TIGHT BINDING BOOK

UNIVERSAL
LIBRARY

OU_158154

UNIVERSAL
LIBRARY

LIQUID AND GASEOUS FUELS

AND THE PART THEY PLAY IN MODERN POWER PRODUCTION

BY

VIVIAN B. LEWES F.I.C. F.C.S. &c.

PROFESSOR OF CHEMISTRY AT THE ROYAL NAVAL COLLEGE, GREENWICH; CHIEF SUPERINTENDING GAS EXAMINER TO THE CORPORATION OF THE CITY OF LONDON; ASSOCIATE MEMBER OF THE COUNCIL OF THE INSTITUTE OF NAVAL ARCHITECTS, &c.

SECOND EDITION

REVISED AND EDITED BY

JOHN B. C. KERSHAW F.I.C. F.S.S. &c. &c.

LONDON

CONSTABLE & COMPANY LTD.

10—12 ORANGE STREET LEICESTER SQUARE W.C. 2.

1921

Printed in Great Britain.

INTRODUCTION.

THE subject of Liquid and Gaseous Fuels has, during the last decade, assumed such importance that no apology is necessary for the present attempt to treat the subject from a popular but comprehensive point of view. The development of the internal combustion motor, the coming of the automobile, and the important part played by liquid fuel in the Navies of the world, make the present time one of the most interesting epochs in the history of power production, and it is hoped that by bringing together the history and practical development of the use of various forms of combustible liquids and gases for the generation of energy this book may do some service in the advancement of the subject.

Although the book is only supposed to treat of fuel in its liquid and gaseous form, it is so absolutely impossible to divorce these from the subject of solid fuel, which is in most cases the parent from which the others have sprung, that in order to retain the necessary sequence in treatment solid fuel has also been considered, in some cases, as with peat, at considerable length. There is not the slightest desire or intention in the author's mind to produce a book which shall in any way take the place with the student of such works of reference as Sir Boverton Redwood's "Petroleum and its Products," Mr. E. Dowson's "Producer

Gas," or Mr. Booth's "Liquid Fuel," but rather to give a general sketch of the whole subject and its bearings on the power problems of the day, and to leave the student to refer to such standard works as may be necessary for the detail of various applications.

In order to facilitate the study of any special branch of the subject a short bibliography is added, which it is hoped will prove of use for reference, and in which are included many works to which the author owes a debt of gratitude.

The first three chapters of the work deal with the phenomena of combustion and the part played by the atmosphere, the formation of fuel in its various forms, and the methods by which we determine its value as a source of heat energy.

In the next following chapters will be found an account of the production, properties, and use of the liquid fuels and their adoption as an auxiliary to coal in European Navies, whilst the subject of coal gas and the factors which have made it one of the most important of domestic fuels will also be found treated at considerable length. Water gas, both as a help to the coal gas maker and the engineer, receives due attention, whilst those gases which, although the poorest in thermal value, have proved themselves the most valuable in cheapening power production, are fully treated with in the section dealing with poor fuel gases and the suction plant.

The last chapter deals with the future of the fuel problem and the probable lines on which a world, bankrupt in fuel, will find means of regenerating the energy which is essential to life and prosperity, and it is hoped that the short discussion on the value of alcohol as a fuel in the

internal combustion motor may lead to an increase in the experimental work in this direction.

Some of the matter utilised in preparing this book has appeared before in lectures and papers given before various Institutions by the author, but where such has been used it has been brought up to date, and the author desires to express his indebtedness to those who have assisted him with photographs of plant and material for diagrams.

V. B. L.

GREENWICH, 1907.

PREFACE TO SECOND EDITION.

IN preparing this second and revised Edition of the late Professor Vivian B. Lewes' book upon "Liquid and Gaseous Fuels," as few alterations as possible have been made in the original text.

Those made fall into three classes, namely, (1) verbal alterations designed to render the author's meaning clearer or more definite; (2) alterations in production figures and data that have required amendment in order to bring them up to date; and (3) alterations relating to new methods, developments or apparatus which have come into prominence since the book was written in 1907.

The original plan of the book and division into ten chapters has been preserved; and the relative space devoted to each branch of the subject remains therefore the same.

The added matter is confined chiefly to the notes at the end

of each chapter, and to the Appendix. The portions of Chapter III. dealing with *Calorimeters*, and of Chapter VII. dealing with methods *of enriching coal gas* have been cut down considerably, in order to make space for descriptions of more up-to-date methods and apparatus. Chapter X. has also been brought up to date by the addition of data and information relating to the manufacture and use of *power alcohol.*

The Appendix contains extracts from recent publications and articles dealing with liquid and gaseous fuels, including three of the late Professor Lewes' own Lectures, delivered before the Society of Arts in the years 1911, 1913 and 1915 respectively.

The Editor of this revised Edition trusts that in its new form the book will prove as useful as its predecessor, and that it will serve to provide the general public with a storehouse of information and data, upon the liquid and gaseous fuels which are certain to be *the fuels of the future.*

Thanks are due to Mr. James Smith, Member of the Institute of Gas-Engineers and Resident Gas-Engineer at Colwyn Bay, for much assistance in the revision of the chapters dealing with *gaseous fuel;* to the Secretary of the Society of Arts for permission to make use of the late Professor Lewes' Lectures before that Society in the years 1911—1915; and to the Director of the Bureau of Mines, Washington, for similar permission to make use of the information and diagrams contained in J. M. Wadsworth's Bulletin on the "Use of Oil Fuel." Thanks are also due to the Editor of *The Engineer*, and to Messrs. Bale and Hardy, of Newark, for assistance rendered in bringing the book up to date.

JOHN B. C. KERSHAW.

9, Grosvenor Road,
Colwyn Bay, N. Wales.

June, 1920.

TABLE OF CONTENTS.

CHAPTER I.

Lavoisier's discovery of the nature of combustion and the part played by the atmosphere—Air a mixture of the two gases oxygen and nitrogen—Oxygen as a supporter of combustion—The properties of nitrogen—Slow and rapid combustion—The ignition point—The effect of condition on ease of ignition—Products of combustion—Water vapour—Carbon dioxide and its properties—Incomplete combustion—Carbon monoxide and its formation—The toxic action of carbon monoxide and its treatment—The phenomena of combustion—Incandescence—Flame and smoke—The formation of smoke and its nature—The effect of smoke on the atmosphere, and the part it plays in inducing the formation of fog . . . . . *pp.* 1—23

CHAPTER II.

The cycle of animal and vegetable life—The growth of vegetation—Cellulose—Wood as a fuel—Charcoal—Peat—The formation of coal—Checked decay—Variation in composition due to geological change—The influence of hydrogen in coal—Methane or marsh gas—Fire damp and choke damp—Safety lamps—Coke—Mineral oil—American and Russian oil—Fuel oils—Gaseous fuel—Producer gas—Water gas—Carburetted water gas—Coal gas—Natural gas—Hydrogen—The elements—The three states of matter—Molecules and atoms—Symbols and their use—Carbon and its combinations . . . . . *pp.* 24—57

CHAPTER III.

Methods of determining calorific value—The calorie and British thermal unit—Heat of combustion factors—Latent heat of steam—Calculation of calorific value from chemical composition—Evaporative duty—Objections to calculated results—Direct determination of thermal value—Calorimeters—The Mahler bomb, and the method of using it—The Darling calorimeter—The use of the bomb for liquid and gaseous fuels—The heat of combustion of gases—The Boys calorimeter . . . . . *pp.* 58—83

CHAPTER IV.

The discovery of petroleum in America—The Russian oil fields—The distribution of petroleum—The conditions under which it occurs—The nature of petroleum, and the products obtained from it—The amount available for fuel purposes—The flash point, and how it is determined—The Abel test—The Pensky-Marten—The requirements in a fuel oil—Shale oil as a fuel—The shale oil industry—Coal tar and its composition—Creosote oil—Blast furnace oil—Shipping regulations for oil fuel—Petroleum spirit and its dangers—The testing of atmospheres likely to contain explosive mixtures of petroleum vapour and air—The Clowes-Redwood apparatus . . . . . *pp.* 84—107

CHAPTER V.

Oil lamps, and the conditions on which their satisfactory working depends—Heating and illuminating power of oil—The history of the use of oil as a fuel—Nobel's troughs—Gasification before combustion—Foote's burner—Simms and Barff process—Eames furnace—Dürr apparatus—Methods of atomising or pulverising oil before combustion — Injectors — Injection under pressure—Körting injector—Swensson burner—Injection by steam—The Holden burner—Rushden and Eele's injector—The Orde burner—Air injection—Furnace arrangements—Conditions of combustion—The formation of smoke—Merits of steam injection as opposed to air or pressure—Furnace space—Liquid fuel for marine use—Advantages for naval use—Employment as an auxiliary to coal—United States Naval Board experiments—Liquid fuel for use in locomotives—Comparative value of liquid fuels in practice *pp.* 108—140

CHAPTER VI.

The history of coal gas—Murdoch, Lebon, and Winsor—The coals used in coal gas manufacture—Gas retorts and carbonisation—Retort settings—Charging and drawing—Sloping and vertical retorts—Crude coal gas, and its purification—Ammonia liquor—Sulphur compounds in gas—The effect of sulphur in gas on its use for domestic lighting—Lime and ore purification—The composition of coal gas—Illuminating standards—Steaming of retorts—Sale of gas on heat unit basis—The cause of luminosity in flame—The chemical changes taking place in a gas flame—Gas burners . . . . . *pp.* 141—185

CHAPTER VII.

Calorific value of coal gas and its constituents—The relation between illuminating power and thermal value—Effect of enrichment on calorific value—The inception of the atmospheric burner—Early forms of burner—The cause of non-luminosity in the "Bunsen" flame—Ratio of air to gas in the flame—Effect of diluents on the flame—Effect of the specific heat of gases in the flame—The structure of the atmospheric burner flame, and the chemical changes taking place—The temperature of the flame—The Le Chatelier thermo-couple and its use—Gas stoves, and their relative efficiency as compared with coal—Methods of heating, and the effect on the air of rooms—Regenerative gas stoves—Flueless stoves—The necessity for leading away the products of combustion—Coal gas in the internal combustion motor *pp.* 186–222

CHAPTER VIII.

The history of water gas—The "European" water gas plant—The introduction of carburetted water gas—Thermal considerations in the manufacture of water gas—Blow and run processes—Dellwik water gas—Chemical actions taking place in the generator—The application of water gas—The Kramer and Aarts process—Carburetted water gas—The early forms of plant—The Lowe process, and its recent modifications—The Humphreys-Glasgow system—The poisonous properties of water gas—Carburetted water gas as an enricher and diluent of coal gas—Blue gas as an adjunct to coal gas works—Various methods by which it is used—Auto-carburetting—Tully's C.H. carbonising plant. *pp.* 223–257

CHAPTER IX.

Incomplete combustion—The principle of the gas generator—Thermal considerations—Bischof generator—Siemens and his work—Air-producer gas—Blast furnace gas—Dowson or semi-water gas—The Dowson type of generator—Anthracite as a fuel, and the considerations governing the size used—The composition of Dowson gas—Mond gas and its production—The Buire-Leucauchez generator—The growth of the internal combustion motor—Suction gas plant—The Berrier suction generator—Pintsch suction plant—Dowson suction plant—The adoption of the suction plant and gas engine for marine purposes—The Emil Capitaine plant—The use of bituminous coal for suction plant, and the troubles to be overcome—The Duff-Whitfield generator—The Boutillier plant . . . . . *pp.* 258–286

CHAPTER X.

Comparison of the thermal values of our fuels, solid, liquid, and gaseous — The internal combustion engine as a measure of efficiency with gaseous fuel—The future of the fuel question—The life of our liquid fuel supply—The era of gaseous fuel—The utilisation of the peat deposits of the world—Modern methods of making peat a valuable fuel—The calorific value of peat briquettes as compared with other fuels—The problem of the future—The fixation of solar energy and its regeneration by combustion—Fermentation, and the production of alcohol from vegetation—Alcohol as a fuel — Denaturated, or methylated spirit — Its calorific value—Practical trials with substitutes for petrol—Future of alcohol as a motor fuel . . . *pp.* 287—318

PAGE

APPENDIX 321

(1) Tables, and scientific data . . . . . 321—330

(2) General characteristics of the different types of fuel-oil burners (illustrated) . . . . . 330—332

(3) Extracts from the late Professor Vivian Lewes' Society of Arts Lectures (1911—1915) . . 332—339

(4) Miscellaneous extracts . . . . . 339—343

INDEX 345

LIST OF ILLUSTRATIONS.

