make both coal gas and carburetted water gas.

For many years gas had been made by the distillation, in retorts, of petroleum and other hydrocarbon oils, such as the Scotch shale oils, but this gas was used only for such special purposes as the lighting of railway cars or the enrichment of coal gas, the amount so used forming a small proportion of the total amount of gas distributed. In California, however, the high price of all carbonaceous materials except petroleum led about 1900 to experiments which resulted in the development of a process by means of which is made, from crude petroleum, or one of its heavier distillates, as the sole raw material, a gas very similar in its composition to coal gas but very different from that produced by distilling oil in retorts.

The generating apparatus employed in making this gas is similar to that employed in the manufacture of carburetted water gas and consists of two cylindrical steel shells lined with fire-clay blocks and filled with checker brick. The heat required for the gasification of the oil is obtained by the combustion, by means of air supplied under pressure at suitable points, of oil sprayed in through burners placed around the circumference of the primary generator near its top. When the proper temperature has been reached the blast valves and the stack valve at the top

of the secondary generator are closed, the supply of oil through the heating burners is stopped and oil is sprayed in through other burners at the top of the primary generator and also at either the bottom or the top of the secondary generator. Because of the large amount of contact with the highly heated surfaces of the checker brick to which the oil vapors and gas first produced are exposed, from 20 to 25 pounds of carbon in the form of lampblack are set free per 1,000 cubic feet of gas made and the handling and disposal of the carbon, which is used as boiler fuel or as the generator fuel for the manufacture of carburetted water gas to be mixed with the oil gas and, in some places, is made into briquettes and sold for fuel purposes, is a problem connected with this process.

This method of manufacturing gas requires the use of from 10 to 14 gallons of oil per 1,000 cubic feet as compared with about 4 to 5 gallons of oil per 1,000 cubic feet of carburetted water gas and so is economical only where the cost of the extra 6 to 9 gallons of oil is less than that of the 30 to 50 pounds of coal which would be required for making the water gas portion of carburetted water gas.

Another source of illuminating gas which has been availed of to some extent both in the United States and in Germany is the distillation of wood.

Wood gas was made in the Philadelphia Gas Works continuously from 1854 to 1864 and during several years of this period formed about 5 per cent. of the total amount of gas made. It was also the only gas that could be manufactured in several southern cities during the Civil War. In these instances it was made as a substitute for coal gas, the wood being distilled in retorts similar to those used for distilling coal.

At the works of the Mutual Gas Light Company in New York City wood gas was made from 1879 to 1884 as a substitute for water gas. The wood was distilled in L-shaped retorts so charged that gas given off in one part of the retort passed through a mass of heated charcoal in another part. This produced a non-luminous gas which was carburetted with oil gas. A similar retort and method of operation is used in the Riché process recently patented in France, which, however, is claimed to produce gas of a fair illuminating value.

At the present time wood gas is being distributed in a small town in Washington, but apart from special local conditions cannot be produced as cheaply as other gases.

As a result of a wide-spread belief that there was a market for a fuel gas of lower calorific value and cheaper cost than ordinary illuminating gas, attempts were made, between the years 1880 and 1896, in twenty-seven different towns in the United States to distribute either blue water gas or water gas partially enriched with oil gas to give it greater calorific value. The calorific value of the gas so distributed ranged from about 300 B.t.u. per cubic foot for the blue water gas to as high as 450 B.t.u. for the partially enriched gas. Many of these attempts were made after the introduction of incandescent gas lights so that the gas could be used, and its use was advocated, for lighting as well as for fuel purposes, but in no instance was the effort to sell such a gas commercially successful and the companies undertaking it soon went out of business or turned to the manufacture of illuminating gas. This result was reached even in the few instances where this fuel gas, being the only gas supplied in the locality, did not have to compete with any other form of gas.

These attempts to distribute fuel gas of a comparatively low calorific value failed because the cost of a given number of heat units could not be made sufficiently lower than that of the same number derived from a gas of a higher heating and illuminating value to counterbalance the disadvantages of having to consume larger quantities of gas and take a much longer time to do the same amount of work.

