# GASEOUS FUEL

B. H. Thwaite

# GASEOUS FUEL

## INCLUDING WATER GAS

*ITS PRODUCTION AND APPLICATION*

### A Lecture

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BY

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"LIQUID FUEL, ITS ADVANTAGES FOR STEAM RAISING PURPOSES,"
"MILL ENGINES," ETC., ETC.

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Dedicated

TO

MY FRIEND

M. H. LE CHATELIER

INGENIEUR AU CORPS DES MINES

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# GASEOUS FUEL:

## *ITS PRODUCTION AND APPLICATION.*

### THE SMOKE POLLUTION OF THE ATMOSPHERE.

ALTHOUGH the mighty prime mover, steam, in its wonderful applications, has been of incalculable value in adding to the well-being and happiness of man, the black pall of smoke that usually accompanies our industrial occupations has desecrated and destroyed, in too many instances, the beautiful work of God, who never intended that grimy walls, streets, and lanes, and a smoke-infested sky, should be the accompaniment of our lives. But He has given us —if we only cherished and preserved the gift—the flowers, the blue sky of heaven, the eye-refreshing green of the fields, and the life-endowing and recuperative beams of the solar light.

What though our art culture and refined civilization prompts and executes dreams of loveliness in stone, if the sombre, depressing, and pall-like hue of smoke hides the lines of beauty in pilaster and fluted column.

What are our hives of industry but blots of unloveliness on England's fair landscape? To England Nature has indeed been bountiful. Besides the pastoral scenery, if undefiled, of unsurpassing charm, there is below the surface the results of actual organic vegetable life, in the form of coal, oil, and gas, of former periods of the earth's history. If these fuel resources were properly consumed, they would not only be free from the black and objectionable smoke, but they would, in the condition of carbon dioxide, be absorbed by the plant and vegetable life, and be returned to us either as solid food or as a useful structural agent in the condition as timber, wood, or bark.

The black smoke or carbon, in finely divided condition, and the gaseous carbon monoxide, also the result of the imperfect combustion or oxidation of coal, is not absorbed by the plants, so that the result of imperfect methods of fuel combustion is an incalculable evil, blackening our livelong days and depriving the animal and vegetable world of sustenance.*

* Have fogs any perceptible effect upon the rate of mortality? There is no doubt that continued, dense, smoke fogs influence very decidedly the rate of mortality. Mr. E. Hart stated before the Select Committee of the House of Lords on Smoke Abatement and Prevention, that sat in 1887, that in a fortnight of heavy fog which occurred in London in 1886 the mortality rose to 40 per 1000, a rate equal to that of the great cholera year. In 1880, the last few days of January and the first few of February were signalized by a particularly dense fog, and during the week it lasted the number of deaths was 2000 above the average. A glance at the Registrar-General's returns for 1873 show very plainly the influence that foggy weather has upon the death-rate. From the 8th to the 12th of December in that year an extremely dense fog prevailed over London. The mortality in the metropolis for the week ending December 6 was 23 persons per 1000; in the week following, during which the fog occurred, the rate rose to 27 per 1000; and in the week after that, when its full effects could be estimated, the deaths were found to number 38 in the 1000. In the same three weeks the deaths from consumption and diseases of the respiratory organs were respectively 520, 764, and 1112. This fog occurred during the Cattle Show week, and killed a great many valuable animals that had been sent for exhibition.

Nature, in her accumulations of carbon and hydrocarbons in the form of coal, oil, &c., has enabled our people to be fed with food from other far off climes. In every way this wonderful gift of Nature to man might be of advantage to his well-being; but, from our neglect or ignorance of simple scientific facts, these fuel treasures have been so imperfectly utilized as to neutralize their life-sustaining values, surrounding our lives with the gloom of artificial clouds, and subjecting it to a smoke-laden atmosphere which hardly permits the passage of the invigorating rays of the sun.

Science is never more beneficial than when its action brings the agents and processes involved in industry into harmony with the natural laws. And if by scientific applications we can remove the stigma at present attached to the use of our carbonaceous treasures, our land and people would be relieved from a great evil that overshadows all others in its production of misery, ay, and of death, and our industrial centres would then be as bright as unsullied day.

Before the introduction of coal, in the time of Edward I., wood and charcoal formed the combustible and heat-giving agent, both of which, from their chemical constitution, are not so difficult to completely and smokelessly consume. The introduction of coal brought with it the difficulty of effective combustion, for, although the artificers of London recognized its high heat value, the smoke produced was soon followed by an urgent protest, as our ancestors loved pure air. Edward I. gave effect to the protest in 1307 by prohibiting the use of sea coal.

## COMBUSTION OF FUEL.

The combustion of fuel is essentially a process of oxidation. The principal agents, carbon and hydrogen, constituting the combustible elements of fuel, are both oxidized.

To perfectly effect this chemical action of oxidation the best conditions are those in which both the agents are in a gaseous condition, so that not only can the equivalent volumes of the two agents be brought together, but the gaseous condition allows the perfect admixture of the two agents. If one agent, say coal, is solid and the other is gas or air, they cannot, from physical causes, be brought into proper and equivalent contact except there is an enormous excess of the oxygen agent, air, over that really or equivalently necessary.

So perfect and colourless is combustion when effected under conditions that ensure a perfect volumetric admixture of the two agents in similar gaseous condition, that the resultant products of combustion are colourless, and it may be flameless, a fact first demonstrated by the masterly series of experiments initiated by one of our illustrious dead, Sir Humphrey Davy. This flameless and colourless or invisible combustion is instanced in the incandescent gas lights, such as the Welsbach and Clamond, and partially so by the burner we owe to that great heat experimentalist, Baron Bunsen. Whether combustion is flameless or not, given that it is perfect, the sum of the heat units evolved is the same. In the instance of the colourless or invisible combustion, the oxidation of the combustible is effected instanter, or at a periodic rate too great to leave a sensible impression on the optic nerve.

The oxidation of hydrogen with carbon, if effected more slowly, permits the eye to observe the incandescence of the carbon particles or atoms as they escape from the zone of the oxidation of the hydrogen prior to their oxidation to $CO_2$, a colourless gas.

The phenomena of oxidation of the ordinary combustible may be expressed as follows:—

The hydrogen having a greater affinity for the oxygen than has the carbon, it is first oxidized to water vapour, thus $H_2 + O = H_2O$.

The heat resulting from this oxidation by the hydrogen raises the carbon, which separates from combination with the hydrogen, into a condition or temperature of incandescence. In this condition the remaining oxygen combines with the carbon to form one of two compound gases. If there is sufficient oxygen the result will be carbonic acid, or carbon dioxide; if there is an insufficient volume of oxygen the carbon will be oxidized to carbonic oxide or carbon monoxide (CO). The respective reactions are as follows: $C + O_2 = CO_2$ and $C + O = CO$.

If the carbon, when separating from the hydrogen on the oxidation of the latter, is allowed to cool below a temperature of visible incandescence, the oxygen cannot combine to oxidize the solid carbon atoms to $CO_2$, and the carbon atoms are consequently deposited as soot or smoke.

The oxygen of the atmosphere is enveloped or accompanied with a volume of a diluent and inert gas nitrogen. This gas moderates the intense energy, or *vis viva,* of the oxygen molecules; but for this gas, all forms of animal and vegetable life would be so enormously accelerated that the dynamic elements or structures of both forms of life would be soon worn out, and life would become extinct from super or excessive action.