FIG.		PAGE
1.	MAHLER BOMB (SECTION)	65
2.	MAHLER BOMB WITH FITTINGS	66
3.	DARLING CALORIMETER	70
4.	DARLING CALORIMETER	71
5.	INSULATING VESSEL AND MECHANICAL STIRRER	72
6.	BOYS' CALORIMETER (SECTION)	75
7.	JUNKER CALORIMETER	78
8.	SIMMANCE-ABADY CALORIMETER	82
9.	ABEL FLASH-POINT APPARATUS	93
10.	PENSKY-MARTEN FLASH-POINT APPARATUS	94
11.	THE CLOWES-REDWOOD TESTING LAMP	106
12.	CLOWES-REDWOOD SAMPLE-COLLECTING APPARATUS	107
13.	NOBEL'S TROUGHS	112
14.	COLONEL FOOTE'S FURNACE	114
15.	EAMES' OIL FURNACE	115
16.	THE DÜRR SYSTEM	116
17.	KÖRTING'S INJECTOR	117
18.	SWENSSON BURNER	118
19.	HOLDEN INJECTOR (LOCOMOTIVE)	119
20.	HOLDEN INJECTOR (MARINE TYPE)	120
21.	RUSHDEN AND EELE'S BURNER	121
22.	ORDE BURNER	122
23.	SMALL GAS WORKS.	147
24.	RETORT HOUSE, GRANTON WORKS	151
25.	CANDLE FLAME	175
26.	COCKSPUR AND COCKSCOMB BURNERS	178
27.	OLD FLAT FLAME BURNER	180
28.	CANDLES AND CALORIES.	189
29.	ORIGINAL FORM OF BUNSEN BURNER	194
30.	BUNSEN BURNER (SECTION)	195
31.	BUNSEN FLAMES	197
32.	SMITHELLS' TUBE—CENTRAL CONE IN POSITION	203

FIG		PAGE
33.	SMITHELLS' TUBE—CONES SEPARATED	205
34.	LE CHATELIER'S THERMO-COUPLE AND ARRANGEMENT	206
35.	HOLDER FOR THERMO-COUPLE	208
36.	TEMPERATURES IN BUNSEN FLAME WITH DIFFERENT AERATION	209
37.	"EUROPEAN" WATER GAS GENERATOR	226
38.	DELLWIK WATER GAS PLANT	236
39.	WELDING BOILER FURNACE WITH WATER GAS	238
40.	FAHNEHJELM COMB	240
41.	HUMPHREYS AND GLASGOW CARBURETTED WATER GAS PLANT.	244
42.	TULLY'S C. H. GASIFICATION PLANT	255
43.	BISCHOF GENERATOR	261
44.	SIEMENS PRODUCER	262
45.	DOWSON GENERATOR	268
46.	MOND GENERATOR	269
47.	MOND PLANT	273
48.	PINTSCH SUCTION PLANT	276
49.	DOWSON SUCTION PLANT	277
50.	CAPITAINE SUCTION PLANT	279
51.	DUFF-WHITFIELD PLANT.	283
52.	BOUTILLIER SUCTION PLANT	284
53.	EFFECT OF MOISTURE ON THE THERMAL VALUE OF PEAT	298
54.	ALCOHOL CURVE	305
55.	LOCOMOTIVE TYPE OF STEAM JET FUEL-OIL BURNER.	330
56.	SECTION OF INTERMIXING STEAM JET FUEL-OIL BURNER	331
57.	SECTION OF AIR JET FUEL-OIL BURNER	331
58.	SECTION OF ADJUSTABLE TIP MECHANICAL FUEL-OIL BURNER	332
59.	SECTION OF GLOVER-WEST VERTICAL CONTINUOUS RETORT.	335

LIQUID AND GASEOUS FUELS.

CHAPTER I.

COMBUSTION.

Lavoisier's discovery of the nature of combustion and the part played by the atmosphere—Air a mixture of the two gases oxygen and nitrogen—Oxygen as a supporter of combustion—The properties of nitrogen—Slow and rapid combustion—The ignition point—The effect of condition on ease of ignition—Products of combustion—Water vapour—Carbon dioxide and its properties—Incomplete combustion—Carbon monoxide and its formation—The toxic action of carbon monoxide and its treatment—The phenomena of combustion—Incandescence—Flame and smoke—The formation of smoke and its nature—The effect of smoke on the atmosphere, and the part it plays in inducing the formation of fog.

ALTHOUGH it was not until the eighteenth century was nearing its close that a true conception of the actions taking place during combustion was arrived at, the fact that heat was most economically obtained by the burning of certain substances, mostly of vegetable origin, was realised from the era when fire worship constituted one of the world's most important beliefs, and the slowness of the advance which was made during the centuries that have elapsed since then is shown by the time it took for the displacement of wood as the universal fuel by coal.

When, however, this point was reached, the use of fuel quickly increased, and the past century marks a period

which will always stand forth as being that in which the energy locked up in our coal deposits was first laid under contribution for the generation of steam power as well as for ordinary heating, with the result that the wealth and power of nations fortunate enough to possess coal fields have grown with startling rapidity, and the fifty years 1857—1907 have been the most prosperous the world has ever known.

It was in 1781 that James Watt patented the first rotary engine, and so initiated a method by which heat energy could be translated into mechanical work, whilst it was not until 1807 that Fulton made the first steam-boat that was a commercial success, and Stephenson only gave the world the locomotive in 1829.

During the past quarter of a century liquid and gaseous fuels have been added to our energy creators, and have been firmly established as rival heating agents in cases where their ease of application, under special conditions, has rendered their use economically advantageous.

Whether heat energy is obtained by the combustion of such solids as wood or coal, or by the burning of fuel oils or gases, a knowledge of the chemical and physical actions causing the combustion and governing the course which it takes, is essential to its successful application, and a short description of the researches which, in the latter half of the eighteenth century, revealed the true nature of combustion, will best lead to a clear conception of its nature.

Antoine Laurent Lavoisier was born in France in 1743, and living at a period when the old alchemical ideas were merging into the true science of chemistry, he did much to justify the title the French nation is so fond of bestowing on him, "The Father of Modern Chemistry," and between the years 1765 and 1794, when the guillotine of Robespierre cut his memorable career short at the early age of 51, he gave to the world a true explanation of the actions taking place during combustion.

Early in his career Lavoisier noticed that air was necessary for combustion, and that if a candle were placed in an enclosed space with a limited supply of air, it gradually burnt dimmer and dimmer, and in a short time went out. Noticing this fact he continued to experiment, and amongst other things found that if he took a candle and enclosed it in such a way that all the products of combustion which came from it were collected and weighed, the gases developed weighed more than the candle itself had done.

The discovery that air was needed for combustion and that the products of combustion weighed more than the body burnt enabled Lavoisier to attack and overthrow the phlogistic theory of Stahl, which had ruled supreme during the earlier years of the eighteenth century, and which attributed combustion to the escape of something pre-existing in the combustible material.

The discovery of oxygen by Priestley in 1774 enabled Lavoisier, a few years later, to explain the actions which take place when substances burn in air, and led him to the great discovery of the fact that air was not an element, as up to that time had been supposed, but contained two perfectly distinct gases, oxygen and nitrogen.

Although the researches of Priestley and Lavoisier showed conclusively that air was not an element, but contained the two gases oxygen and nitrogen, it had still to be shown whether these two gases were present in it in the state of mere mixture, or whether they were combined together as a definite chemical compound.

When in mechanical mixture the distinctive properties of the substances present are retained, although often modified by the properties of the other constituents: but in a chemical compound the properties of the original factors entirely disappear, and are merged into new characteristics distinctive of the compound formed. In determining whether a given substance be a compound or merely a

mixture, a most important point to be ascertained is whether it varies in composition or not. A chemical compound is unalterable in composition, so that if a substance be a true compound it will always consist of the same elements combined in exactly the same proportions.

During the years that Priestley and Lavoisier were making their memorable experiments on the composition of air, the Hon. Henry Cavendish was also devoting his life to the cause of science, and these three men did much to make the close of the eighteenth century a most remarkable epoch in the history of both chemical and physical science.

Cavendish, who was one of the wealthiest men of his day, devoted his whole life and wealth to scientific research, and it is to him that we owe the first exact determination of the relation existing between the oxygen and nitrogen in air. In the year 1781 he made nearly four hundred determinations of the composition of air in order to find whether the amount of oxygen in it varies to any appreciable extent. For this purpose he determined the amount present under every possible condition of weather; but no matter if the weather were fair or clear, wet or foggy, no difference of which he could be certain could be detected.

He likewise experimented to see whether the air in London differed from the air in the country; but the results of all his experiments so closely agreed that the differences came well within the limit of experimental error found in the rough processes of analysis then in use. He finally came to the conclusion that 100 volumes of air contain 20·83 parts by volume of oxygen. The remarkable constancy of his results naturally led him to the conclusion that air was a chemical compound, an opinion which was shared and strongly upheld in the succeeding years by Prout, Dobereiner, and Thomson, all of them maintaining that air was a chemical compound of one volume of

oxygen with four volumes of nitrogen. Chemists were, however, not wanting to oppose this idea, and foremost among these was John Dalton, the father of our present system of chemical theory, who held that air was merely a mechanical mixture kept in a constant condition by certain natural forces. He also propounded the theory that, because nitrogen is lighter than oxygen, there must be a larger proportion of oxygen present in the air near the earth's level than at an altitude from its surface. In this, however, he was wrong, for as Gay-Lussac and Thenard afterwards showed, the air at a considerable height contains the two gases in exactly the same proportion as at sea level—a fact which they proved by going up in a balloon and collecting samples of air at a considerable altitude. Their results have since been corroborated by Brunner, who analysed air taken at the bottom and at the top of some of the highest of the Swiss mountains.

Before, however, this war of compound versus mixture could be brought to a satisfactory conclusion, it became necessary to institute newer and more accurate methods of analysis, and when this was done the researches of Bunsen, Leroy, and Regnault demonstrated that the atmosphere shows sensible, though very small, variations in its composition—normal air containing 20·9 to 21 per cent. of oxygen, although under abnormal conditions, more especially in warm and swampy countries, the percentage sometimes falls as low as 20·3 per cent. It was from the observation of these small discrepancies in composition that, in the middle of the last century, the conclusion was finally arrived at that the atmosphere was a mechanical mixture and not a chemical compound, and that the ratio in which its two main constituents exist is—

	By weight.	By volume.
Nitrogen	76·9	79·1
Oxygen	23·1	20·9

It is usual to speak of all gases besides oxygen and nitrogen which are present in the atmosphere as impurities, but this is manifestly incorrect, as there are several compounds present to a greater or less extent, which are absolutely essential for the carrying out of nature's laws, and which do not become real impurities unless they rise above a certain limit.

These compounds are carbon dioxide, water vapour, ammonia, and nitric acid; the water vapour being almost as essential as oxygen and nitrogen for animal and vegetable life, whilst the others are needed for certain phases of plant life.

Inasmuch as the atmosphere entirely enfolds the world in a vast aeriform mantle, it is evident that all gaseous impurities escaping from the surface of the earth must find their way into it, and we can form a very sound judgment as to which of these constitute the real impurities, and which are only impurities after a certain limit is reached, by noticing their distribution in nature. The impurities pure and simple only exist at those spots where the causes which give rise to them are to be found, whilst the natural impurities, or, more correctly speaking, "minor constituents," are equally distributed throughout the atmosphere.

The average composition of atmospheric air may be taken as being—

Oxygen	20·61
Nitrogen	77·95
Carbon dioxide	0·04
Water vapour	1·40
Nitric acid	trace
Ammonia	trace
	100·00

All the marked characteristics of air are derived from the oxygen, which is a colourless, odourless, and tasteless gas, possessing the property of entering into vigorous chemical combination with such substances as are generally spoken of as being combustible, whilst it will combine with all the elements with the exception of fluorine.

The nitrogen, on the other hand, is marked by extreme inertia in its power of combining with other elements, and in the atmosphere one of its chief functions is diluting the too vigorous oxygen.

Nitrogen neither supports combustion nor does itself burn in the ordinary acceptance of the term, but inasmuch as it forms no less than five compounds with oxygen, it is evident that this phenomenon is due to our inability to produce a sufficiently high temperature to bring about a direct combination. That this is the true explanation is manifest from the fact that compounds of oxygen and nitrogen are to be found in the atmosphere after thunderstorms or other electrical disturbances, whilst an electric spark passed for some time through a confined volume of air soon causes it to assume a brown tint from the formation of some compounds of nitrogen and oxygen, so that at the temperature of the electric spark it is evident that the nitrogen becomes inflammable.[1]

Nitrogen gas can be collected over water, but as it is very sparingly soluble, 100 volumes of water only dissolve $1\frac{1}{2}$ volumes of gas at ordinary temperatures. It is a tasteless, odourless, and colourless gas, which, although so inert in its behaviour towards most substances, combines with some of the rarer elements, such as tungsten and titanium, with such energy that they become incandescent when thrown into the pure gas.

In comparing the weights of gases, hydrogen, which is the lightest gas known, is always taken as unity, and the weight of equal volumes of other gases measured off at the

[1] See note (1) on p. 23.

same temperature and pressure are compared with hydrogen, in order to give what is called the density of the gas, which expresses how many times it is heavier, volume for volume, than hydrogen. Oxygen is found to have a density of 16, whilst nitrogen is 14, and the atmospheric mixture of the two gases is 14·47 times heavier than an equal volume of the standard gas.

Lavoisier, having ascertained many of the more important of these facts with regard to the atmosphere, then continued his experiments upon combustion, and using oxygen as a medium, burnt in it such bodies as phosphorus, sulphur, and charcoal, and noticed the great increase in brilliancy and vigour of combustion brought about by the absence of the diluting nitrogen, and further found that not only did such substances as burn in air burn with exaggerated effect in oxygen, but that many substances not generally looked upon as combustible will, under its exciting influence, undergo vigorous combustion, zinc and steel burning in the gas with the most brilliant effects.