No attempt to distribute gas of low calorific value has been made in the United States since 1897, but there is in England a company which was organized about six or seven years ago for the purpose of supplying to a populous manufacturing district "Mond gas" for use by large consumers for power and fuel purposes. "Mond gas" is a producer gas made by passing through a bed of incandescent fuel air mixed with as much steam as it is possible to use without reducing the temperature of the fire below the point at which the decomposition of the steam with the formation of water gas will take place. It contains about 40 per cent. of combustible matter mixed with a total of 60 per cent. of nitrogen and carbon dioxide and has a calorific

value of about 156 B.t.u. per cubic foot. The use of the large amount of steam leads to the formation of large quantities of ammonia and the recovery and sale as a residual of this ammonia is one of the principal features of the process, which can only be used on a large scale, and it was thought that the recovery of the ammonia and the large scale working would make it possible to sell the gas at a price at which it would be attractive to users of fuel and at the same time pay a good return on the investment. As late as two years ago, however, the annual report of the company showed that the operating expenses had been barely met and that nothing was being earned upon the investment. The low cost of manufacture and the comparatively small investment in manufacturing apparatus seem to make it impossible to meet the relatively larger distribution costs and investment and still compete with isolated plants.

Analyses of some of the various kinds of gases mentioned above are given in the appendix.

The problem of the destructive distillation of carbonaceous bodies for the production of gas for illuminating and heating purposes has two distinct divisions, the first being the proper application of heat to the material in order to secure the greatest possible quantity of gaseous products of good quality and the second being the proper treatment of the volatile portions of the products of distillation in order to conserve in the gas the greatest possible amount of light and heat giving bodies.

The determination of what constitutes the best possible heat treatment to apply to the raw material is rendered difficult by the complex nature of the reactions which take place when coal or any other material consisting largely of carbon and hydrogen is heated to a high temperature without any access of air.

A clear knowledge of the character of, and the effect of heat upon, the substance called hydrocarbons is requisite for the successful solution of the problem. The hydrocarbons with which the manufacturer of coal gas is concerned belong to five groups, each group consisting of a number of substances which resemble each other in composition but have varying densities and boiling points. These groups are the paraffins with a composition represented by the formula C_nH_{2n+2} ; the olefins with a formula of C_nH_{2n} ; the acetylenes with a formula of C_nH_{2n-2} ; the benzene

series with a formula of C_nH_{2n-6} , and naphthalene. In the paraffin group the affinities of the carbon atoms are fully met by the hydrogen atoms and consequently they are known as saturated hydrocarbons and are more inert than the members of the other groups in which the affinity of the carbon is not so fully satisfied by the hydrogen contained in them. In each group the bodies containing the smaller number of carbon atoms in the molecule have the lower densities and boiling points.

The lower members of the paraffin, olefin and acetylene series are all gases, while the higher members of these series and all of the benzene series are liquids, and naphthalene is a solid, at ordinary temperatures and pressures. Certain amounts of the vapors given off from these liquids and from naphthalene can be carried, however, by a gas under ordinary conditions.

The exposure of hydrocarbons to heat produces changes in composition which in general consist of a splitting off of hydrogen atoms and result in the formation of hydrogen and hydrocarbons simpler than the ones acted upon. The exact nature of these changes depends, however, upon the character of the hydrocarbons and the nature and intensity of the heat to which they are exposed.

It is probable that the first products of the heat action are complex hydrocarbons, largely paraffins of high density and boiling point, and that, during their passage through the retort, these by further exposure to heat are broken down into hydrogen and simpler hydrocarbons. The primary products are either liquids or vapors at ordinary temperatures and consequently little gas would be formed if they were permitted to remain in their original condition. On the other hand excessive exposure to heat, and especially to contact with highly heated surfaces, produces secondary reactions resulting finally in the formation of a gas consisting largely of hydrogen through which are diffused hydrocarbon vapors, most of which will be condensed at temperatures and pressures frequently met with during the distribution of gas, and the setting free of carbon which causes much trouble in the generating apparatus. The problem, therefore, is so to adjust the conditions under which the secondary reactions occur as to secure the proper amount of breaking down while avoiding anything in excess of this amount.

Starting with a given amount of carbon and hydrogen in the

raw material the heat treatment to which the material should be subjected to obtain any desired character of gas depends upon the following principles: Radiant heat tends to split up complex paraffins into simpler paraffins and olefins and if the exposure to such heat is continued for a sufficient length of time at a sufficiently high temperature the final result is the decomposition of the complex bodies into methane, the lowest of the paraffin series which is not affected by radiant heat, and several of the lower members of the olefin series. On the other hand, heat communicated by surface contact tends to produce from a paraffin, hydrogen and hydrocarbons of the benzene group. In each case the action is accelerated and intensified by increase in temperature of the radiant, or contact, surfaces.