This diluent gas, nitrogen, plays an important part in the action of oxidation or combustion, and is no unimportant factor in the difficulty in obtaining any approach to proper combustion of fuel in a solid condition. Assuming the fuel is in a solid condition, the lumps of coal simply allow the air to pass through their interstices, the lower or sub-layer of fuel being in flame. The carbonic oxide due to partial combustion, along with the water vapour due to the oxidation of hydrogen and the inert gas nitrogen, flow through the interstices of the fuel along with the volume of air intended to oxidize the superincumbent layers of fuel. The result is, that the incombustible gases and nitrogen prevent the contact of the oxygen of the air with all the carbon, the hydrogen attracting what oxygen there is available. The carbon excluded or separated, is either only partially oxidized to the colourless carbonic oxide, or is unoxidised and flows to the chimney in a solid but finely divided condition, as smoke, along with the nitrogen, watery vapour, and carbonic acid, or carbon dioxide ($CO_2$).

Although with an excess of air it is possible, when coke or anthracite is used in a solid condition, to produce a combustion that shall have colourless products; when coal is used the conditions are entirely changed. Coal contains varying percentages of rich hydro-carbons that are highly volatile, and at a temperature of from, say, 500 to 900 degrees Fahr., these hydro-carbon constituents are volatilized. Now, when a new supply of coal is added to the fuel in an incandescent condition, the temperature of volatilization is almost immediately attained, and the rich hydro-carbon gases are evolved, and, although there may be sufficient air to more or less completely oxidize the coal if freed from its rich hydro-carbons, nevertheless the supply is inadequate to oxidize these rich hydro-carbon gases, that constitute, in their ensemble, the ordinary coal gas.

Hence, each time the fresh fuel is charged, these rich and powerfully thermic gases escape to the chimney more or less incompletely oxidized or burnt.

Another disadvantage in solid fuel firing is the fact that if the slack coal is very small or dusty it is liable to be carried forward into the chimney flues. The method usually adopted to prevent this is to damp the dust slack, but the application of wet fuel involves the loss of heat due to the water which has to be evaporated, and represents so many heat units entirely lost.

As if to reproach us for a flagrant and inexcusable abuse of the wealth of solid fuel we possess, Nature has provided us with a wonderful example of the advantages of perfect fuel combustion by supplying vast subterraneous stores of natural gas.

This natural gas has, in the instance of its discovery and application in Pennsylvania, transformed a black and smoky region of manufacturing industry, into one almost as pure as that accompanying rural pursuits. This natural gas will be referred to more fully further on. We will now endeavour to ascertain some idea of the national financial loss by our wasteful methods of use of the national carbonaceous treasures.

## A NATIONAL WASTE.

If we take the average annual coal consumption of the United Kingdom between the years 1850 and 1890 at 75 millions of tons, and assume an actual calorific efficiency of 50 per cent. to have been obtained—and this figure is much above the mark—the net loss in the forty years will be 1400 millions of tons. If the value of the coals is taken at 5*s.* per ton, the net loss to the country will attain the colossal figure of 350 million pounds sterling, or nearly half the National Debt.

If the figures relating to the period of exhaustion of our coalfields by Mr. Price Williams are to be taken *au sérieux,* we are within a living periodic distance when coal by its scarcity will—when, perhaps, too late—force users to employ means of utilization that shall give them a near approach to the full thermic value of the fuel they use. It behoves us, therefore, from every reason, financial, hygienic, and patriotic, to at once apply ourselves to the work of popularizing means of effecting fuel economy in our industries and our homes.

## NATURAL GAS.

In the Aspheron Peninsula, known to fame as the Land of Eternal Fire,* gaseous fuel has issued from the earth in powerful streams, which have burnt and illumined the country for unknown centuries, and have, up to quite a recent date, been worshipped with reverence by a curious sect known as the Fire Worshippers, whose priests have watched through night and day unceasingly these wonderful streams of fire. The Chinese, pioneers in many of the arts and industries, have, as far back as 3000 years ago, conveyed the natural gas found in their salt mines to the surface by means of bamboo canes, and utilized the fuel for evaporating the salt brine. In the year 1658 a communication to the Royal Society by Mr. Shirley described some experiments with natural gas that issued from a well near Wigan, and in 1733 Sir James Lowther communicated to the same society particulars of a discovery of natural gas issuing from his coalpits at Whitehaven. This gas was conveyed by pipes to the surface, and it burnt vigorously with a flame six feet high, and continued to do so without intermission for two years. I suggested some two years ago in *Engineering*, that as this gas was the dangerous marsh gas, if coalfields were drilled to a sufficient depth at various and well-distributed locations, this deadly gas might be drawn from the substrata and

* *Vide* "Baku: The Petrolia of Europe," by Charles Marvin.

utilized, and thus remove the source of danger to the coal workers, and in a manner that might give a good return for the expenditure. This proposition has been carried out at the Hebburn Colliery, near Newcastle. A blower found in the workings has been utilized by connecting the source of gas exudation with the surface by means of six-inch pipes, and the gas has been utilized for firing steam boilers with great success, and a considerable saving, stated to be £3000 per annum, has been realized. Possibly this gas may be derived from the volatile hydro-carbons of the coal, which may have been driven off by inter-terrestrial heat, or it may be that, similar to the Pennsylvania coalfields, there is a substratum of oil rock and its accompanying strata of natural gas. Whatever the source, it will be accepted, *nemine contradicente,* that it would be a humane and probably economic action on the part of the great colliery owners if, by a series of well drillings, the deadly sting of these black hives of industry could be extracted.

Accompanying the great natural oil stores in Pennsylvania, natural gas has been known to exist for over a century; indeed, as far back as 1821, a little village in the New York States was lighted with natural gas. The oil drillers have almost invariably struck the gas wells when drilling for oil.

## THE CHEMISTRY OF NATURAL GAS.

It may be asked, What are the chemical characteristics of this natural gas, known by the name of marsh gas or deadly firedamp? Few miners will fail to recognize it. It is a light, carburetted hydrogen, one of the gaseous paraffines or methane, its principal formula being chiefly $CH_4$. The other constituents are shown in the following analysis by Dr. George Hay :—

VOLUMETRIC COMPOSITION.

| | | |
|---|---|---|
| Light carburetted hydrogen (marsh gas) $CH_4$ | 95·20 | per cent. |
| Heavy hydro-carbons (olefiant gas) . . | 0·50 | ,, |
| Carbonic oxide . . . . . . | 1·00 | ,, |
| Hydrogen . . . . . . . . | 2·00 | ,, |
| Oxygen . . . . . . . . . | 1·30 | ,, |
| | 100·00 | |

Specific gravity . . . 0·520

The gas is quite dry as it leaves the well. To form an explosive mixture, it requires 9 volumes of air to 1 of natural gas. The value of this natural gaseous fuel compared with that artificially formed is shown in the accompanying tables.

## THE ORIGIN OF NATURAL GASEOUS FUEL.

The theories set forth by various scientists explanatory of the origin and formation of natural gas are very varied, and this divergence demonstrates the absurdity of deductions on hypothetical bases.