In all these cases the phenomena observed are dependent upon the formation of combinations of oxygen with the bodies burnt, the phosphorus yielding phosphorous pentoxide, the charcoal carbon dioxide, the sulphur the gas known as sulphur dioxide, whilst the steel, the only one of these substances, be it noted, which burns absolutely without flame, gives the solid oxide of iron as the result of the chemical action.

During these combinations energy is developed, and owing to its intensity by concentration into a short space of time, this energy manifests itself as heat and light.

Here, then, is to be found the key to all the actions which we speak of under the general term of "fire," and further experiment soon shows that in order to start this rapid combination between the substances oxidised and the

oxygen of the air, it is only necessary to heat the combining bodies to a temperature known as the "ignition point," a temperature which varies very widely with different substances, but which is a constant factor in all bodies of the same composition. Some substances, such as certain organic compounds with zinc, ignite below the ordinary air temperature, and such bodies are called "spontaneously inflammable," whilst others, like phosphorus, have only to be slightly warmed in order to produce the rapid combination known as combustion. Others, again, like coal, have to be heated to a temperature of a little over 500° C. before their ignition point is reached, whilst bodies like steel, having their ignition point above the temperature reached in ordinary combustion, are looked upon, as a rule, as non-combustible.

The spread of ordinary fire and flame is due to the fact that when combustion is started by the ignition point being reached, the combustion raises the temperature generally well above the ignition point of the burning body, so that as one particle burns it ignites the next, and this action continues until the burning body has entirely combined with oxygen, but if the heat generated be insufficient to raise the body to the ignition point, combustion ceases as soon as the external heat is withdrawn. In the case of a watch spring burning in oxygen gas, the combustion of a piece of German tinder attached to the end of it is sufficient under the exciting influence of the pure oxygen to raise the spring to the point of ignition, and then the temperature developed by the oxidation of the metal in the oxygen is sufficient to continue the combustion until the whole of the spring is burnt away. If, however, instead of allowing the action to go on in the pure oxygen the spring, whilst still vividly burning, is withdrawn from the jar of oxygen into the air, combustion ceases after a few moments, owing to the dilution of the oxygen in the atmosphere by nitrogen lowering

the intensity of the combustion, so that the ignition point of the metal is no longer reached.

Although the igniting point of any substance is a fixed and unalterable temperature, the size of the mass to be ignited plays a very important part, as the smaller the mass the more easy it is to raise it to the ignition point.

For instance, iron ignites at about 1,500° C., and gunpowder at a little over 250° C., yet if some alcohol in a dish be ignited and finely divided iron dust be thrown into it, the iron burns brilliantly in the flame, whilst grains of gunpowder may be thrown through the flame without ignition and will remain unacted upon in the alcohol until it is nearly all burnt away, when the flame, burning down to them and being in contact with them for some time, heats them to the necessary temperature, and so ignites them. In the same way a very small flame held in contact with a block of wood fails to ignite it, whilst a splint or shaving cut from the block is easily ignited by the same flame.

So far we may summarise the facts with regard to combustion by saying that combustion is the generation of energy as heat by extremely rapid chemical combination, which is brought about by the ignition point of the substances entering into combination being attained.

Although the ignition point marks the temperature at which ordinary combustion gives rise to the phenomena of light and heat, the same chemical action may be proceeding at temperatures short of the ignition point, but at so slow a rate that the energy developed is able to spread itself to the surrounding objects, and so escapes notice.

All those processes utilised by Nature for the cleansing of the surface of the earth and the conversion of waste matter back into carbon dioxide and water vapour, which are the food of Nature, and from which she can reconstruct everything anew (processes which are generally spoken of as decay) are actions of this character. It must, however,

be remembered that for a given weight of material converted by chemical combination into the same compounds, whether the action be slow, as in decay, or rapid, as in ordinary combustion, the total amount of heat generated is the same, the only factor in the action which varies being the length of time over which the development of energy is spread.

A tree left to rot upon the ground gradually disappears in the course of years, being mainly oxidised into gaseous products such as carbon dioxide and water vapour, and yet scarcely any evolution of heat is observed, although the same amount of heat is generated as if the tree had been cut into logs and burnt.

It has been seen that if a steel watch-spring be taken, and a small piece of German tinder attached to the end of it is ignited and plunged into a vessel of oxygen gas, the combustion of the tinder ignites the watch-spring, which burns away in the gas with the greatest brilliancy, and the evolution of heat is sufficient to fuse the metal, the final result being that the watch-spring is converted into a chemical compound of iron and oxygen.

The amount of heat developed in this experiment can be approximately judged by the fact that the steel watch-spring is fused as it burns, and it is known that this requires a temperature of 1,500° C. If, however, a second watch-spring be taken, of the same weight as the first, and exposed to moist air for two or three months, it would also be converted into oxide, but in the slow rusting away of the metal no appreciable heat could be distinguished, it having been dissipated to the earth, the air, and the surrounding objects as rapidly as it was generated. If, however, one could construct a calorimeter sufficiently delicate to measure all the heat evolved during the slow rusting away of the metal, it would be found that exactly as much heat had been developed as would have been the case had it been

burnt away in pure oxygen. Indeed the atmospheric rusting of iron may become so rapid as to create a temperature sufficiently high to attract attention: as for instance, when a mixture of sawdust and iron filings is swept up from a workshop floor and the heap moistened with water. After a few hours it is found that steam is being evolved, the heat of oxidation having been kept in by the non-conducting sawdust until the temperature had risen to the evaporation point of the water.

The more finely the iron is divided the larger will be the surface which it will present to the oxidising influence of the air, and if by chemical means we prepare extremely finely divided iron in an atmosphere devoid of oxygen, on throwing the powdered iron into the air it rusts so quickly as to become red hot.

The action taking place below the ignition point is chemically identical with the action taking place during rapid combustion, and only differs from it by being spread through a longer space of time, and is therefore called "slow combustion."

In our fuels, be they solid, liquid, or gaseous, we find that the elements entering into combination with oxygen during combustion and generating the heat energy are hydrogen and carbon, the former burning to water vapour, whilst the latter produces either carbon dioxide or carbon monoxide, according as there is an abundance or shortage of atmospheric oxygen present.

These gases, because water vapour at the temperature of combustion may be looked upon as a gas, are called "the products of combustion," the water vapour and carbon dioxide being products of complete combustion, and the carbon monoxide the product of incomplete combustion, the latter being capable of a further combustion with a fresh supply of air.

Whenever hydrogen, or any compound containing hydrogen, such as paper, wood, coal, oil, coal gas, etc., burns in

air or oxygen, the hydrogen and oxygen combine in the ratio of 2 parts by weight of hydrogen to 16 parts by weight of oxygen to form water; and weight for weight the combustion of hydrogen produces a greater amount of heat than any other known substance, 1 lb. of hydrogen in combining with 8 lbs. of oxygen giving out sufficient heat to raise 34,500 lbs. of water through 1° C. The Centigrade scale differs from the Fahrenheit in that the point at which water freezes is called "zero" in the Centigrade, and "32" on the Fahrenheit scale: and the boiling point on the former is 100, whilst with the latter it is 212, and tables will be found in the Appendix facilitating the translation of temperatures and heat values from the one scale to the other.

When carbon or carbon compounds burn in a free current of air so that ample oxygen is present to complete the combustion, 12 parts by weight of carbon unite with 32 of oxygen to yield carbon dioxide, and the heat generated by the combination of 1 lb. of carbon with 2·65 lbs. of oxygen is sufficient to raise 8,137 lbs. of water through 1° C.

The gas so produced, carbon dioxide, is a clear colourless gas, possessing a peculiar slightly acid taste and smell: it is a heavy gas, being twenty-two times as heavy as hydrogen, and can be poured from one vessel to another like water. It does not burn or support combustion in the ordinary sense of the term, but a piece of the metal potassium heated in an atmosphere of the gas will burn in it, decomposing it, and forming potassium oxide and depositing flakes of carbon. Carbon dioxide is very soluble in water, the water, under normal conditions of temperature and pressure dissolving its own volume of the gas: that is to say, with the barometer at 30 inches and at a temperature of 15° C one pint of water will dissolve one pint of the gas. If a change be made either in the temperature of the water or the pressure a corresponding alteration will take place in the amount of

gas dissolved, a lowering of the temperature or an increase in the pressure causing the solution of a greater quantity of gas. When however the standard conditions are restored the excess of gas will escape, causing the water to effervesce. The gas can be condensed to a liquid by extreme cold and pressure.

Carbon dioxide in its chemical properties very much resembles nitrogen, but can be distinguished from it by its giving a white precipitate when agitated in contact with a solution of lime in water, when a white precipitate of chalk or calcium carbonate is formed from the combination of the carbon dioxide with the lime or calcium oxide; the weight of the gas also serves to differentiate it from nitrogen.

When a mass of incandescent carbon is fed with an insufficient supply of air or carbon dioxide is passed over incandescent carbon, a lower oxide of carbon, containing only one half the quantity of oxygen found in carbon dioxide, is produced, and 12 parts by weight of carbon unite with 16 of oxygen to form carbon monoxide.

In the combustion to the lower oxide a far less amount of heat is developed: when 1 lb. of carbon burns with 1,325 lbs. of oxygen to produce it the heat generated would only raise 2,489 lbs. of water through 1° C.

The gas differs very widely in its properties from the dioxide. It is colourless and tasteless, it does not itself support combustion, but is inflammable, burning with a pale blue flame, in which process it takes up another atom of oxygen and becomes carbon dioxide: it has no action on lime water, and is only 14 times heavier than hydrogen. Owing to its capacity for combining with more oxygen to form the higher oxide of carbon, the gas has a powerful reducing action, and will take the oxygen from several of the metallic oxides under the influence of heat, leaving the metal free. This action is utilised in many commercial processes for the reduction of different metals from their ores.

Carbon monoxide has such powerful poisonous properties that less than 1 per cent. of it in air causes death when inhaled, and many fatal accidents have arisen from its being formed during checked combustion, as when metal surfaces cooled by water are exposed to a gas flame, as is the case in some forms of "water heaters": also by the imperfect combustion taking place in kilns, in slow combustion stoves, and in charcoal pans. The gas acts as a poison by forming a compound with the hæmoglobin of the blood, and preventing it from carrying on its natural function of taking up oxygen during respiration and carrying it to the capillaries of the body.

Dr. J. S. Haldane, who has made a special study of the toxic action of carbon monoxide, gives the following data as to the effect of the gas on man :—

Percentage of Carbon Monoxide.	Effects on Man.
0·05	After half-an-hour to two hours, giddiness on exertion.
0·1	,, ,, ,, inability to walk.
0·2	,, ,, ,, loss of consciousness and perhaps final death.
0·4	,, ,, ,, probable death.
1·0	After a few minutes loss of consciousness, followed before long by death.

The treatment for carbon monoxide poisoning or "gassing," as it is usually termed, is to apply artificial respiration without a moment's delay, if the breathing has ceased or is feeble. The use of oxygen is a valuable adjunct to recovery. Whilst artificial respiration is being applied, the oxygen should be supplied to the patient from a cylinder of compressed oxygen, provided with a length of rubber tubing terminating in a metal mouthpiece which is placed loosely in his mouth, and the oxygen supply should be continued for at least ten minutes. A person who has been

seriously gassed, even if he is not unconscious, should be kept warm, and protected as much as possible from cold air, which often causes sudden and dangerous fainting. He should also be prevented from exerting himself by walking, and should be kept lying down for some time. If there is any tendency to spontaneous fainting a little brandy or whisky should be given.

The ordinary phenomena of combustion consist of incandescence, flame and smoke, and, as has been shown, these are caused by the heat energy liberated during the combination of the burning body with the oxygen of the air. If the substance burnt be a solid, which is non-volatile at the temperature of combustion, or is not decomposed by it into gaseous products before burning, incandescence alone is the result of the combustion, and the colour of the light given by the glowing fuel is a fair indication of the temperature of the burning mass.

With most ordinary solids the power of emitting light seems to differ but little, *i.e.*, they mostly emit light of the same intensity and character when heated to the same temperature. The following table, giving roughly the character of the light for different degrees of heat, is the one most usually quoted, although the higher temperatures are open to doubt.

Just glowing in the dark	525°C.	977°F.
Dark red . . .	700	1292
Cherry red . . .	908	1666
Bright cherry red . .	1000	1832
Orange . . .	1150	2102
White	1300	2372
Dazzling white . .	1500	2732

Flame, the second phenomenon of combustion, is in all cases caused by the combustion of gaseous matter. We know that if bituminous coal or resinous wood be burnt

flame is formed, whilst if coke or charcoal be used as the fuel no flame accompanies the primary combustion, this being due to the fact that in the former case hydrogen and carbon in various forms of combination are driven out from the coal or wood by the temperature generated in the combustion, and being in the form of gaseous or vaporous products, burn with flame. When these hydrocarbons have been got rid of however in the gas-maker's retort or the charcoal burner's heap, it is the residual carbon alone that burns, and being non-volatile at the temperature employed, no flame results, save under certain conditions which lead to the formation of carbon monoxide.

The smoke which accompanies most ordinary forms of combustion is a product of great complexity, and differs very widely with the nature of the substances being burnt.