The mixture of olefins and methane has a larger volume and a higher illuminating value than the original paraffins, but is exceeded in both respects by the mixture of hydrogen and benzene vapor. The latter mixture will not contain, however, sufficient hydrogen or other permanent gas to carry the vapor at the ordinary temperatures unless some of the carbon originally present is set free and lost as far as the resulting gas is concerned.

Therefore when a hydrocarbon gas is to be used alone as in the case of the manufacture of coal gas, or is even to be used to enrich another hydrocarbon gas, and illuminating or calorific value is of importance, the gas and vapors escaping from the coal or other material being distilled should be exposed to the action of radiant heat at not too high a temperature but should be protected from contact with highly heated surfaces. When, as in the case of the manufacture of carburetted water gas, the hydrocarbon gas is to be used for the enrichment of a mixture of simple gases, which can carry comparatively large amounts of hydrocarbon vapors, contact with heated surfaces produces good results, especially when the hydrocarbons are exposed to such heat action while being carried by the simple gas, since the presence of that gas arrests the action before it reaches the point at which carbon is set free.

There is no such protecting and carrying gas present in the manufacture of oil gas as carried on along the Pacific Coast and consequently in this process the contact of the hydrocarbons with highly heated surfaces results in the setting free of sufficient

carbon to form the hydrogen required to protect the remaining methane and uncombined olefins and carry the vapors of the benzene group. The setting free of a certain amount of carbon and its recovery in the form of lampblack is therefore an inherent feature of this process whatever the character of the oil used as the raw material.

Even when no importance is attached to illuminating value the calorific value of the gas derived from a given quantity of material will be greater the smaller the amount of carbon set free and since methane, one of the most important constituents of coal gas from the calorific standpoint, is not affected by radiant heat but is decomposed by contact with hot surfaces, especially at temperatures above 600°C . (1112°F .) it is still important, when making a hydrocarbon gas by itself, to subject the gas only to the action of radiant heat and avoid as far as possible contact with highly heated surfaces.

Practice in carbonization in gas works had gradually come to agree with these principles even before they were thoroughly understood. Early in the manufacture of coal gas it was recognized that better results as far as the production of gas was concerned were obtained when coal was carbonized in thin layers and at comparatively high temperatures. In working along these lines, however, the portion of the walls of the retort above the charge of coal afforded a large amount of hot surface in proportion to the amount of gas being made and as the temperature at which carbonization was carried on was increased much trouble was experienced from the free carbon produced by the action of this heated surface. To avoid this trouble it was found necessary to increase the weight of the charges placed in a given size of retort and lengthen the time during which the carbonization of the charge lasted until finally as a result of experience with intermittently charged vertical retorts it has become the practice to fill horizontal retorts as completely as possible and make the duration of the period of carbonization sufficiently long to drive all of the gas out of these large charges. The gas, however, is still exposed to contact with hot coke during at least portions of the long period of carbonization and while the use of these large charges has increased both the quantity and quality of the gas produced from a given weight of coal

the results obtained from them are probably not as good as could be obtained by the carbonization of coal in smaller charges with the proper exposure of the gas to radiant heat of a low intensity. The use of large charges reduces labor costs, but it is questionable whether a point is not soon reached at which any saving in this direction is more than overcome by a loss in the quantity and quality of the gas made, and it is possible that experiments with horizontal retorts, of much smaller dimensions than those now used, completely filled with coal would show sufficiently better gas results to compensate for increased labor costs, but the continuously operated vertical retort, into which coal is introduced in small amounts at intervals of a few minutes and in which it is possible to regulate very closely the extent to which the gas is subjected to radiant heat, seems to offer the best means of solving the problem of securing the proper heat treatment during the distillation of coal.

Even when the best conditions of heat treatment are attained the gas issuing from the retorts or other generating apparatus is a mechanical mixture, the principal constituents of which are hydrogen, methane and more complex hydrocarbons, some of the latter being vapors, with smaller amounts of carbon dioxide and various impurities, and the second portion of the problem of the manufacture of a hydrocarbon gas is to so treat this mixture that, when the cooling from the high temperature at which it leaves the retort to atmospheric temperatures and the removal of the impurities has been completed, it will retain as large an amount of these hydrocarbon vapors as it is possible to carry to the consumer. The problem of doing this is rendered difficult by the fact that being the vapors of liquids mutually soluble in each other the combined tension of these vapors is much below the sum of the vapor tensions of each and when one of high boiling point is condensed into the liquid form it will carry down with it some of the others whose boiling points are such that, if left to themselves, they could be retained in the gas. It is, therefore, necessary to effect the cooling of the gas in such a way that the condensing out of the vapors which it is impossible to retain in the gas shall be accompanied by as small a loss as possible of those vapors which can be retained. The problem is further complicated by the fact that the employment of the