No doubt the theory the author holds to be the most reasonable one in explaining the formation of rock oil, or petroleum, is also true, for natural gas—*ergo*, rock oil—is the result of the action of sea water on organic marine, animal, and vegetable life, that has, by volcanic and eruptive agencies, been upheaved, the sand of the oceanic beds forming, in their new position, storage spaces for the sea water and vegetable and animal accumulations. The salt has been deposited either in rock form or become condensed as brine.

The action of inter-terrestrial heat has gradually decomposed the organic matter into a hydro-carbon solution of varying character, as oil, and the more volatile gases, being, by the influence of heat, separated in a gaseous condition as natural gas, which, owing to the superincumbent and impermeable strata, has not been able to escape, but has been compressed in many instances to one-fortieth of its volume at atmospheric pressure.

All the oil rocks are of a sedimentary character, and many thousand feet in thickness, but divided into varying strata by impermeable shale strata. Salt deposits generally accompany oil-storing rocks.

Occasionally the immense compression of the natural gas forces it into neighbouring and surrounding strata for miles, but the latter stores are, as a rule, very shallow.

The geographic location of the oil and natural gas fields can hardly be defined. Stores of both oil and gas are found accompanying the salt deposits of China, Burmah, the Caucasus, Roumania, Pennsylvania, Western Ohio, Central Indiana, Venezuela, and Canada; and I am strongly of opinion that the British and European saltfields are no exception to the rule, and, had we the enterprising spirit of the Americans, prospectors would have drilled for oil and gas beneath the saltfields of Cheshire and the Cleveland district and those of Ireland. The salt strata are rarely at a greater depth than 500 feet, whereas the normal depth of the gas strata is about 2000 feet.

## METHOD OF DRILLING A NATURAL GAS WELL.

The site for the test well having been located, a lofty pyramidical wooden structure is erected some 72 feet high, and with a base measurement of 20 feet and a summit measurement of 3 feet.

The well is generally six inches in diameter, and is drilled by falling chisel-shaped steel tools suspended from a cable, which is raised by a steam winch; the tools are allowed to fall into the well from the height of four or five feet, the driller turning the drill as it falls, so that the hole is made circular; the drill and attached jars are made sufficiently heavy—about 1½ to 2¾ tons—to pierce the hardest rocks. The work of drilling, once started, is proceeded with night and day until the gas is struck.

Modern wells are lined in such a way that the gas can either be stored or drawn off for distribution at any time.

In the wells near Pittsburgh the drilling depth is about 1500 to 1800 feet; but in shallow and soon exhausted wells gas has been met with at a depth of 500 feet.

The cost of drilling a gas well varies according to the depth, from £700 to £1200.

One of the wells in Ohio evolves nearly thirteen million cubic feet per diem of 24 hours, at an initial pressure of 500 lbs. to the square inch. This pressure is reduced by specially designed regulators to a more safely workable limit. The gas evolved from this typical well per diem is thermically equivalent to 400 tons of coal. The annual production of natural gas in Western Pennsylvania is estimated to reach two hundred and forty thousands of millions of cubic feet, having a thermic value equivalent to 10,000,000 tons of coal.

In the Pittsburgh district there are six important Natural Gas companies, having a total of 107 wells, of which the Philadelphia Company owns 68, and from which it is estimated they delivered in 1886 no less than sixty thousand millions of cubic feet. Taking 1000 cubic feet as equivalent to $81\frac{32}{49}$ lbs. of coal, the heat value in weight of coals would be 2,500,000.

The total capital invested in natural gas undertakings in the United States is estimated at £10,000,000, a figure that may be justly described as a splendid monument to the enterprise of our Transatlantic cousins.

### DISTRIBUTION AND TRANSPORTATION.

At the end of 1886 it was estimated that 2300 miles of main distributing pipes had been laid. In Pittsburgh alone there was, at the date mentioned, some 500 miles of pipes, varying from 30 to 40 inches in diameter; wrought iron pipes being used for sizes up to 16-inch, and cast iron pipes for the larger diameters.

In the pioneer installations the leakage of the gas could not be prevented, owing to the enormous initial pressure, but by well-designed reducing pressure regulators the difficulty has been surmounted. The high initial pressure of the gas has the great advantage of allowing distribution to be effected over great distances, in some instances over 60 miles.

### APPLICATION OF NATURAL GAS.

Natural gas is utilized for almost every conceivable industry requiring the application of heat—glass-works, iron and steel works, oil stills, salt pans, brick kilns, and drying floors, raising steam, horticulture, and floriculture. It is only some four or five years since it was introduced to Pittsburgh in supplies of any importance, but to-day, in the words of Mr. Weeks, of Pittsburgh, than whom there is no one more interested or better versed in this wonderful agent, "it cooks the food of thirty thousand families; warms as many houses; it puddles the iron and rolls the steel; it melts the glass; it burns the pottery; it drills the wells, and pumps the oil, and refines it; it furnishes carbon for ink, for paint, and for electric lamps; it raises the steam in many industrial works; in a word, it is the fuel for domestic purposes, and for use in the arts whenever it can be obtained; and so much superior, that cities with coal at their very doors pipe the gas sixty or seventy miles for use in their houses and workshops." The experience of users of natural gaseous fuel has shown that the absolute control of the supply (although the chemical quality varies) of the gas allowed the staple industries to be produced with greater perfection, uniformity, and with reduced cost in fuel and labour. Steam with an even pressure could easily be maintained, and in warming houses and for floriculture and horticulture any required temperature is attainable.

It has promoted health and happiness and made cleanliness possible in the household. The lesson impressed on every user of natural gas leaves no doubt in his mind that gaseous fuel is immeasurably superior to the solid form. An American authority states that, as the feasibility of successfully manufacturing gaseous fuel is already an established fact, and its advantages are so great compared with coal, surely its manufacture should proceed at once in every locality where natural gas cannot be found in abundance.

Pittsburgh and Alleghany are incontestable examples of the wonderful metamorphosis on the atmosphere and general cleanliness of towns.

In wintry nights, when the aqueous vapour of the atmosphere is frozen, the region of the oil wells occasionally presents a most remarkable phenomenon. The reflection by the particles of ice suspended in the atmosphere of the roarers from the natural gas wells appear in meteor-like streaks of light of marvellous beauty.

## FUEL CALORIMETRY.

The extraordinary fuel resources of this country and the comparative cheapness of coal have been responsible for the treatment of the fuel value of different costs as a factor of no importance.

Investigation will, however, show that a knowledge of the thermic or heat value of a fuel is of the highest importance, and can be accurately measured by a simple process without any scientific skill.

Lavoisier, the brilliant French savant, may be said to have designed the first reliable instrument for the measurement of the heat value of fuel.

Favre and Silbermann, Berthelot and Lewis Thomson have designed calorimeters of varying degrees of efficiency, but one of the best instruments for practical use, now that by the Brin process oxygen can be cheaply and conveniently obtained, is that designed by my friend, Mr. William Thompson. F.R.S.Ed., of Manchester. By means of this instrument any steam user can ascertain the exact heat value of the fuel he proposes to contract for, and the test would be unerring in its reliability for all practical purposes. The coal giving the greatest number of heat units per unit of value being chosen, the next desideratum is the proper means of utilizing this fuel, and from the arguments already advanced I think it will be clearly seen that the only way to properly use the solid coal is to imitate Nature and convert the combustible fuel into a gaseous condition. This principle has been acknowledged to be the correct one by the greatest scientists.