Of the three gaseous products of combustion steam alone plays an important part in the formation of smoke, whilst the other important constituents are tar vapour, minute particles of unburnt carbon, and ash, drawn upwards by the draught created by the fire.

The popular idea held by many is that smoke consists mainly, if not entirely, of particles of carbon rendered slightly adhesive by tarry matters, and that it is in fact like the soot found deposited in the chimney. But a microscopic examination of smoke reveals a far more interesting condition of things. A very beautiful experiment, first made by Mr. Frederick Hovenden, is to show that if one takes the smoke from a cigar or cigarette, and blows it into a little glass chamber highly illuminated from below by focussing upon it the beam from an electric lantern or limelight, and examines it under a microscope, it presents a most remarkable and wonderful appearance. Such smoke contains no particles of free carbon, but appears to consist of an immense number of little round particles in the wildest condition of commotion and movement, each particle rushing

about and never coming in contact with its neighbour. Indeed, it presents as beautiful a picture as one could imagine of the molecular movement with which theorists have endowed matter. On still further examination these little particles prove to be tiny vesicles, the skins of which are formed of condensed vapour and liquids from the burning substances which give rise to them. These vesicles, being filled with gases, are excessively light, and float in the atmosphere until brought forcibly in contact with some surface, which causes them to burst and deposit the liquid film, so setting the contents free.

Whether this cloud of floating vesicles be derived from a cigarette, a coal fire, or other source, if they are collected in such a way as by friction to cause the tiny vessels to burst, one obtains a liquid which comes under the generic heading of "tar," this tar being a highly complex mixture of many different organic liquids formed by the action of heat on the constituents of the burning matter, whilst the gases which escape from the interior of the vesicles on the rupture of the skin consist of nitrogen, carbon dioxide, carbon monoxide, hydrogen, traces of oxygen, and such hydrocarbons as methane.

The smoke, however, from the combustion of coal or oil, when burnt with an insufficient air supply, forms a heavy black cloud, the deepening of density and colour being due to the presence in it of minute particles of unconsumed carbon, which have been deposited by premature cooling or during secondary chemical actions taking place in the flame of the burning material.

The domestic grate using bituminous coal is the chief cause of the smoke curse which pollutes our town atmospheres. Coal of a bituminous character was first introduced as a fuel in the thirteenth century, but the smoke it gave rise to appeared so serious a drawback to those unaccustomed to it that in 1306 a decree was passed

forbidding its use. Time, however, somewhat allaying the apprehensions concerning the various properties of the smoke, coal was again used, only to be again banished as a fuel in the reign of Queen Elizabeth. Its use being once more revived, there were always found reformers to protest against it, and each century since has seen one or more crusades directed against the production of smoke and the pollution by it of our town atmosphere, but there is little chance of success in the abolition of smoke until gas and coke take the place of coal as a general fuel.

The idea that smoke means a large waste of fuel is erroneous, and, in point of fact, the carbon wasted as soot is extremely small, and varies in smoke with the state of the fuel which is fed on to the fire. Under the ordinary conditions experienced in an ordinary fire grate, in which the fire has just been made up with bituminous coal, the heavy smoke escaping will contain on an average $1\frac{1}{2}$ per cent. of the total weight of fuel consumed, and as the temperature of the mass gradually increases, this falls to less than $\frac{1}{2}$ per cent., whilst when the fire is burning clear, no smoke at all is given off. In the same way that we have a rapid fall in the carbon given off as soot, so we also find a fall in the hydrocarbons liberated as tar vapour, whilst the gases evolved as products of combustion vary in the same way with the condition of the fire. When the coal is first put on the fire imperfect combustion in its mass takes place, and the gases passing up the flue under these conditions will closely approximate to the following analysis—

Carbon dioxide	0·70
Methane	0·36
Hydrogen	0·29
Carbon monoxide	0·01
Oxygen	19·85
Nitrogen	79·79

showing that the combustion, owing to the cooled surface at the top of the fire and excessive dilution with the inert nitrogen, is very incomplete. Gradually, however, as the temperature rises, less and less combustible matter escapes, whilst as soon as the fire begins to burn clear, the products of combustion are practically simply carbon dioxide and water vapour.

This applies to the open fire grate, and also to a great extent to the combustion taking place in a furnace. When we come, however, to examine the solids escaping into the atmosphere under the influence of the stronger draught in the boiler furnace, we find that the solid matter contains large quantities of particles of ash and finely divided organic matter sucked up by the chimney draught.

Smoke formed by these processes finds its way from the chimney into the atmosphere, and is rapidly diffused through the air by means of the air currents, and it is manifest that if there were no means of removing it, the air would soon become perfectly opaque from its accumulation in large quantities. When, however, rain falls it rapidly washes the air free from such suspended solid and liquid impurities, which constitute the visible portion of smoke. Snow is even more efficacious than rain in doing this: where the snow has fallen on the glass roof of a greenhouse it will be noticed that when it melts it leaves behind a black deposit, consisting of the solid matter it has collected in its passage through the air.[1] An analysis of a deposit of this character formed on glass roofs of some orchid houses at Chelsea gives a very good idea of the constituents of these solid impurities—

Carbon	39·00 per cent.
Hydrocarbons . . .	12·30 ,,
Organic bases . . .	1·20 ,,
Sulphuric acid . . .	4·33 ,,

[1] See note (2) on p. 23.

Ammonia	1·37 per cent.
Metallic iron and magnetic oxide	2·63 „
Other mineral matter, chiefly silica and ferric oxide .	31·24 „
Water not determined.	

In cases where long drought prevents the rapid clearance of the air by this means, the heavier of the solid particles settle by gravity, whilst the particles of carbon and carbonaceous organic matter are slowly oxidised by the oxygen and ozone into carbon dioxide, in which form vegetation removes them from the air.

There have not been wanting people who have absolutely defended smoke, declaring that its presence in the air of large towns was most healthful and kept down the percentage of contagious diseases by the absorbent and antiseptic properties of the carbon and hydrocarbons included in its constituents. There are not probably many at the present time who are prepared to take this view of the case, as the amount of free carbon which could exert any absorbent action on deleterious substances is so excessively minute that its action in this direction may be entirely disregarded, whilst the hydrocarbons which may or may not contain substances like creosote are also too limited in quantity to do good in this way. Moreover, if we could credit them with a slight beneficial action in this direction, we must also remember that deleterious action can be proved to be due to their presence. In the first place, solid particles of all kinds set up irritation in the lungs, and so add their iota to the increase of diseases of the chest, whilst the rapid dirtying of buildings and the peculiar characteristics of London fog can undoubtedly be traced to the smoke-laden air.

Fog, whether it be in the form of white mist which is

found in the country or the yellow abomination which we know so well in town, is formed by the condensation of water vapour in the air, and this is brought about by any cause which rapidly cools a large volume of moist air. If, instead of the surface of the ground and the objects on it only being cooled, the air for a considerable height above it is also lowered in temperature, then the moisture which is deposited from it, instead of forming dew, condenses in the air, forming particles so minute that they remain suspended and floating in the air, and constitute fog or mist. In pure air the mist so formed consists of little else than these minute drops of water, and has no irritating effect on the eyes or lungs. But in a large town like London the air is charged with an enormous number of minute particles, the heaviest of which settle on a horizontal or roughened surface in the form of dust, whilst the lighter particles continue floating in the air. These particles of dust consist of a heterogeneous collection of all kinds of matter—ground-up particles from the roadway reduced to an impalpable powder by the incessant traffic, small organic spores, which are the germs of organic decay and disease, and particles of unconsumed fuel which have escaped from our chimneys in the form of smoke, and which in larger masses form "blacks." All these floating solids cool with great rapidity, on account of the smallness of their bulk, and in doing so cause the rapidly cooling air to deposit moisture upon them, and so aid in the formation of the fog.

The air of towns in which much coal is used also contains the volatile tarry matter distilled off during the imperfect combustion, and this condensing with the moisture coats it on the outside with a thin film, which does much to prolong the existence of the fog, as when the temperature of the air again rises, the clean mist is once more absorbed by the atmosphere, but the tar-coated yellow fog has its power of evaporation retarded to an enormous extent. Experiments

made by the late Sir E. Frankland show that the evaporation of water in dry air is reduced nearly 80 per cent. by blowing some smoke from burning coal on to its surface.

Many proposals have from time to time been made with the idea of abolishing, or at any rate reducing, the polluting influence of improper fuel and faulty combustion on the air, and anthracite, coke, and stoves of weird device have all had their advocates, and it is quite certain that cleansing the atmosphere of our big towns will only become a practical success when bituminous coal is abandoned as a domestic fuel, and is replaced by coal from which the smoke-forming constituents have been eliminated and by gaseous fuel.[1]

[1] See note (3) below.

(1) The electric arc method of manufacturing nitric acid and nitrates from the air is now carried on upon a large scale in Norway and Switzerland; and a chemical oxidation process, which prior to 1905 was regarded merely as an interesting lecture experiment, has become the basis of a flourishing electrochemical industry. The first factory of this kind was erected at Notodden in 1905, and to-day the larger portion of the 1,000,000 H.P. developed from waterpower in Norway is devoted to the fixation of atmospheric nitrogen either by the original Birkeland and Eyde method or by one of its modifications.

(2) A Committee for the Study of Atmospheric Pollution was formed in London in 1912—and since that year this Committee, acting in conjunction with the Municipal Health authorities of our more progressive cities, has carried out a most valuable series of observations upon the Soot- and Dust-fall of London, Birmingham, Liverpool, Glasgow, Newcastle, and many other cities and towns of the country.

The detailed figures giving the results of the observations have been published in five annual reports, and these contain a mass of valuable information upon the amount and character of atmospheric pollution in the cities and industrial towns of the United Kingdom.

(3) The efforts at present being made upon an industrial scale to solve the technical and financial problems connected with the production of a cheap fuel which will burn smokelessly in the open type of fire-grate will no doubt be crowned ultimately with success—and the domestic smoke problem will then be solved without sacrifice of the average English-man and woman's love of the "domestic hearth."

"Coalite" suffered from the unwise financial boom which accompanied its introduction to the public notice before the technical difficulties of its production had been properly studied or overcome. The difficulties attending low temperature carbonisation are now being attacked in the right way, and before many more years have elapsed this method of coal carbonisation is certain to be adopted in our gas works in order to increase the yields of valuable liquid and solid fuels—and the whole efforts of the gas engineer will not be devoted, as at present, to the production of the largest possible yield of gas without any regard for the other valuable products of the carbonisation process.

CHAPTER II.

FUEL, ITS FORMATION AND COMPOSITION.

The cycle of animal and vegetable life—The growth of vegetation—Cellulose—Wood as a fuel—Charcoal—Peat—The formation of coal—Checked decay—Variation in composition due to geological change—The influence of hydrogen in coal—Methane or marsh gas—Fire damp and choke damp—Safety lamps—Coke—Mineral oil—American and Russian oil—Fuel oils—Gaseous fuel—Producer gas—Water gas—Carburetted water gas—Coal gas—Natural gas—Hydrogen—The elements—The three states of matter—Molecules and atoms—Symbols and their use—Carbon and its combinations.

COMBUSTION being merely the development of heat energy during excessively rapid chemical combination, and fuel being the name which custom has given to the substances which enter into combination with the oxygen of the air with the development of sufficient heat to produce incandescence, it is clear that the name "fuel" might be applied to anything which would satisfy these conditions, but usage has limited the term to those bodies which are sufficiently abundant and easily obtainable to allow of their universal employment for the generation of heat, and amongst the solid fuels all are derivatives of vegetable growth.

In the whole of Nature there is nothing more beautiful than the wonderful cycle by which matter is kept in circulation by the compensating agencies of animal and vegetable life. As was shown in the last chapter, the process of combustion taking place below the ignition point gives in Nature all those phenomena which we call decay, and in

the vegetable kingdom the actions for the most part set up by certain germ growths convert waste matter into atmospheric carbon dioxide and water vapour, while the processes of life carry on an action of the same kind in the living body, the burning up of the tissues of the body by the slow process of internal combustion giving warmth to the body and the energy needed for all actions, voluntary or involuntary.

It is in this process that respiration and the circulation of the blood supply blood-borne oxygen to the tissue, and the actions which ensue convert that tissue into carbon dioxide, respired from the lungs, and water vapour, respired from the lungs and also thrown off from the skin, the tissue as used being renewed by the assimilation of food and drink. In this way the tissues of the body are continually undergoing destruction and renewal, and it has been computed that a period of something like seven years suffices for the complete renewal of the whole of the body, with the exception of the skeleton, so that during life the constant using up of oxygen from the atmosphere and its conversion into water vapour and carbon dioxide take place.

After death the same action continues by a process of decay with even greater rapidity, and the albumen of animal matter containing sulphur, this also becomes disengaged in combination with hydrogen and organic matter, yielding those malodorous gases and vapours which mark the progress of decomposition.

In the early half of the last century the great chemist Faraday calculated the total amount of oxygen present in the atmosphere, and found that there were present no less than 1,178,158,000,000,000 tons; but enormous as this quantity is, the amount which is daily used up by processes of animal life, combustion, and decay would rapidly cause a deterioration in the atmosphere.