best method of achieving this result is apt with coal gas to lead to trouble in the distribution system from the saturation of the gas with naphthalene, a heavy vapor which condenses directly to the solid form, unaccompanied by other vapors which condensing simultaneously into liquids would dissolve the naphthalene. It is therefore necessary to compromise and suffer a small loss in one direction in order to avoid trouble in another. On the whole, however, the best treatment consists in the removal of the tar, formed by the condensation of the heavier vapors, while the gas is still at a temperature of above 100° F., and a subsequent gradual cooling of the gas to atmospheric temperatures, the condensed liquids formed at different temperatures being removed before any great further drop in temperature has taken place.

When the gas has reached atmospheric temperature it is necessary to remove the ammonia which has not been absorbed by the condensation during the cooling of the gas, of the aqueous vapor which it contained when it left the hydraulic main. This removal is effected by the use of water. After the removal of ammonia the gas must be treated for the removal of sulphuretted hydrogen and the reduction of the amount of other sulphur compounds if this latter amount is excessive. The purifying material commonly used in the United States for the purpose has as its active agent hydrated sesqui-oxide of iron. This combines with sulphuretted hydrogen to form sulphide of iron, which upon exposure to the atmosphere is oxidized with the re-formation of the hydrated ferric oxide and the setting free of sulphur. The efficiency of this portion of the process increases with rise in temperature and in many gas works the gas is heated to a temperature of about 100° F. at the inlet of the purifiers.

The purifiers complete the chemical and physical treatment of the gas, which leaves them fit for distribution, but for economical reasons it is measured and then passed into storage holders before being sent out.

In the early years of the industry the treatment given the raw material and the resulting volatile products was largely governed by rule-of-thumb, but in recent years all the manufacturing steps have been studied scientifically and great progress has been made both in knowledge as to principles and in the practical application of this knowledge. Much remains still to

be investigated and there is no reason to doubt that the processes now employed will be improved as time goes on and that the debt of humanity to the gas industry, accumulated during the first century of its existence, will be largely increased during the second.

APPENDIX.

	Coal gas.	Carburetted water gas.	Water gas.	Crude oil gas.	Oak wood gas.
Candle-power	16.7	24.5	—	19.7	26.0
Specific gravity	0.430	0.625	0.53	0.482	0.580
B. t. u. per cubic foot					
Observed	—	626.8	316.8	679.9	—
Calculated.....	659.7	626.7	302.2	—	—

ANALYSIS.

		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Illuminants—unfixed ..	C_2H_6	0.80	0.6	—	7.01	6.46
fixed	C_nH_m	4.00	11.4	—		
Carbon monoxide	CO	8.20	31.3	42.8	9.21	26.11
Hydrogen	H_2	45.20	36.1	50.3	39.78	30.44
Marsh gas.....	CH_4	37.40	12.6	0.4	34.64	33.12
Ethane	C_2H_6	0.70	2.3	—	—	—
Carbon dioxide	CO_2	1.60	3.0	3.0	2.62	0.48
Oxygen	O_2	0.30	0.4	0.4	0.16	—
Nitrogen	N_2	1.80	2.3	3.1	6.58	3.39
		100.00	100.0	100.0	100.00	100.00

Peat-gas Plant. ANON. (*Elect. Rev.*, lxix, 1017.)—This is a producer-gas plant, made by Messrs. Crossley Brothers, installed in a factory at Portadown, Ireland, for power purposes. It consists of two producers, each of 200-horsepower capacity, with a coke scrubber, centrifugal tar extractor, sawdust scrubber (or filter), exhaustor fan, and expansion box. It is worked by suction produced by the high-speed fan exhaustor, which also delivers the gas to a gas-holder. The feeding hoppers on the producers are larger than those usual with coal fuel, but the gas is similar in constitution to suction gas from Welsh anthracite, though with less hydrogen; its thermal value is 140 B.t.u.'s per cubic foot. The peat has about 26 per cent. moisture as charged into the producer, but in exceptionally dry seasons it is as low as 19 per cent. With an average load of 275 horsepower the fuel cost—allowing 35 s. per week for tar sold—is £4 5 s. (\$21), as against £13 16 s. 3 d. (\$69) per week for anthracite, which was used in the Mond plant replaced by this peat-gas installation. The tar from the peat amounts to about 5 per cent. of the weight of fuel used. Analysis shows it to contain a small amount of paraffin wax and a considerable proportion of heavy oils distilling above 270° C.