## THE HISTORIC DEVELOPMENT OF THE PRODUCTION OF GASEOUS FUEL.

The practical application of the principle of the conversion of solid fuel into a gaseous condition was initiated by one of a group of three men, whose united labours have had more influence on the development of civilization and in procuring the greatest happiness for the greatest number than all the efforts of our heroes of war and statecraft. I allude to James Watt and his partner, that fine old type of the English gentleman, Matthew Boulton, and their once employé, Willie Murdoch. It may here be stated that these two latter famous men of Soho, Birmingham, deserve a special recognition from the enlightened townsmen of that famous industrial centre. This might be fittingly accomplished by the foundation of scholarships, bearing the names of Murdoch and Boulton, in the Midland Institute, as well as a memorial tablet or statue in the hall of that admirable institution.

The procedure of Murdoch's system consisted in simply heating the coal in a closed retort until the temperature of volatilization of the volatile hydro-carbons was attained. The rich hydro-carbon gases burnt with a highly luminous flame, and Murdoch's gas system became for an era the agent of artificial lighting. The coke or carbon is simply withdrawn from the retort, hence only a part of the thermic value of the coal is abstracted by Murdoch's system, with the result that the cost of production prevented the general extension of the application of the gas for heating purposes. About half a century ago Herr Bischof, of Magdeburg, introduced an apparatus for generating gas for fuel or heating purposes. This apparatus was said to have given excellent results, and it is surprising that the system did not have more extended application, although there were several systems of producing gaseous fuel at work before 1850. But the conversion of solid fuel, such as coal or coke, into a gaseous condition for heating purposes received an impetus from the labours of two members of the remarkable Siemens family, Frederick and Charles Wilhelm. The original specification of the patent for the furnace in which the great advantages of gaseous fuel were more fully realizable bears the name of Frederick. This furnace embodies the principle named by the inventors as regeneration, and is curiously the outcome of his brother Wilhelm's experiments in a development of the Rev. R. Stirling's famous regenerative engine, which was intended to obtain the greatest possible thermo-dynamic efficiency from an engine measured according to Sadi Carnot's law. Regeneration, or, by the more correct definition, recuperation, signifies that in this Siemens furnace the sensible heat of the waste gases is by a reversible cycle, utilized to heat the combustible gases and the air for combustion. By this means not only is a very much higher temperature attainable, but also the highest possible economy.

## ECONOMY OF GASEOUS FUEL APPLICATIONS.

The practical development of Frederick's invention is due to the late Sir William Siemens, who possessed the rare characteristic of great business talents and a cultured and inventive mind, and the advantages of a thorough knowledge of thermo-dynamic, thermo-chemical, and physical science. This masterly invention of the Siemens Brothers has revolutionized the art of manufacturing structural steel and glass: it has enabled the former structural agent to be produced by a mixture of scrap, wrought iron, and pig, or by a mixture of iron oxide and pig at a cost in fuel equal to from 9 to 10 cwts. per ton of steel ingots, whereas fuel used in the laborious puddling process, in which solid fuel firing is employed, per ton of wrought iron bars varies from 2 to 3 tons.

This Siemens gas-fired recuperative furnace allows the highest temperature to be used without producing a particle of smoke, and, with the exception of the white and almost colourless vapour, there need be no visible sign that one of our great national pursuits is being carried on.

### CHEMISTRY OF CARBONIC OXIDE GASEOUS FUEL.

The gaseous fuel required for these furnaces is produced as follows :—

Large chambers of brickwork, rectangular in plane shape and placed side by side, are erected with three vertical sides and an inclined one, the fuel resting on the latter, and into which it is charged by special feeding hoppers, arranged so as to prevent the escape of the gases during the feeding of the fuel.

The chemical action of gasification is in this gas generator as follows :—

The air, either blown or flowing by natural draught through the lowest layers of fuel, ignites them, and maintains an active combustion ; the resulting carbon dioxide, in ascending through the superincumbent fuel, is converted into carbonmonoxide by the reaction $CO_2 + C = 2CO$. This latter gas, or carbonmonoxide, along with the volatile hydro-carbons distilled from the upper fuel layers, ascends the vertical uptake, rising some twelve feet above the ground, passes for a short distance along a horizontal tube, in which the gases are condensed, and the tar is deposited. The cooled gases descend the downtake to the distributing flues, through which the gas flows to the furnace.

Although the furnace has a high thermic efficiency, and satisfies most requirements, this character cannot be given to the gas generator. This apparatus is clumsy, and occupies far too much space for the volume of gas it produces, and requires too much laborious work in its management. It is obvious that, as the gas leaves the generator at a temperature varying from 500 to 900 deg. Fahr., this sensible heat is lost by the gas in passing through the overhead tubes. Moreover, the condensation of the volatile gases in tar form is a double evil; it clogs and arrests the passage of the gas, and involves cleaning operations, and also reduces the thermic or heat value of the gas; and, although the apparatus has done good service, it may, I think, be considered in the light of a pioneer but obsolete arrangement. The type of gas-producing or generating apparatus now usually employed is a decided improvement on the old Siemens type. For the most modern form the gaseous fuel generating apparatus is either cylindrical or cupola shaped, and is enclosed in a sheet iron casing.

The air is injected into the fuel by means of a steam jet injector. The steam jet aspires or induces, and then forces the air forward into the fuel direct by means of special shaped tuyeres, or under fire bars, that, by the action of the steam and air, are kept cool.

The steam and air ascending through the mass of fuel (piled up on the solid hearth or on the fire grate, as the case may be) converts the fuel into a gaseous condition.

The volatile hydro-carbons distilled from the upper layers of the fuel in well-devised gas generators are compelled to flow through the hottest part of the fuel, and in their contact with the incandescent carbon the rich gases are rendered less condensable; and, if the gaseous fuel is led by brickwork flues immediately into the furnace, the only loss of heat due to conversion of fuel into a gaseous condition will be that radiated from the side of the gas-generating vessel.

In the Thwaite gas producer this radiant heat is utilized to heat the air required for generating the gaseous fuel, and where the gaseous fuel is intended for generating steam the side heat radiation from the gas producer may be utilized for heating the feed water.

If the flues for conveying the gaseous fuel are not too long, the loss of sensible heat of the gas is insignificant. Once the gas has arrived at its destination, or where it is required to be used, it has the following *primâ facie* advantages over fuel in a solid condition:—

1. The supply is entirely under control, and can therefore be turned on or off instanter.

2. The exact temperature required can be attained and maintained uniformly.

3. The chemical nature of combustion is entirely under control; it can be made oxidizing, deoxidizing, or reducing and neutral at will.

4. Perfect and smokeless combustion can be effected with very little over the theoretical volume of air.

5. Entire prevention of smoke.

6. Higher ranges of temperature are attainable.

7. The furnaces are not subjected to such intermittent changes of temperature, and the walls of the furnaces are more durable.

8. The flue plates of steam generators have a far longer life, and there is a more uniform temperature throughout the length of the flues, which are not exposed to the action of violent combustion.

9. Steam raising is more uniform, and the engines run steadier.

10. A commoner quality of fuel is available.

The one disadvantage is that, with gaseous fuel firing applied to ordinary Lancashire or Cornish boilers, it is difficult to attain the evaporation obtained with hand fired solid fuel.