It was Faraday also who first calculated approximately

the amount of the life-supporting constituent of the air which is in this way daily used up, and his results are tabulated as follows:

	Lbs.
Respiration of whole population . .	1,000,000,000
Respiration of animals. . . .	2,000,000,000
Combustion and fermentation . .	1,000,000,000
Decay and other processes . . .	4,000,000,000
	8,000,000,000

8,000,000,000 lbs. = 3,571,428 tons in a day, or 1,304,642,357 tons in a year, a rate of consumption which would use up the total oxygen present in about 900,000 years: but it must be remembered that the withdrawal of even 1 per cent. of the oxygen present would exercise a serious effect upon the health of men and animals, and that moreover the withdrawal of the oxygen is due to its conversion into carbon dioxide, which would itself rapidly render the air unfit to breathe.

It is manifest from this that Nature must have at hand methods not only for the removal of carbon dioxide from the air, but also for the production of oxygen, as otherwise the composition of the atmosphere, instead of being so constant as to defy the detection of any considerable variation, would rapidly deteriorate and become unfit to support life.

The main factor in this natural regeneration is to be found in the plant world, as it is the growth of vegetation, urged on by the power of the sun, which performs the work of undoing the vitiation of the atmosphere by animal life, and once more liberating oxygen from the carbon dioxide.

The surface of every form of vegetation contains innumerable small openings, called "stomata," which end in little cells filled with a green colouring matter, called "chlorophyll," the presence of which gives the distinctive colour to the plant. But little is known of the composition of this

remarkable substance, which may be extracted by macerating grass or green leaves with spirits of wine, when the green colouring matter from the ruptured cells dissolves in the spirit, and yields a green solution which may afterwards be concentrated by evaporation. This chlorophyll appears to consist of two compounds, one of them a yellow substance, the other a blue, and it is generally supposed that the autumn tints are to a great extent due to a gradual disappearance of the blue colouring matter, which causes a change in colour, from green to yellow and yellowish-brown

During the growth of a plant many changes take place. As soon as the seed is germinated it begins to absorb from the soil and the air water and oxygen, and when a certain stage is reached the formation of chlorophyll commences, and from that moment the growth of the plant is as dependent upon the air as upon the soil for its nourishment; for under the exciting influence of sunlight the chlorophyll absorbs carbon dioxide, and this, together with the water vapour partly absorbed from the air and partly drawn up from the soil, forms the constituents from which by a beautiful series of reactions Nature builds up the solid portion of the plant, fixes the energy derived from the sun in such a way that it can be regenerated on combustion, and at the same time returns the surplus oxygen to the air, so renewing the amount abstracted by decay, respiration, and combustion.

The solid portion of the plant is built up of a compound of carbon, hydrogen, and oxygen, called "cellulose," which has the percentage composition—

Carbon	44·44
Hydrogen	6·17
Oxygen	49·39
	100·00

In wood the main constituent, cellulose, is common to all species, the chief differences being in the density and constituents of the sap.

As a fuel, the value of wood varies with the amount of moisture it contains and the ash, which is made up chiefly of the mineral constituents of the sap.

The moisture in wood varies with many circumstances, such as the season of the year at which it was cut down, the species of tree, and the way in which it has been kept between the times of cutting and burning. When wood is cut in the spring, say during April, it will often contain nearly 10 per cent. more water than the same species of timber cut in the winter. For instance—

Wood.	Cut in January. Water.	Cut in April. Water.
Ash	28·8	38·6
Sycamore	33·7	40·3
Horse chestnut	40·2	47·1
White fir	52·7	61·0

It also varies in quantity according to the species of tree, the average quantity of moisture present being shown in the following table:—

Water contained in 100 parts of fresh-cut wood.

Hornbeam	18·6
Willow	26·0
Sycamore	27·0
Ash	28·7
Birch	30·8
Oak	34·7
Horse chestnut	38·2
Pine	39·7
Elm	44·5
Larch	48·6
Poplar	51·8

A certain amount of this moisture can be got rid of by exposing the wood to air and at the same time protecting it from rain, but under favourable circumstances, and after a year's exposure, air-dried wood will still contain about 20 per cent. of moisture, whilst after several years' keeping in a warm room it will often retain 17 per cent. of moisture.

For all practical purposes, therefore, wood will, under favourable circumstances, only contain 80 per cent. of combustible matter, whilst the large amount of heat absorbed in heating and evaporating the water present is a serious drawback to its employment as a fuel. The ash left on burning wood varies from $\frac{1}{2}$ to 5 per cent., and an excess of ash, as it is incombustible, must be looked upon as diminishing the value of fuels for heating purposes.

The amount of combined oxygen present in any fuel seriously detracts from its value, as its presence means that some of the combustible constituents of the fuel are already combined with oxygen, and are no longer available for generating heat.

Wood, when heated out of contact with air, yields a variety of volatile products and leaves a residue of charcoal. This charcoal is not pure carbon: it always contains oxygen, hydrogen, and a small quantity of nitrogen, in addition to the mineral constituents or ash of the wood; but the moisture and a large percentage of the combined oxygen having been got rid of, the charcoal is, bulk for bulk, a much more valuable fuel than wood, so that in cases where great local heat is required, it is preferable to convert the wood into charcoal before using.

Charcoal which is to be used as fuel is nearly always prepared in this country in charcoal heaps, in which the combustion of some of the wood subjects the remainder to destructive distillation, air being as far as possible excluded by coating the heap with clay or loam. During the partial burning of the heap, some moisture is distilled off as water, whilst the combined oxygen and most of the hydrogen escape, partly

combined together and partly combined with carbon as tar, wood naphtha, and other hydrocarbons, which distil out of the heap and are lost. In foreign countries, however, wood is frequently subjected to destructive distillation almost entirely for the sake of the tar (Stockholm tar) and pyroligneous acid which are evolved, and in order to collect these substances the carbonisation is carried on in closed vessels. When the charcoal is to be used for the manufacture of gunpowder, it must be prepared with great care and at a low temperature, superheated steam being often employed as the heating power. The rate at which the carbonisation takes place has a great effect upon the yield of charcoal obtained: with rapid heating there is a considerable loss, not more than from 17 to 20 per cent. by weight of charcoal being obtained, whilst with careful heating as much as 25 per cent. of the weight of wood taken remains as charcoal.

As a fuel, charcoal has about double the calorific value of air-dried wood.

Another kind of fuel much employed for domestic purposes in certain parts of the world is peat, which is composed of vegetable matter, generally mosses and aquatic plants, which under the combined agency of time and pressure has been converted into the spongy brownish-black substance found in the peat bogs. This peat is cut out in long square blocks, and is piled up exposed to air until dry. The relative heating power of dense, air-dried peat is about the same as wood, but when well dried and converted by pressure into briquettes it may be converted into a really valuable fuel. In composition, peat occupies a position intermediate between wood and coal, and there is no doubt that the formation of peat is a stage in the great natural process by which woody fibre is converted into the most valuable of our fuels—coal.

When any form of vegetation has ceased growing and is left exposed to moist air, the cellulose begins to decay, the

oxygen of the air once again unites with the carbon of the woody fibre, forming carbon dioxide, which mingles with the atmosphere, whilst the hydrogen and oxygen of the fibre combine as water and escape unseen into the atmosphere in the form of aqueous vapour. Consequently a tree which has been felled and left on the ground will, in the course of years, be entirely resolved into gaseous constituents once more, leaving behind only a small quantity of mineral matter which had been present in the sap sucked up from the soil, and which, had the wood been burned, would have formed the ash left behind by the combustion. If, instead of allowing the wood to decay away in free contact with the atmosphere, this action had been checked by keeping the wood under the surface of water or a sufficient layer of soil to cut off the atmospheric oxygen, a checked process of decay would have taken place, in which the oxygen present in the woody fibre would gradually have combined with carbon and hydrogen to form gaseous constituents, whilst some of the hydrogen and carbon, also combining together, would have yielded small quantities of such gaseous hydrocarbons as methane. We know by experience that if a pool of water, at the bottom of which there is decomposing vegetable matter, be disturbed with a pole, bubbles of gas rise to the surface; and if we collect and analyse them, we find that they consist of carbon dioxide and methane, which latter has from this fact been given the name of "marsh gas." Where the vegetation undergoing the checked process of decay of this kind is very abundant, a solid residue is left of the character of peat, whilst if the action is continued over a far longer period of time, and also under conditions of pressure and increased temperature, the peat becomes more dense, a larger quantity of gas is eliminated, and a form of coal results.

At one time it was supposed that coal was of mineral origin: but it has now been conclusively established that it is entirely formed from vegetable matter.

Long before man inhabited the earth, and when the atmosphere was probably far more highly charged than it is at present with carbon dioxide and water vapour, there flourished a monster vegetation, which, in its general characteristics, was not unlike a collection of the marsh plants that are now to be found in any swampy land: but, instead of growing to a height of a few inches, its exuberant growth would in some cases reach 40 to 50 feet.

This vegetation, like the marsh plants of to-day, grew with enormous rapidity, and as rapidly faded away; and by precisely the same process as that from which we obtain the peat bogs existing at the present time, so beds of far greater thickness were formed from the vegetation of that period.

Ample proof of this origin is to be found in the strata immediately above the coal seam, which abound in fossil remains of upwards of 500 different kinds of mosses and ferns; whilst in the layer immediately below the seam, fossil roots are found in abundance.

The three principal varieties of coal are lignite, bituminous coal, and anthracite. The lignite, or brown coal, is the least carbonised, and shows indications of organised structure, and also contains considerable proportions of hydrogen and oxygen; whilst anthracite is the most carbonised, and often contains little else than carbon and the mineral matter which forms the ash. The following table will serve to show the variation in chemical composition due to geological change (Butterfield):—

	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Cellulose .	44·4	6·2	49·4	—	—	—
Dry wood (average)	48·5	6·0	43·5	0·5	—	1·5
Dry peat .	58·0	6·3	30·8	0·9	trace	4·0
Lignite .	67·0	5·1	19·5	1·1	1·0	6·3
Coal . .	77·0	5·0	7·0	1·5	1·5	8·0
Anthracite.	90·0	2·5	·25	0·5	0·5	4·0

The gradual conversion of woody fibre into peat, coal, and graphite, is even better illustrated by the following table, due to Dr. Percy, in which, to show the gradual elimination of hydrogen and oxygen, the carbon is kept as a constant number:—

	Carbon.	Hydrogen.	Oxygen.
Wood.	100	12·18	88·07
Peat	100	9·85	55·67
Lignite	100	8·37	42·42
Bituminous coal . .	100	6·12	21·23
Anthracite (Wales) . .	100	4·75	5·28
Anthracite (Pennsylvania) .	100	2·84	1·74
Graphite	100	0·00	0·00

The theory that bituminous coal is a "younger" coal than anthracite is not, however, borne out by the fact that in the eastern part of Wales the coal is of a bituminous nature, gradually shading away into the anthracite found in the western portion of the Principality, as it is extremely unlikely that there is any very great difference in the age of the several parts of the Welsh coal field.

The quantity of hydrogen present in a fuel exercises an important influence upon the way in which it burns, as hydrogen is expelled at a fairly low temperature in combination with some of the carbon as gases which are inflammable at a moderate temperature. The burning gas surrounds the fuel and continues to heat it, whilst the escape of the gas leaves the remaining and less inflammable carbon in a porous condition, which is favourable to carrying on the combustion. Flame is burning gas, and therefore the nearer to pure carbon that our fuel approaches, the less the amount of flame produced by its combustion, because the smaller will be the quantity of inflammable gas evolved. Lignite contains a larger amount of hydrogen than any

other variety of coal: and it is for this reason more easily ignited, and burns with more flame than any of the others. The next in this respect are the bituminous coals, such as the Silkstone and Wallsend: whilst the anthracites are difficult to ignite, and when lit, can only be kept burning by a strong draught, this rendering them unfit for use in ordinary grates.

Our knowledge of the composition of coal is limited to the total amount of carbon, hydrogen, nitrogen, oxygen, and foreign materials which it contains: and at present we know practically nothing of the way in which these bodies are combined. There can be but little doubt, however, that it is correct to look upon it as carbon which contains, either mixed with it or combined with it, hydrocarbon compounds of much the same character as the paraffins, and also compounds of carbon, hydrogen, and oxygen of somewhat similar kind to the woody fibre from which it has sprung, whilst other compounds containing nitrogen, and probably of more complexity, are also present.

As has already been pointed out, methane and carbon dioxide are produced during the process of checked decomposition which leads to the formation of the coal. In the early days of the coal epoch, when the monster vegetation was flourishing, and the surface of the earth had hardly yet hardened, frequent changes of level took place, with the result that many of these beds of decomposing vegetable matter became covered with running water, which, bringing down with it silt and mud, gradually built up over the surface of the rotting mass a dense deposit of soil: and this hardening and undergoing various changes, enclosed the gradually forming coal and kept it under great pressure. Under these conditions the marsh gas or methane and carbon dioxide evolved could not escape, and they created for themselves, in the faults and fissures of the coal, an enormously high pressure, while the coal itself, being

slightly porous, absorbed these gases in large quantities: so that when, in mining the coal, a gallery is cut through the seam, the occluded gas escapes in considerable quantities into the workings of the mine. In some cases the gas so evolved proves to be nearly pure methane, as is shown by the following analysis:—

Methane	89·61
Nitrogen	9·61
Carbon dioxide	0·23
Oxygen	0·55
	100·00

Methane or marsh gas, when mixed with ten times its volume of air or twice its volume of oxygen, constitutes a mixture which explodes with great violence on the application of a light, forming carbon dioxide and water vapour.

In many coal mines, not only is marsh gas present occluded in the coal itself and ready to issue into the workings when a fall in the barometer takes place, but is also often found accumulated under high pressure in cavities in the coal seams, discharging itself with considerable violence into the mines from the fissures made in hewing out the coal. The gas issuing from the fissures would burn quietly if a light were applied to it, since methane is not explosive unless mixed with the air: but when the gas escapes into the workings and mingles with the air, it forms an explosive compound as soon as the proportion of gas amounts to one-eighteenth of the volume of air, the most explosive combination consisting of one volume of methane and ten volumes of air. The explosive mixture of methane and air is called "fire damp," and the gases resulting from the explosion, carbon dioxide, water vapour and nitrogen, are called "choke damp," the latter being often as fatal in its effect as the explosion itself.

The mixture of methane and oxygen requires a fixed temperature to ignite it, and unless this temperature be reached, explosion cannot result. If a piece of wire gauze is held over a gas jet, the gas may be ignited above it without the flame passing through and igniting the gas on the under side, the metallic wires composing the wire gauze conducting the heat away so rapidly that the temperature of the gas on the lower side does not rise to the point of ignition. This simple principle was utilised by Sir Humphrey Davy in the construction of the safety lamp for miners. It consists of an oil lamp entirely surrounded with fine wire gauze, through which the air can enter and the products of combustion go out, but no flame can pass from the inside to the outside of the gauze, even if the explosive gases burn in the interior of the lamp.

The old form of lamp first used was entirely surrounded with wire gauze, but it gave so feeble an illumination that the gauze immediately surrounding the flame was replaced by a glass cylinder, and until 1887 this was the best form in use. It has been shown, however, that although the flame, when burning under normal conditions, cannot pass through the gauze, yet a sudden disturbance of the air, such as is caused by the blasting of coal in the mine, will sometimes jerk the flame by a sudden impulse through the gauze, and so communicate with the explosive mixture outside.

To do away with this risk, in the later forms of lamp the wire gauze cylinder is entirely surrounded by a shield of iron plate, which prevents the direct impact of the air upon the gauze, and greatly increases the safety of the lamp. It would considerably decrease the risk of explosion in petrol and oil stores, coal stores, coal bunkers, and coaling vessels if, when a light is required, only such lamps were used, and the employment of a naked flame never allowed, as, besides the gas, it has been shown that the presence of fine dust

of coal or other combustible very much increases the liability to explosion.

In the same way that charcoal is obtained from wood by destructive distillation, so coke may be obtained from coal, the hydrogen and traces of other substances which it contains being driven off on heating it out of contact with air.

When this is done in the manufacture of coal gas, the resulting coke is called gas coke, but for many metallurgical processes coke is specially prepared in ovens from well-washed small coal, temperatures being reached at which the escaping gases are of no use for illuminating purposes, and can only be used to heat boilers, etc., but at which temperature a very dense and superior quality of coke is produced. This kind of coke is called oven or metallurgical coke.

Coke began to be made from coal in the eighteenth century, but it was well into the nineteenth before the depletion of the wood supply turned attention to coke as a substitute for wood charcoal for metallurgical processes, and it was not until 1860 that the subject of coke production attracted any scientific attention, but since then a large amount of work has been done in coke manufacture, and the means of obtaining the desired results are fairly well known.

The drawbacks of coal for such metallurgical processes as the smelting of iron are obvious, as if any coal but anthracite were used, the swelling of the mass under the influence of heat and consequent choking of the blast furnace would result, whilst the smoke, high sulphur, and friability of the coal all unfit it for use for such purposes.

Another factor which led to the special coking of coal was that in bringing the coal to the pit's mouth considerable breakage of the material took place, and that from 30

to 50 per cent. of small coal or slack was produced, and that although this only commanded a very low market price as a fuel it answered admirably for making coke from.

The characteristics needed to make a good metallurgical coke are—

1. Strength, *i.e.*, it must not be friable.
2. Infusibility.
3. Low sulphur.
4. High calorific value.

The need for strength depends upon the fact that if the coke easily broke up, in tall columns of mixed coke and ore, such as are used in the blast furnace, a crumbling of the material would take place, which would tend to choke the furnace, whilst freedom from or at any rate low percentage of sulphur is very important, as its presence in the fuel would deteriorate the metal made by its use.

Sulphur occurs in the coal largely as iron pyrites or disulphide of iron, but also as sulphate of lime and organic sulphur, and with coals rich in sulphur this element is reduced in quantity by crushing the small coal and levigating it, which gets rid of the heavy pyrites, whilst nearly half the remaining quantity is volatilised during the coking, and of the remainder some escapes as sulphuretted hydrogen when the coke on removal from the ovens is quenched in water.

It is not every kind of coal which at the temperature of the coke oven will fuse together before complete decomposition of the hydrocarbons to form a mass of sufficient density, but most bituminous slacks will do so, and when it refuses to do so the admixture of the slack of a good caking coal will often lead to good results and a high coke yield.

The composition of some English coking coals and

the coke yield from them are given in the following table :—

Source.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.	Percentage yield of coke.
Durham .	83·47	6·68	8·17	1·42	0 60	0·20	62·70
South Wales	83·78	4·79	4·15	0·93	1·43	4·41	72·60
Derbyshire .	79·69	4·94	10·28	1·41	1·01	2·65	59·32
Lancashire .	77·90	5·32	9·43	1·30	1·44	4·88	60·22

whilst a good coke will approximate to—

Carbon	92·98
Oxygen	1·30
Nitrogen	0·23
Sulphur	0·27
Ash	5·22
	100·00

The heating effects produced from coke are theoretically a little better than those obtained from coal, but in practice the amount of heat obtainable from coal and coke is about the same.

It was not until the middle of last century that the oil industry and oil as a fuel may be said to have originated.

The first step in the introduction of mineral oil dates back to 1849, when James Young had his attention drawn to the small driblets of oil that ran down from the shale measures in the Riddings colliery near Alfreton. On distilling this oil, he obtained an excellent lubricant, but he soon found that the demand exceeded the supply, and that the source of his oil showed signs of being exhausted.

Later on he succeeded in obtaining an abundant supply by distillation from some of the Scotch shales, and in this way he founded the Scotch Oil Industry. In 1859 oil was obtained in enormous quantities in America from wells bored

into the oil measures, and the result was that a large supply of oil was soon obtainable all over the civilised world, which was added to when the Russian oil fields were opened up about 1870, and the supply from this source soon made Russian oil an important competitor with the American trade.

For some years after this Russia and America practically supplied all the oil, but since that period oil has been discovered in many different parts of the world, so that with wider distribution its use as a liquid fuel is rapidly increasing, thus bringing it nearer and nearer to a universal fuel.

All forms of mineral oil as they leave the wells are mixtures of hydrocarbons, which, however, vary a good deal in composition, according to the part of the world from which they are obtained.

There are several theories to account for the formation of petroleum. One class of theorists insists upon its vegetable origin, declaring that it is the result of distillations from such fossilised vegetation as coal. Another and perhaps a larger class argues that it has been formed from animal remains, whilst a third party is perfectly clear in its views as to these hydrocarbons having been formed by the action of water or steam under considerable pressure upon metallic carbides. Carbides are substances formed by the combination of metals and carbon: there is one carbide perfectly well known—calcium carbide—and by the action of water it yields acetylene. In the same way as water and calcium carbide give acetylene, so water and some of the carbides of the rare earths will give hydrocarbons of exactly the same composition as many of the hydrocarbons found in the mineral oils.

Liquid fuel has been introduced in nearly all the navies of the world, but as the total supply at present is quite inadequate to meet the demand, its use is restricted to the ships in which speed and radius of steaming power are the first consideration.

The World's Coal Production.

	1905. Tons.	1913. Tons.
United States	350,820,000	506,630,000
United Kingdom	236,129,000	287,430,000
France	34,778,000	40,096,484
Germany	119,349,000	271,746,364
Belgium	21,506,000	22,756,410
British India	8,425,000	16,145,650
Australia	7,496,000	12,363,861
New Zealand	1,586,000	1,880,742
Canada	7,836,000	13,344,159
Transvaal	2,327,000	7,281,106
Natal	1,129,000	
Cape of Good Hope	147,000	
Total	791,528,000	1,179,673,776

Lignite.

	1905. Tons.
Germany	47,853,000
Austria	21,635,000
Hungary	5,430,000
United States	5,725,111
Total	80,643,111

Mineral Oil Production of the World.

	1899.	1905.
United States	8,152,980	16,452,000
Russia	9,821,750	6,870,000
Other Countries	1,000,112	2,790,000
Total	18,974,842	26,112,000

	1912.	1915.
United States	29,615,096	40,142,043
Russia	9,317,000	20,957,292
Other Countries	8,343,929	
Total	47,276,725	61,099,335

The world's production of mineral oil is proved by the figures given on p. 41 to have increased relatively much more rapidly than that of solid fuel. The aggregate output of oil in 1915, however, in heating value, was still less than one-twelfth that of the coal output.

It is manifest that crude petroleum, being a mixture of many hydrocarbons, will emit inflammable vapour at so low a temperature that its use as a fuel would be attended with danger on land, and would certainly never be permissible afloat, and it is to such residues as are left after the distillation of the more volatile portions and the lamp oil that we must look for the chief source of our liquid fuel, and this further reduces the available supply by about two-thirds.

The fuel oils differ but little in the ratio of carbon and hydrogen present, and the following table gives the ultimate composition of the chief available fuel oils:—

FUEL OILS.

	Carbon.	Hydrogen.	Oxygen, etc.
American	84·9	13·7	1·0
Russian	86·6	12·3	1·1
Borneo	87·8	10·78	1·24
Texas	85·6	11·03	3·51
Caucasus	84·9	13·96	1·25
Burmah . . .	86·4	12·10	1·50

The ease of application and many advantages presented under certain conditions by the use of gaseous fuel in various manufacturing processes have led to considerable attention being paid to the subject, and ever since the discovery of water gas by Fontana in 1780, engineers have busily attempted to perfect methods for its economical production.

Under the heading of gaseous fuel may be comprised:—

(1) Coal gas.

(2) Water gas, made by the action of steam on incandescent carbon.

(3) Mixed producer and water gases, now called mixed gas, made by the passage of both air and steam over the highly heated fuel.

(4) Generator or producer gas, made by the passage of air through incandescent carbon.

Generator or producer gas is a mixture of carbon monoxide and nitrogen, and is the poorest in thermal value of the gaseous fuels. It is formed by passing air through a column of heated coke, when the carbon at the lower surface of the column burns to carbon dioxide, combining with the oxygen of the air: the carbon dioxide, by contact with the heated carbon over which it has to pass, is then reduced to carbon monoxide, and this and the residual nitrogen from the air form the "generator gas."

The heating power of such a gas is very low, but its production is inexpensive, and when burnt hot it is a very effective form of fuel for glass melting, the heating of gas retorts, brick burning, pottery kilns, and many processes of this character, in which, used in connection with a Siemens regenerative furnace, it gives splendid results.

Siemens gas only differs from generator gas in that small coal or slack is used as the fuel instead of coke, with the result that the gas contains a small proportion of gaseous hydrocarbons, which increase its thermal value.

Water gas depends for its formation upon the fact that at high temperatures carbon has a greater affinity for oxygen than hydrogen has, and that when steam and carbon (in any of its amorphous forms) are heated to such temperatures, the steam is decomposed with liberation of hydrogen and either carbon monoxide or dioxide, the oxide formed being to a great extent dependent upon temperature, and the quantities of steam and carbon interacting.

The value of the gas produced as a fuel largely depends upon the closeness of approximation to theoretic proportions, but the ideal composition is rarely, if ever, reached, water gas consisting practically of a mixture of carbon

monoxide and dioxide, hydrogen, and small quantities of methane formed by secondary reactions between liberated hydrogen and carbon oxides.

The following analysis will give a fair idea of the composition of ordinary water gas :—

	Per cent.
Hydrogen	48·31
Carbon monoxide	35·93
Carbon dioxide	4·25
Nitrogen	8·75
Methane	1·05
Sulphuretted hydrogen	1·20
Oxygen	0·51
	100·00

The ratio of carbon monoxide and carbon dioxide present depends entirely upon the temperature of the generator and the kind of carbonaceous material employed. Using a hard anthracite coal a temperature can be reached at which practically no carbon dioxide is formed: but with an ordinary generator and a loose fuel like coke, a certain percentage of that gas is generally produced. The sulphur present in gas coke gives rise to the sulphuretted hydrogen, but by using a material like anthracite, practically none is formed. The nitrogen is the result of heating the fuel by air blast, which leaves the pipes full of producer gas—nitrogen and carbon monoxide—which is carried over into the holder by the first portions of water gas. Water gas so produced is non-luminous, and it forms a useful and valuable fuel for many metallurgical purposes. In recent years, water gas has been employed largely as a diluent for the gas produced by the ordinary carbonisation process in gas works. The general adoption of the incandescent gas-mantle for illuminating purposes has now rendered it unnecessary for the gas works to supply a gas which is self-luminous on combustion—and the majority of

companies and undertakings have taken the necessary legal steps to free themselves from the obligation to provide a gas of a definite candle-power. The modern practice of steaming the gas retorts, in fact, produces a mixture of water gas and coal gas, but the larger gas works all possess separate water gas plants. This subject is more fully dealt with in Chapter VIII.