The generation of heat and the production of steam can be effected so uniformly that the pressure gauges can be practically kept stationary, and the regular running of the engines consequent on this advantage is alone of considerable importance. It may, however, again be stated that when gaseous fuel replaces a hard fired boiler, the conditions are not at all satisfactory for obtaining the best results.

The ordinary carbonmonoxide gaseous fuel produced from coal other than anthracite is, however, not available for purposes where heat of concentrated intensity is required, or where the gas is required to pass through small-bore pipes, or for purposes where it is required to be quite clear from tar. Referring to the table of analyses (*vide* p. 29), it will be seen that the carbonmonoxide gas contains, first, a small proportion of the olefiant or volatile hydro-carbon series; and, secondly, also a large volume of the inert gas nitrogen. The first characteristic prevents the gas from being used for gas-motor cylinders, as the particles of condensed hydro-carbons may clog the ignition slides of the cylinder. The second characteristic prevents the gas from being conveyed through small pipes, because the large percentage of nitrogen would prevent continuous ignition of gas issuing from a small orifice.

These defects of carbonmonoxide gaseous fuel do not affect its use in the direction I have named, or for general furnace and steam raising work; but for gas-motor purposes, for gasing yarns, singeing, and for domestic work, the characteristics named are insuperable objections. For these purposes, or when a clean and more highly combustible gaseous fuel is required, other combustible agents and cycles of operation are employed. The combustible agent is of a kind that does not possess any of the rich hydro-carbons, such as anthracite, principally found in

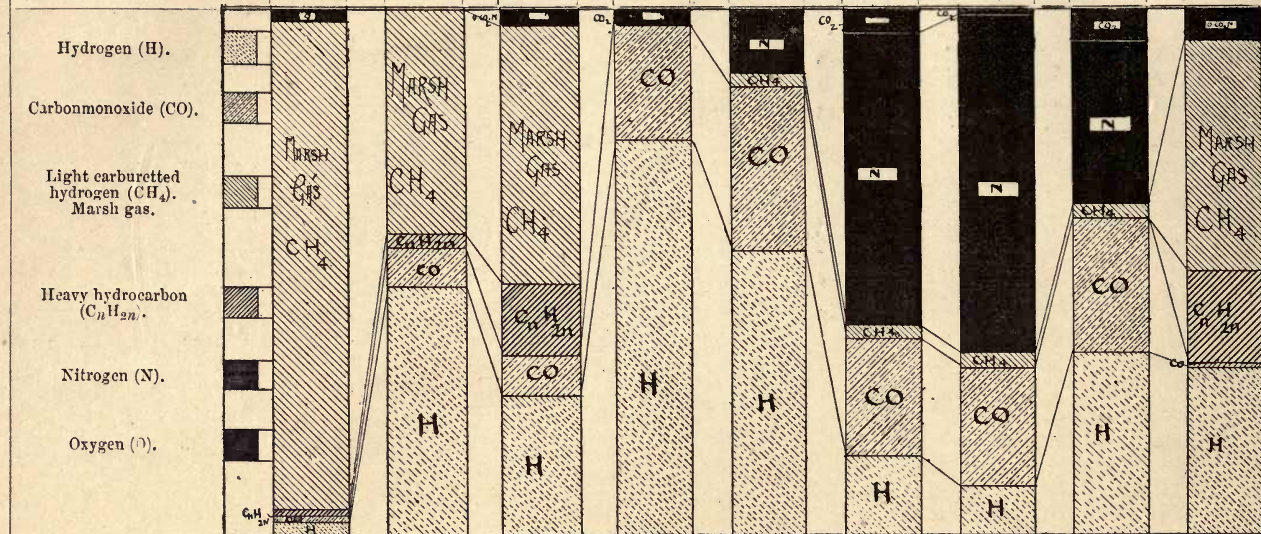
South Wales. Anthracite is almost pure carbon. If nthracite is not attainable, coke is used. This latter form of fuel is produced by subjecting coal to heat in a closed retort, by which the volatile or rich hydro-carbons are driven off, leaving the almost pure carbon behind.

Either anthracite or coke, if employed in the carbon-monoxide gas apparatus, should produce a gas suitable for all ordinary heating purposes if large delivery pipes are used, but the gas is too largely diluted with the inert nitrogen to pass through very small pipes.

Another method of production employed to overcome these defects is to convert coal into what is absurdly named water gas. The misconception derivable from this ridiculous cognomen was forcibly, if amusingly, impressed upon me some two years ago, when I received a letter from a gentleman in Algiers, inquiring if I could provide him with an apparatus that would supply the town with water gas. He added that, although there was no coal, there was abundance. of water near Algiers. Evidently the title had left him with the impression that the gas was an inflammable water vapour, such as that from dissociated water. The expression, no doubt, originated from the fact that steam plays a part in the production of the gas. The cycle of operation of this water gas generating system may be said to have been originated by two Americans, Messrs. Strong and Lowe, some seventeen years ago, although a M. Gillard introduced a system in 1849 for producing water gas, which had one application at Vauxhall Gardens, but with what success I do not know.

Carbonaceous fuel, preferably free from volatile hydro-carbons, such as coke or anthracite, is raised to a high temperature of bright incandescence by the passage of air through it; the air is then turned off, and the fuel is subjected to contact with superheated steam. The result

## *Diagram and Tables, showing various Constituents of Combustible Gases.*—Prepared by B. H. Thwaite.




| | Natural Gas. | Ordinary Towns Gas. Common Coal. | Ordinary Towns Gas. Cannel Coal. | Enriched Water Gas. | Water Gas. | Steam-jet Producer or Carbonic Oxide Gas. | Natural Draught-producer Gas. | Thwaite's Semi-water Gas. | Oil Gas. |
|---|---|---|---|---|---|---|---|---|---|
| Carbondioxide & oxygen } Incombustible. | 1·30 | 0·00 | 2·07 | 2·29 | 12·00 | 4·00 | 0·00 | 8·00 | 0·00 |
| Nitrogen, N. . . } | 0·00 | 0·00 | 0·00 | 0·00 | 0·00 | 56·78 | 63·40 | 28·40 | 5·06 |
| Light carburetted hydrogen ($CH_4$) | 95·20 | 41·53 | 51·20 | 0·00 | 1·62 | 2·22 | 2·20 | 1·92 | 17·02 |
| Heavy hydrocarbon ($C_nH_{2n}$) . | 0·50 | 3·05 | 13·06 | 0·00 | 0·00 | 0·00 | 0·00 | 0·00 | 46·17 |
| Carbonmonoxide (CO) . . | 1·00 | 7·82 | 7·85 | 20·04 | 31·86 | 23·00 | 24·20 | 27·42 | 0·14 |
| Hydrogen (H) . . . | 2·00 | 47·60 | 25·82 | 77·03 | 54·52 | 14·00 | 10·20 | 34·26 | 31·61 |
| | 100·00 | 100·00 | 100·00 | 99·36 | 100·00 | 100·00 | 100·00 | 100·00 | 100·00 |

is the dissociation of the steam according to the following reactions:—

$$4H_2O + 4C = 8H + 2CO_2 + 2C = 8H + 4CO.$$

An alternate equation is

$$C + H_2O = CO + H_2.$$

This gas possesses a high thermic character.

Its disadvantage is the fact that, during the blowing up of the fuel with air period, the carbonic oxide produced is generally wasted, and there is also the disadvantage that either coke, which occupies a relatively large cubic space in relation to its value, or anthracite, which is very expensive, have to be resorted to.

In other respects the cycle of operations of this method of generating gaseous fuel leaves little to be desired. The gas has many important characteristics. As a reducing agent, some experiments instigated by me appear to show that it is more powerful than carbonmonoxide.* For many purposes, such as welding boiler tubes, flanging, rivet heating, lighting by incandescence, and even metallurgic operations, the intense thermic character of combustion of this so-called water gas is well adapted. There are many towns and villages in the United States that are supplied with water gas. A few nervous individuals made a strong objection to its use during the early stages of its application. It was decided by the Massachusetts luminaries that no gas should be supplied having a greater percentage than 10 per cent. of CO. This legal definition, had it been respected, would have prevented the gas from being used at all.

The disadvantages of inodorousness can of course be

---

* *Vide Engineering*, January 15, 1886. The summary of the experiments appear to show that water gas is a more powerful reducing agent than carbonic oxide gas, in the ratio as 4·21 : 6·72, or $\frac{4{\cdot}21 \times 100}{6{\cdot}72} = 52\,\%$.

overcome by adding to the gas an odorous inflammable vapour, such as the spirit of naphthaline, or by an admixture of the ordinary illuminating gas, or by an admixture of the ordinary carbonmonoxide gas that has its own generic odour. For further information respecting water gas, *see Appendix.*

The third system of producing gaseous fuel is that introduced by me, and effected in the Duplex Gas Generator.

In this system there are two cycles of reactions, one resembling that involved in the production of water gas, in the other the reaction produces carbonmonoxide gas, both gases being intermixed, and leaving the generator together. The following is the formula of reactions:

$$CO_2 + H_2 + 8N + 2CO = 3CO + H_2 + 8N.$$

In this Duplex Gas Generator the volatile hydrocarbons are compelled to descend through the incandescent fuel, by which they become thoroughly fixed and permanent.

The ordinary carbonmonoxide gaseous fuel is available for all kinds of ordinary furnace work, and for steam raising its production entails very little labour, and when used for metallurgic and chemical operations the exact control over the chemical nature of combustion is an immense advantage, and has enabled the beautiful process known as Bower-Barffing to be performed, which consists fundamentally of an alternate process of oxidation and dioxidation of iron, by which the black and stable magnetic oxide of iron is produced.

For annealing processes, the control over the temperature and uniformity of heat maintenance are advantages of the highest importance, and by gas firing there need be no danger of overheating.

For steel manufacture on the open hearth process, the very elevated temperature available, up to 3500 deg. Fahr., allows steel to be manufactured at one-sixth of the cost in fuel of the production of one ton of puddled bars. (*See Addenda.*)

I have successfully introduced gaseous fuel for drying clay for the semi-plastic brick process. This system has the advantage of rapidity of operation, and requires very little space.

For drying clay of the aluminous kind, such as China clay, gaseous fuel has been applied with great success.

For baking pottery, the uniformity of heating and high temperature available by the use of gaseous fuel are *primâ facie* advantages.

The system of drying China clay on the old process is most unhealthy, and is really a process that would be fatal to any but very strong workmen, who are bound to succumb in the long run to the fatal influences of the operation. I have applied gaseous fuel to this process, along with a special furnace, with the greatest success, the process being effected automatically, and requiring hardly any manual labour. In this process, although the flame of gaseous fuel is brought into contact with the clay, so perfectly pure is combustion that the white clay is unsullied.

For mineralogic purposes, such as roasting ores, the uniformity of temperature attainable is a great advantage. I have erected mineral roasting gas furnaces of a length of nearly 40 feet by 4 feet in width, with about 250 feet of heating surface, and the temperature throughout is almost exactly uniform, and the process of manufacture has been reduced to an almost exact science.

For the calcination of cement, gaseous fuel is also applicable, and in combination with a revolving furnace this process of manufacture can be carried on with much greater rapidity than in the old process.

## THE COMBUSTION OF GASEOUS FUEL FOR GENERATING MOTIVE POWER.

Gaseous fuel is also applicable for a direct production of motive power. This is now patent to every observer. Few in this country have not seen the famous Otto gas engine, the invention of which may be placed alongside that of the steam engine by James Watt.

This remarkable instrument (the Otto gas engine) for the conversion of heat into work we owe to two German scientists, Dr. Otto and Herr Langen, who, like the Siemens Brothers, are an example of the advantages to inventors of scientific knowledge. Prior to the date of this invention, gas engines had a comparatively limited application, but, thanks to applied science, this instrument of industry has been raised to a high pitch of efficiency, and the enormous sale of this engine, some 26,000, is a magnificent proof of its utility and excellence.

The principle of the development of motive power by the instantaneous combustion of gaseous fuel rests in the laws of Charles Gay Lussac and Boyle—*ergo*, that the pressure exerted by a gas varies directly as its volume, and as the combustion of a gas in a cylinder with only one movable end, generates heat and expands the gases, the pressure produced by the tendency to expansion forces forward the movable end or piston, with a pressure corresponding to the temperature produced by combustion and the expansion due to that temperature.

By means of the cycle of operations of a compression gas engine or in which the combustible mixture is compressed before ignition, one indicated horse-power can be produced at an expenditure varying from $1\frac{1}{4}$ to $1\frac{1}{2}$ lbs. of coke or anthracite. I am now experimenting with a gas generating apparatus by which it is anticipated that the same amount of dynamic power will be produced with an expenditure of $1\frac{1}{8}$ lbs. of washed slack coal, equivalent to 33 h.p. per hour at a cost of one penny.

Besides the Otto gas engine there are many excellent motors in the market; one especially, Atkinson's cycle engine, has given a remarkably high thermo-dynamic efficiency at a recent trial instituted by the Society of Arts, another simple and excellent motor is that known as the Campbell gas engine.

The following list, although far from complete, showing the numerous applications of gaseous fuel to industrial purposes, demonstrates that this principle of fuel combustion is becoming recognized as the true one, and it may be stated, *nemine contradicente*, that the days of solid fuel are numbered.

LIST OF SOME APPLICATIONS OF GASEOUS FUEL.

Steel, zinc, and glass melting.
Roasting ores.
Annealing steel, wire castings, &c.
Re-heating steel and iron blooms.
Calcining Portland cement.
" aluminous clay.
Burning pottery, terra cotta, and bricks.
Raising steam.
Generating motive power.
Boiling and evaporating liquids.
Singeing and gassing yarns.
Welding and forging purposes.
Cremating and destroying organic matter.
Core drying.
Baking.
Salt cake manufacture; and
Chemical processes.

## Project for the distribution of gaseous fuel produced at the coalfields.

It has already been mentioned that the natural gas from the wells in Pennsylvania is conveyed through pipes to distances of 60, and even more miles, before its general distribution, and that there are 2300 miles of distributing pipes.

On the basis of the distribution of natural gas in Pennsylvania the author has elaborated three projects of production and distribution of gaseous fuel in this country, the source of generation being situated in the centre of the coalfields.

For the supply of the Midland towns and the Metropolis there would be arranged three gaseous fuel-producing installations, one in South Wales, one in Staffordshire, and one in South Yorkshire.

The gas produced would be conveyed in as direct a line as possible from the neighbourhood of Barnsley to the Stafford installation, and from thence, through the Midland towns, to which by branch lines the gas would be supplied, to where the junction with the South Wales pipe line would be effected.