In the formation of generator or producer gas heat is evolved by the processes taking place in the generator, whilst in the making of water gas a very large amount of heat is absorbed, so that the temperature of decomposition has to be attained and kept up either by exterior heating, as used in the retort processes of making water gas, or by blowing up the fuel to incandescence by an air blast, as practised in all the successful water gas processes. A large number of gas generators are now made in which air and steam are simultaneously passed through the incandescent fuel in such proportions that the formation of producer gas, by partial combustion of the carbon by oxygen of the air, shall raise the temperature in the same ratio that the decomposition of the steam by the red hot carbon into water gas lowers it, the result being a uniform temperature in the generator and the production of a gas which is practically a mixture of generator or producer gas with water gas ; this has a higher thermal efficiency than the producer gas alone, and answers well in gas engine practice.

Producers for making these mixed gases are known by the names of their inventors, and the Wilson, Dowson, Dawson, and Duff processes are all of this character. Mond gas however differs from these inasmuch as, by using an excess of steam in the generator, the temperature of the fuel is kept low, and a large proportion of the carbon monoxide is converted into dioxide, this however being accompanied by an increase in the volume of hydrogen produced, and the low temperature favouring the formation of ammonia from the nitrogen in the slack used as fuel, yields a valuable by-product.

Blast furnace gas consists of the gases which until lately were blown to waste from the mouth of the blast furnace during the reduction of iron from its ores; this gas has a composition not very different from that of producer gas.

Coal gas is year by year rapidly increasing in favour for power purposes, and as a fuel for domestic purposes, such as heating and cooking, the only drawback being the cost of gas as compared with coal as a fuel. When used for such purposes the gas is burnt mixed with air in atmospheric burners, and during complete combustion a very high temperature is attained: but per unit of heat evolved the cost is considerably more than that of coal, against which however must be set the economy of being able to turn on the gas just when required, and to turn it off when the desired effect has been produced, and this, when taken in conjunction with the saving of labour and absence of dirt and smoke considerably decreases the margin in favour of coal.

The natural gas issuing from the wells and bores in Pennsylvania, Baku, and elsewhere, has much the same composition as the gas from many coal measures, and contains from 80 to 98 per cent. of methane, but higher members of the paraffin series of hydrocarbons are also frequently present in small quantities, marking the fact that the gas is disengaged from the oil and not from the coal measures.

Composition of Natural Gas.

	Russian (Baku).	American (Ohio).	English (Heathfield).
Hydrogen	0·98	1·89	0·00
Methane	93·09	92·84	93·16
Ethane	3·26	0·35	2·94
Carbon dioxide	2·18	0·75	0·00
Nitrogen	0·49	3·82	2·90
Oxygen	0·00	0·35	0·00
Carbon monoxide	0·00	0·00	1·00

It is the most valuable of the gaseous fuels from a heating point of view, but is unfortunately rapidly diminishing in quantity in most of the districts before rendered prosperous by its presence.

Having seen that our fuels, be they solid, liquid, or gaseous, contain hydrogen and carbon as the essential constituents for the production of heat during combustion, it will be well to now consider the chemical properties of these elementary substances, and the methods by which we determine their calorific value, and also the composition and calorific value of the various forms of fuel which contain them in combination.

Hydrogen was first discovered by the alchemist Paracelsus in the sixteenth century, although it was not until Cavendish's experiments with it in 1766 that the true nature of the gas was thoroughly understood.

Practically, hydrogen does not exist free to any great extent on the earth, as with the exception of small quantities found in the gases escaping from volcanos it is never found by itself: indeed water, the compound of hydrogen with oxygen, is the great storehouse of hydrogen, whilst it also occurs in combination, although in much smaller quantities, with such elements as chlorine, sulphur, and nitrogen, and forms an important constituent of nearly all organic compounds.

The most marked and characteristic property of hydrogen is its wonderful lightness. It is the lightest gas known, and is for that reason taken as the standard to which the weights of all other gases are compared.

Pure hydrogen is a clear, colourless gas, having neither taste nor smell, and being practically insoluble it may be collected and stored over water, one hundred volumes of which dissolve less than two volumes of the gas. Hydrogen burns in air or oxygen with a non-luminous but intensely hot flame, water vapour being the only product of its

combustion. It does not support combustion in the ordinary sense of the term, and a lighted taper plunged into a jar of the gas is at once extinguished.

Hydrogen being one of those bodies that resist further decomposition, it is called an element, and of these simple forms of matter some seventy-eight are at present known (*see* Table in Appendix).

The distribution of the elements in Nature is most irregular. Some are found in very large quantities and very widely distributed, whilst others occur in such minute quantities that their properties are scarcely yet known. Indeed, nearly half the elements known at present might be eliminated without, as far as our present knowledge goes, causing any considerable disturbance of the laws of Nature.

The general distribution of the elements is roughly indicated in the following tables :—

Approximate Composition of the Crust of the Earth.

Oxygen	45·5
Silicon	29·4
Aluminium	8·2
Iron	6·3
Calcium	2·4
Magnesium	1·6
Sodium	2·5
Potassium	2·0
All the other elements	2·1
	100·0

Composition of Air.

Nitrogen	76·9 parts by weight.
Oxygen	23·1 „ „
	100·0

COMPOSITION OF WATER.

Oxygen . . .	88·8	parts by weight.
Hydrogen . . .	11·1	„ „
	99·9	

To these elements must be added carbon, which exists in all matter of organic origin, and it is then seen that 99 per cent. of known substances are composed of eleven elements, whilst oxygen alone constitutes upwards of 52 per cent. of earth, air and water.

Elements combine to form chemical compounds, or, more rarely, exist free.

By matter we understand anything that has weight, and it may be either solid, liquid, or gaseous in its nature. These three states of matter are entirely dependent upon heat. It so happens that at the ordinary temperature zinc is a solid, water is a liquid, and carbon dioxide is a gas, but if water be cooled down below 0° C. it becomes a solid—ice, whilst heated above its boiling point (100° C.) it is converted into gaseous steam. In the same way all substances which are not decomposed by heat can be obtained as solids, liquids or gases.

If the size of a bar of zinc at the ordinary air temperature be carefully determined, and it is then heated, it is found that the action of heat is to cause it to increase in bulk, this increase proceeding at a definite rate until the temperature is raised to 423° C., when it becomes liquid. If now the liquid be further heated it will be found to still continue to expand until a temperature of 1,040° C. is reached, when it boils like water and is converted into the gaseous state.

If carbon dioxide, which is a gas at ordinary temperatures, be cooled down to near the freezing point of water, and be subjected to a pressure of 36 atmospheres (540 lbs.

on the square inch), it is reduced to the liquid state, and in this condition can be kept in steel vessels of sufficient strength to resist the pressure necessary to keep it liquid. On allowing some of this liquid to escape suddenly into a small box at ordinary atmospheric pressure, it is instantly converted into gas, and in the change from the liquid to the gaseous state takes up so much heat as to produce a degree of cold sufficiently intense to freeze some of the liquid escaping from the vessel into solid carbon dioxide.

From these three experiments it is clear that those bodies which we look upon as solids are simply those which have a melting point above the ordinary temperature, whilst a liquid has a melting point below the ordinary temperature, and a gas its boiling point below the ordinary temperature.

It was seen that when the solid zinc was being heated up to the point at which it became liquid, a continuous expansion was taking place, and that the expansion continued until the zinc was converted into vapour, the volume of the vapour being enormously greater than that occupied by the original zinc bar.

In the same way when water is boiled it is converted into steam, the vapour so formed occupying about 1,700 times the volume of the water taken. Roughly, a cubic inch of water forms a cubic foot of steam. This enormous increase in volume may be explained in one of three ways: either the cubic inch of water is stretched under the influence of heat, like a piece of indiarubber, until it assumes the dimensions of the cubic foot, or the cubic inch of water is built up of an innumerable host of small particles which, when heated, undergo individual expansion, which mounts up to the enormously increased volume, or else this multitude of small particles do not themselves expand, but under the influence of heat tend to repel each other, and by

spacing themselves further apart give the increase in volume.

If the first or second theory be correct, then every part of the cubic foot of steam would be perfectly homogeneous, and without condensing some of the steam it would be impossible for any other vapour to find room in the space so occupied, whilst experiment shows us that one vapour can act as a vacuum to another, so that other vapours can occupy the space already filled with water vapour, a phenomenon which can only be explained on the assumption that the vapours do not completely fill the space they occupy, although equally distributed through it: that is, they are built up of particles, which by the action of heat become widely separated from each other, thus leaving spaces within which the particles of other vapours may find place.

It has been seen that these three states of matter are merely dependent upon temperature and pressure, and it is clear, therefore, that if the vapours and gases consist of particles, then it must be assumed that liquids and solids also are built up in the same way, an assumption which is entirely borne out by experiment.

In the solid state, these particles, each of which has the same properties as the mass of which it is a part, are held together by the force of cohesion, a force which varies with the nature of the substance: so that when a solid is heated, the particles tend to separate, but in different substances they do so to a different extent. The stronger the force of cohesion existing between the particles, the greater is the work the heat has to do in separating them. At a certain temperature the particles are so far asunder that the force of cohesion is weakened to a certain extent, and the particles become free to move round each other, *i.e.*, they assume the liquid state: continue the heating, the distances between the particles grow greater and greater

until a point is reached at which cohesion exerts no influence, the particles move independently of each other, and we have the gaseous state.

In the solid and liquid states various substances expand unequally for an equal increment of temperature, whilst in the gaseous state all substances behave alike, an equal increment of temperature producing in each case an equal increase in volume, because cohesion has ceased to act between the particles.

These particles, of which all matter is composed, and which have the same chemical and physical properties as the original mass of which they form part, are called molecules: but when we investigate the composition of any compound mass, we find that these molecules, although they are ultimate particles as far as the particular substance is concerned, are built up of other kinds of elementary matter held together by chemical affinity.

For instance, a molecule of chalk is the smallest particle we can imagine to possess the properties of the mass of chalk: yet inasmuch as we can decompose chalk into quicklime and carbon dioxide, and these again into calcium, carbon, and oxygen, it is evident that each molecule of the chalk must contain still smaller particles of these elements: and these small particles which go to build up the molecule we call "atoms." We define the molecule as being the "smallest particle of matter which can exist free, and still retain the properties of the mass of which it forms a part, and these particles are built up of two or more atoms."

The atom is the smallest particle which can exist in combination, and is the smallest indivisible particle of an element that we can assume.[1]

In order to facilitate the expression of chemical reactions, each of these elementary atoms is represented by a symbol, consisting of the initial letter of its Latin name, or in case of two or more elements commencing with the same letter,

[1] See note (4) on p. 57.

the initial and first distinctive letter are used. For instance:—

Carbon	is	represented	by C.
Calcium	,,	,,	Ca.
Cadmium	,,	,,	Cd.
Chlorine	,,	,,	Cl.
Copper	,,	,,	Cu. (Latin—Cuprum).

Inasmuch as these symbols stand for an atom of the element which they represent, we can, by experimentally determining the number of atoms of each element present in the molecule of a compound, represent symbolically the molecule by placing together the atomic symbols in the right proportions. We conclude by analogy that the molecule of methane contains one atom of carbon (C) and four of hydrogen (H), and this being so, the molecule can be represented by CHHHH. It would, however, be inconvenient to repeat the symbol for an atom when the same element occurs more than once, and we therefore express the number of the elementary atoms by placing a small numeral after and below them, so that the molecule of methane would be written CH_4. The symbolical representation of a body is called a "formula," and by experimentally determining the proportions in which substances react upon each other, we can by means of the formulæ build up a representation of the changes taking place.

When methane is heated to a high temperature, it breaks up into carbon and hydrogen, and the decomposition can be represented as—

Methane. Carbon. Hydrogen.

$$CH_4 = C + 2H_2$$

The large numeral in front of the symbol for hydrogen multiplies the molecule, whilst the sign of addition between the carbon and hydrogen shows that they are no longer in

chemical combination. Such a symbolical representation of a chemical change is called an "equation."

The molecules and atoms are so minute that the mind fails to grasp the immensity of their smallness, but Lord Kelvin gave an excellent picture of it in saying that if a drop of water could be magnified until it was the size of the world, we should then see the molecules that composed it, and they would be between the size of swan-shot and cricket balls.

Minute as these particles are, yet we are able by physical and chemical means to find the ratio of weight which the various atoms bear to each other, and this, taking hydrogen as unity, is called their atomic weight: for instance, if the atom of hydrogen weighs 1, then the atom of nitrogen weighs 14, oxygen 16, carbon 12 (*see* Table of Atomic Weights in Appendix), and these are their atomic weights. In writing the formula for a molecule we represented each atom composing it by the symbol for that atom, so that if we add together the atomic weights of the elements comprising the molecule we obtain the molecular weight. We found by experiment that the molecule of methane contained one atom of carbon and four of hydrogen: therefore we wrote the formula for its molecule CH_4, and now, knowing that carbon has an atomic weight of 12 and hydrogen 1, we can say that the molecular weight of methane is $12 + (1 \times 4) = 16$.