The mains would be four in number from Staffordshire for a length of 120 miles. The South Wales branch main would consist of two pipes 100 miles in length, and the South Yorkshire branch pipe line of 70 miles in length.

The coal would be converted into gas at the coalfields, and delivered to the distributing mains under great pressure by means of compression engines, and could be distributed in the towns in the day time for heating purposes by the ordinary mains, and by means of special incandescent burners the gas could be utilized for illuminating. The saving in cost of fuel by this system in its application to the Metropolis will be understood from the fact that in the year 1887, 12,055,000 tons of coal were delivered into the London district. The total cost of this coal at the coalfields would be fairly estimated at £3,013,750; the amount paid by the London populace for this coal would be about £12,657,750 per annum. The difference between cost of fuel at the source of supply and at the place of use is therefore £9,644,000. This amount is absorbed in cartage, merchants' profits, railway carriage, and London Corporation dues. Assuming one third of this amount represents the reduction in price of fuel to the consumers, this would leave a balance of £6,429,324 to pay for cost of generating gas and interest on capital invested on plant and pipe lines and maintenance. There is little doubt but that the net profit would justify an expenditure of fifty millions sterling in gaseous fuel installations and distributing pipe lines.

The advantage to the Metropolis by the general distribution and application of gaseous fuel would be a colossal one. The increasingly heavy and dangerous fogs, which are greatly due to the condensation of the aqueous vapour on the atoms of unburnt carbon and sulphur, would disappear. The splendid architectural monuments of modern Babylon could be relieved from their dirty covering, and London would be metamorphosised, and might rival Paris in the clearness of its atmosphere, after allowing for the different climatic conditions.

Birmingham and the other Midland industrial centres could also join in the economic and sanitary advantages of a cheap and abundant supply of gaseous fuel for all purposes.

The Lancashire project consists in the establishment of a gaseous fuel-producing installation in the neighbourhood of Wigan. The pipe lines would distribute the gas to Manchester and Salford, and along the Rossendale Valley to Bacup, Accrington, Bury, Blackburn, Preston, and Bolton, and another branch would lead the gas to Stockport, Oldham, and Ashton.

The West Riding project consists in the establishment of a gaseous fuel installation at Barnsley. The pipe lines could convey the gas to Sheffield and to Wakefield, where one pipe would branch off to Batley, Dewsbury, Mirfield, Huddersfield, Slaithwaite, Brighouse, Halifax, and Todmorden; the other branch would convey the gas to Cleckheaton, Bradford, and the other towns *en route* to Leeds.

By this arrangement manufacturers and other steam users could have an abundant supply of gaseous fuel, costing merely a fraction above that of the cost at the pit, and enabling the user to obtain the fullest practical thermic efficiency of the fuel.

This project of distributing one of the great natural agents would, if carried out even on a smaller scale than that proposed, be as great an improvement over the costly, wasteful, and unhealthy present system as the present system of distribution of water by pipes from one great source of supply is to the isolated wells and bucket or cart distribution of water.

Another advantage that would accrue from a national and central fuel distribution system would be the facility for collecting the nitrogenous constituents of coal. The value of these nitrogen compounds to the agriculture of this country and to our industrial operations could hardly be over-estimated, as it would render our farmers almost, if not altogether, independent of foreign supplies.

Such a central gaseous fuel producing and distribution system, even if confined to the generation of the gas at locations near to each of the large industrial centres, would be of an immense economic and hygienic advantage, and would enable gas motors to be used for generating electricity, which could be produced at a cost that would permit this surpassingly beautiful and hygienic means of illumination, to be obtained at a very moderate cost, and enable it to be within the reach of all.

# APPENDIX.

## RECOVERY OF AMMONIA.

Taking the internal or home consumption of fuel to be 75 millions per annum, and estimating that each ton of coal would produce 20 lbs. of ammonia sulphate, this would, if abstracted, represent some 670,000 tons of ammonium sulphate per annum. If we take this agent as worth £11 15*s*. per ton, this output alone would have a value of £7,872,500; by the conversion of the fuel into gas a great part of this valuable manurial agent could be easily recovered.

## ANALYSES OF CHIMNEY GASES.

### SOLID FUEL.

Date of trial, 1884. Test conducted by B. H. Thwaite. Gases analysed by G. J. Norman Tate, F.C.S.

Description of Boiler—Vertical Millitubular, partially gas-fired. Fuel slack coal. Carefully fired.

| | |
|---|---|
| Nitrogen | 80·08 |
| CO | 1·10 |
| $CO_2$ | 12·77 |
| O, by difference | 6·05 |
| | 100·00 |

### SOLID FUEL.

Date of trial, 1887. Test conducted by Sir F. Bramwell and W. Anderson.

Ordinary Steam Coal. Average of 11 tests. Very carefully hand-fired.

| | |
|---|---|
| Nitrogen | 80·360 |
| CO | 00·186 |
| $CO_2$ | 10·900 |
| O, by difference | 8·842 |
| | 100·288 |

*Solid carbon percentage by weight of smoke,* 4·18 *per cent.*

## GASEOUS FUEL.

Date of trial, April 1889. Test conducted by R. Forbes Carpenter, H.M.'s Inspector of Alkali Works. Instigated by A. E. Fletcher, Esq., H.M.'s Chief Inspector of Alkali Works.

Gas-fired Lancashire Boiler—Thwaite's System. Ordinary Steam Coal.

| | Sample 1. | Sample 2. | Sample 3. |
|---|---|---|---|
| N | 80·60 | 80·00 | 79·80 |
| O | 11·15 | 13·00 | 13·70 |
| $CO_2$ | 8·25 | 7·00 | 6·50 |
| CO | 0·00 | 0·00 | 0·00 |
| $CH_4$ | 0·00 | 0·00 | 0·00 |
| H | 0·00 | 0·00 | 0·00 |
| | 100·00 | 100·00 | 100·00 |

These analyses show absolute immunity from combustible or unburnt gases and smoke.

## NOTES ON METALLURGIC OPERATIONS.

The excess of air required to produce a near approach to perfect combustion of fuel cannot be attained in the instance when combustion is required to be of a deoxidizing or reducing nature.

In order to avoid waste of metal by oxidation, the forge furnace man is compelled to produce a state of combustion involving the evolution of an enormous excess of unburnt combustible gases, and this explains why his furnace chimney belches forth great streams of thick smoke.

With gaseous fuel firing, the furnace man has perfect control over the chemical nature of combustion, and he can, with a trivial excess of combustible gases, obtain a deoxidizing flame, and even this excess of combustible gases can be burnt in the recuperative chambers, and the heat restored for combustion, so that there need be no loss of thermic units.

In forge furnaces fired with solid fuel there is loss of heat and time during the scaling of the bars, which is avoided when gaseous fuel is employed.

If we estimate the fusion point of steel at 2,900 deg. Fahr., and take its specific heat to equal 0·113, the units of heat required to melt 1 ton of steel would therefore equal the sum of 2900 × 2240 × 0·113.

| | |
|---|---|
| Log of 2900 . . . . . . . . | 3·46240 |
| ,, 2240 . . . . . . . . | 3·35025 |
| | 6·81265 |
| Log of 0·113 . . . . . . . . | 1·05308 |
| 734·307 B.U. . . . . . . . | 5·86573 |

Taking the calorific value of 1 lb. of coal to equal 14,000 B.U., then the weight of fuel required to melt 1 ton of steel would be represented by the following fraction :—

$$\frac{734·048}{14,000} = 52·4 \text{ lbs.}$$

The usual amount of coal required per ton of puddled bar would exceed 2 tons, but if we take this figure, then the waste or excess of fuel over that theoretically necessary is strikingly demonstrated—

$$\frac{4480}{52·4} \text{ lbs.} = 85,$$

or about eighty-five times more fuel is used in hand-fired solid fuel puddling furnaces than is theoretically necessary. The useful calorific efficiency, therefore, hardly exceeds 1·2 per cent.

With the most modern type of gas-fired recuperative gas furnaces, the weight of fuel per ton of steel ingots should not exceed 8 cwt. This represents an actual efficiency of 5·8 per cent. These efficiencies are only given as relative ones. Berthelot has shown, by experiments carried out with the most refined precision, that the value of specific heats increases with the temperature; * but as the increase of the specific heat of iron has not been ascertained, the ordinary specific heat value has been taken. In metallurgical furnace operations, the very elevated temperatures of metallic fusion, are only divided from that of the atmosphere by walls of refractory material, whose inner sides attain the temperature of fusion, of the metal under treatment, and whose outer sides are exposed directly to the atmosphere. The difference of the temperature of the outer side of wall and the air, often exceeds 500 deg. Fahr., so that the relative heat radiation per superficial unit is at least five times greater in metallurgical furnace operations, than in steam generation.

By a judicious selection of refractory material, and careful building of the furnace walls, there is no doubt but that the loss of heat by outside wall surface radiation may be much reduced. But there will always remain a considerable excess of loss due to this cause over that of the instance of the application of heat to steam raising, where the highest temperature of initial combustion is surrounded by a jacket of water whose temperature can never exceed that equivalent to the pressure of steam, which rarely exceeds 200 lbs. to the square inch.

If the combustion of fuel could be perfectly attained in flues of a steam generator, the latter would be practically a calorimeter, and the fullest possible thermic efficiency of the fuel might be obtained in the actual work of raising steam.

---

* *Vide Engineer*, October 2, 1885: "The Properties of Gaseous Explosive Mixtures," by Berthelot. Translated and abstracted by B. H. Thwaite, from the *Annales de Chimie et de Physique*, January 1885.

## NOTES ON WATER GAS.

For high local temperatures water gas is exceptionally valuable.

Bessemer steel can be melted with water gas fuel with cold air.

## THE RELATIVE THERMIC VALUE OF PRODUCER GAS AND WATER GAS.

The entire absence of nitrogen in water gas is in some applications a decided advantage. But, in making a comparison between the heat of combustion carried off as sensible heat by the products of combustion between ordinary producer and water gas, we should not forget that there is a considerable loss due to the heat absorbed, and rendered latent by the steam resulting from the reoxidation of the hydrogen, between ranges of temperature of combustion, from 100° Cent. to 400°—we shall find the loss is greater than with ordinary producer gas.

Taking the reaction represented by $C + H_2O = CO + H_2$ to produce water gas, and its complete combustion to be represented by

$$CO + H_2 + 2O + 8N = CO_2 + H_2O + 8N,$$

and acknowledging producer gas to be evolved according to the following sequence of reactions—(Note, for facility of calculation $N_4$ is taken instead of $N_{3 \cdot 6}$)—let

$$2N_4O + C = 8N + CO_2 \text{ and } 8N + CO_2 + C = 8N + 2CO,$$

then the combustion would be effected as follows:—

$$8N + 2CO + 2O + 8N = 16N + 2CO_2.$$

Assuming that in each case as an example 12 grammes of carbon are used, and are used first to produce water gas, and afterwards the same weight is used to produce carbonic oxide, and assuming that both kinds of gas are consumed and the products of combustion are allowed to escape at a temperature of 300° Cent., then

$$300\left(\overset{CO_2}{[12 + 32 \times 0{\cdot}219]} + \overset{H_2O}{[2 + 16 \times 0{\cdot}481]} + \overset{N}{[112 \times 0{\cdot}244]}\right)$$

$$= 13{\cdot}660 \text{ units of sensible heat}$$

$$18 \times 606{\cdot}5 = 10{\cdot}917 \text{ latent heat units of steam}$$

$$24{\cdot}577 \text{ units lost.}$$

Now, taking the combustion of producer gas for the same weight of fuel, then

$$300\left(\overset{CO^2}{[12 + 32 \times 0{\cdot}217]} + \overset{N}{[112 \times 0{\cdot}244]}\right) = 11{\cdot}062 \text{ units lost}$$

as sensible heat. The ratio of heat units lost to the total units produced by the combustion of the two gases will be as follows:

WATER GAS.

$$28 \text{ grms. } CO \text{ to } CO_2 = 67{\cdot}284 \text{ units}$$
$$2 \text{ grms. } H \text{ to } H_2O = 57{\cdot}924 \text{ units}$$
$$125{\cdot}208$$

Ratio of loss will therefore be

$$= \frac{24{\cdot}577 \times 100}{125{\cdot}208} = 19{\cdot}6 \text{ per cent.}$$

PRODUCER GAS.

$$28 \text{ grms. } CO \text{ to } CO_2 = 67{\cdot}284 \text{ units}$$

Ratio of loss will therefore be

$$= \frac{11{\cdot}062 \times 100}{67{\cdot}284} = 16{\cdot}4 \text{ per cent.}$$

Hence the advantage in favour of the producer gas is 3·2 per cent.

The real value of water gas is found in its high thermic character per unit volume; in any given equal volume of producer and water gas the ratio of thermal units is as 60·8 is to 277 in favour of water gas.

This higher thermic value of water gas means a greater calorific effect in a given period, and a consequent reduction of loss by radiation. In the instance of the application of water gas to a recuperative open-hearth steel furnace, 7,392,000 B.U.'s are required per ton of steel ingots, whereas with producer gas the heat units required equal 14,400,000.

### WATER GAS FOR LIGHTING.

By the introduction of a durable form of refractory material into the zone of combustion, the water gas can be utilized for illuminating purposes. I have applied the Welsbach burner (a zirconium hood) for use with water gas produced in my own apparatus with the most satisfactory results, the light being both beautiful and steady.

Theoretically, gas lighting by incandescence, if it could be accomplished by recuperation, or the restoration of the sensible heat of the products of combustion, would be most perfect, because the temperature of incandescence is the result not only of the oxidation of the hydrogen, but of the—and almost simultaneous oxidation of the—carbonic oxide (CO) to $CO_2$ as well, whereas, with ordinary illuminating gas, burnt in any ordinary burner other than a Bunsen, the temperature of incandescence of the carbon atoms constituting the luminous part of the flame is simply that resulting from the oxidation of the hydrogen. The Fajenhelm comb burner, which consists of suspended magnesian rods, gives, it is said, for a consumption of 5·3 cubic feet per hour, about 20 candles. This photometric value is reduced after an expiration of 50 hours to 15 candles, and in 100 hours the value is further reduced to 10 candles.

### FOR MOTOR PURPOSES.

About 35 cubic feet of water gas required per I.H.P., in comparison with from 70 to 90 of ordinary producer gas.

The volumetric production of water gas per ton of fuel equals 30,000 cubic feet.



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