It has also been determined by experiment that all molecules in gaseous matter occupy the same space, no matter how many atoms are crowded into them, and that this space is just double that occupied by an atom of hydrogen with its atomic weight of 1.

This at once gives us a relation between weight and volume in gaseous molecules, as if we take the unit of hydrogen and call it 1 gram, we can measure the volume that weight of gas occupies at standard temperature and

pressure (0° C. and 760 mm.), and we find it to be 11·16 litres: now, if we call the units in the molecular weight of any gas grams, the number of grams will occupy $2 \times 11{\cdot}12$ or 22·32 litres, so that, taking CH_4 with its molecular weight of 16, we know at once that 16 grams of CH_4 will occupy 22·32 litres at standard temperature and pressure.

If we now burn methane in pure oxygen, we find by experiment that the reaction may be represented by the following equation :—

Methane.		Oxygen.		Carbon dioxide.		Water.
CH_4	+	$2\,O_2$	=	CO_2	+	$2\,(H_2O)$
1 molecule		2 molecules		1 molecule		2 molecules

whilst the weight relations will be—

$$(12 + 4) + (16 \times 4) = (12 + (16 \times 2)) + 2\,(2 + 16)$$

or 16 + 64 = 44 + 36

and by volume—

22·32	+	2 (22·32)	=	22·32	+	2 (22·32)
litres		litres		litres		litres
Methane		Oxygen		Carbon dioxide		Water as steam

So that not only does an equation give us the means of symbolically representing a chemical action, but also affords us the data from which all the gravimetric and volumetric factors can be ascertained. In the Appendix the relation between the weights and measures employed in the metric system and their English equivalents will be found, so that, if desired, the results can be translated into pounds and cubic feet.

Carbon, next to oxygen, is perhaps the most widely distributed of the elements. It occurs in the free state as the diamond and as graphite, substances which, although they are physically dissimilar, yet can be proved to be chemically identical, the dissimilarity of physical properties being probably due to some difference in the atomic arrangement.

In Nature, as we have seen, carbon is found combined with hydrogen in coal, bitumen, shale, naphtha, the paraffins and numerous other hydrocarbons. With oxygen it is found as carbon dioxide, which is present in the earth in enormous quantities, and which forms the large class of metallic salts called carbonates. In the vegetable kingdom the dry solids contain nearly 50 per cent. of it, whilst all animal matter is largely made up of it, fat containing as much as 79 per cent.

Carbon is insoluble, non-volatile, and infusible at all ordinary temperatures, but signs of volatilisation are apparent in the electric arc. The diamond does not easily conduct heat or electricity, but the other forms of carbon are conductors.

Carbon forms an enormous number of compounds with hydrogen, these bodies being known by the generic name of "hydrocarbons."

Twelve parts by weight of carbon will unite with four parts by weight of hydrogen, and when these elements are united in this proportion, the body formed is incapable of combining with chlorine or any other element of the same kind, the constituents having formed what is termed a "saturated" compound, but the compound may exchange the whole or part of its hydrogen for other elements.

Most elements in forming compounds only exist in the molecule in a very limited number of atoms, but carbon has the property of existing in different bodies to a very large number, so that although the simplest compound of carbon and hydrogen known is represented by the formula CH_4, it is only the first of a long series of compounds in which the carbon is saturated with hydrogen, each member of this series containing one atom of carbon and two atoms of hydrogen more than the member of the series preceding it.

This series is known as the "saturated hydrocarbon" or

"paraffin" series, and all its members contain carbon and hydrogen in the ratio of C_nH_{2n+2}, n being the number of atoms of carbon.

Besides this series there are many others in which the ratio of hydrogen to the carbon is not so high, and which can therefore unite directly with some other elements, and for this reason are called "unsaturated hydrocarbons."

As examples of these series may be cited—

The Ethylene series, having the ratio $C_n H_{2n}$.
The Acetylene series, having the ratio $C_n H_{2n-2}$.
The Benzine series, having the ratio $C_n H_{2n-6}$.

In the paraffin series the lower members are gaseous, whilst as the molecule becomes more complex they assume the liquid state, and become less volatile and more viscid as the series is ascended, the higher members being solids.

(4) Since the Author wrote these lines in 1905, the older conceptions regarding the constitution of matter have undergone a radical change, for the investigations of the characteristics and properties of that remarkable element radium, carried out by the two Curies, Lewis, Ramsay, Rutherford, Soddy, and a host of other workers in this branch of research, have proved that the older ideas of the constitution of atoms and molecules are no longer in harmony with the observed phenomena. In a lecture delivered before the Chemical Society in December, 1918, Soddy summarised recent progress, and stated that the modern view of the structure of the atom is that it resembles a miniature solar system; and that the externally revolving particles (the electrons) determine the chemical and spectroscopic characters of the atom, while the mass and radio-active properties are determined by the nucleus or core.

Langmuir, in America, has developed these modern views of the constitution of matter into a constructive theory which explains not only the general features of the entire periodic system, but accounts for the position and properties of the so-called eighth group of the rare-earth elements, and also serves to correlate the magnetic properties of the elements.

His latest contribution to the subject states that from the atomic numbers of the inert gases, we are able to determine the number of electrons in the various layers, or shells, of electrons which exist in the atoms.

CHAPTER III.

THE DETERMINATION OF CALORIFIC VALUE.

Methods of determining calorific value—The calorie and British thermal unit—Heat of combustion factors—Latent heat of steam—Calculation of calorific value from chemical composition—Evaporative duty—Objections to calculated results—Direct determination of thermal value—Calorimeters—The Mahler bomb, and the method of using it—The Darling calorimeter—The use of the bomb for liquid and gaseous fuels—The heat of combustion of gases—The Boys calorimeter.

THE heating value of a fuel, solid, liquid, or gaseous, may be arrived at by one of two methods:—

(1) By analysis of the fuel and calculation of its calorific value from that of its individual constituents.

(2) By direct determination in a calorimeter.

The heat generated during the combustion in oxygen of different elements and compounds was first determined by Andrews, and later by Favre and Silberman, Thomson, and others. Some small discrepancies exist between the values obtained by these observers, which must have an influence on the calculated results, and figures derived from determinations made by Berthelot in the bomb calorimeter are now generally accepted in preference to those obtained by older methods. The determinations taken as the basis for all calculations are given in the table on p. 59.

The scientific unit of thermal value is the calorie, which is the amount of heat required to raise a unit weight of water 1° C. at the point of maximum density, whilst the

HEATS OF COMBUSTION (BERTHELOT).

	Calories.	B.T.U.
Hydrogen	34,500	62,100
Carbon to carbon dioxide	8,137	14,647
Carbon to carbon monoxide	2,489	4,480
Carbon monoxide	2,435	4,383
Methane	13,343	24,017
Ethylene	12,182	21,927
Acetylene	12,142	21,856
Cellulose	4,200	7,560
Peat	5,940	10,692
Naphthalene	9,690	17,442
Sulphur	2,500	4,500

usual English engineering unit is the British Thermal Unit, which is the amount of heat needed to raise a unit weight of water 1° F. As long as the unit weight of fuel burnt to give the increase in temperature of the water is the same as the unit weight of water heated, the relation between the two units will be the same as the ratio between the thermometric scales, *i.e.*, a gram or a kilogram or a pound of fuel respectively will heat a like weight of water to the same extent, so that if we find that a kilogram of carbon in burning to carbon dioxide raises 8,137 kilograms of water 1° C., we call that the calorific value in calories, and if we desire to convert it into B.T.U. all that has to be done is to multiply the result by $\frac{212 - 32}{100}$, or by the factor 1·8, which will give us the rise in temperature expressed in degrees F. when one pound of carbon is burnt in such a way as to impart all the heat of combustion to one pound of water. If, however, we use a constant weight or volume of fuel, say, a pound or a cubic foot, and take the calorie as the amount of heat necessary to raise 1 kilogram or litre of water 1° C., and the B.T.U. as the amount of heat necessary to raise one pound of water 1° F., then it is evident that in

the calorie not only is there the difference due to the thermometric scales, but also to the fact that the kilogram of water is 2·2 times the weight of the pound, so that to convert the pound or cubic foot calorie to the B.T.U. it must be multiplied by 1·8 × 2·2, or 3·96.

When a fuel consists of carbon and hydrogen only, it is considered sufficiently accurate in practical working to determine its composition, and then to multiply the carbon present by 8,137, and the hydrogen by 34,500, the sum of the numbers so obtained being taken as representing the calorific value of it as a fuel. For instance, on analysing methane, we find that it has a percentage composition of:—

Carbon	75
Hydrogen	25
	100

and $\frac{(75 \times 8{,}137) + (25 \times 34{,}500)}{100} = 14{,}727.$

14,727 would therefore be taken as the calculated calorific value of methane.

This value, however, is far higher than the figure obtained by direct determination, and this is due to the heat of formation of the compound being neglected in the calculation.

When a chemical compound is formed, heat is either absorbed or given out, and when the compound is again decomposed during combustion, as much heat reappears or is absorbed as was the case during its formation, and to make the calculation of calorific value correct this must be allowed for.

The heat of formation of the molecule of methane, which contains 16 units by weight, is + 20,414 calories, and our value for methane so corrected would be $14{,}727 - \frac{20{,}414}{16}$

or 13,451 calories, a number much more nearly approaching that obtained by actual experiment, namely 13,343.

When water is one of the products of combustion, it is clear that the available heat will depend on whether this water escapes as steam, as from a boiler, or is condensed to the liquid form, as in most calorimeter determinations. In practice it is usual to assume that the water formed is always condensed, but allowance can readily be made for its escape as steam by taking the latent heat of steam into account.

In the conversion of water into steam the enormous expansion that takes place is due to heat spacing the particles or molecules of the water further asunder, and heat which is engaged in doing such intermolecular work disappears as sensible heat and remains in the steam until it is again condensed back to the liquid state, when the latent heat once more appears as sensible heat.

If steam be passed into cold water it condenses, and giving up the stored heat within it, rapidly raises the temperature of the water. It is found that where a unit weight of steam at 100° C. is condensed into a unit weight of water at the same temperature, enough heat is given out to raise 536 unit weights of water from 0° C. to 1° C., and we therefore say that the latent heat of steam is 536 thermal units.

The calculation of the thermal value of a fuel also becomes rather more complicated when the fuel already contains a certain amount of oxygen in a state of combination, for such elements as are partially oxidised can only yield a certain portion of their total heating value. Further, if moisture be present, a certain amount of the heat will be used up in vaporising this.

Taking the case of dry cellulose, there are present 44·44 per cent. of carbon and 6·17 of hydrogen, but there is also present 49·39 of oxygen, and as this oxygen has already

entered into combination with the carbon and hydrogen present the quantities of these elements so combined are no longer available for the generation of heat during combustion.

Oxygen combines with one-eighth of its weight of hydrogen to form water, and if we look upon all the oxygen present as being combined with hydrogen, the calorific value would be found from the following formula:—

$$(C \times 8{,}137) + \left((H - \tfrac{O}{8}) \times 34{,}500\right)$$

which, if applied to cellulose, would give—

$$\frac{(44{\cdot}44 \times 8{,}137) + \left((6{\cdot}17 - \frac{49{\cdot}39}{8}) \times 34{,}500\right)}{100} =$$

$$\frac{44{\cdot}44 \times 8{,}137}{100} = 3616{\cdot}08.$$

In other words, the oxygen present in combination is sufficient to entirely use up the hydrogen, and the calorific value of the fuel is practically the value of the carbon present. It is evident, therefore, that the combined oxygen in a fuel means that a certain percentage of it is not available as a fuel.

Since in an ordinary analysis the oxygen and nitrogen are usually determined by difference, and the amount of nitrogen in coal approximates closely to 1 per cent., the oxygen present will be (O + N) — 1, and this oxygen is always assumed to be wholly combined with the hydrogen, which requires eight times its weight. A formula suitable for coal, therefore, is—

$$\frac{1}{100}\left(8{,}137\ C + 34{,}500\ (H - \frac{(O + N) - 1}{8}) - 600\ H_2O\right)$$

the latter term making a sufficiently close approximation to the loss of heat in vaporising the water present in the coal from ordinary temperatures.

An example of the use of such a formula may be cited. A sample of coal gave on analysis—

Carbon	76·71
Hydrogen	4·67
Water	1·94
Oxygen + nitrogen	7·46

then—

$$\frac{1}{100}\left((8{,}137 \times 76{\cdot}71) + \left\{34{,}500 \times \left(4{\cdot}67 - \frac{7{\cdot}46 - 1}{8}\right)\right\} - (600 \times 1{\cdot}94)\right) = 7{,}563 \text{ calories per unit}$$

whilst the actual determination in a bomb calorimeter gave 7,527 calories.

The results expressed in calories or B.T.U. serve for a comparison between different fuels, but to the engineer the evaporative duty of the coal is the important factor, and this is usually stated as "lbs. of water at 100° C. (or 212° F.) converted into steam at the same temperature": therefore, by dividing the calories by 536·5 (the latent heat of steam on the Centigrade scale), or the B.T.U., by 965·7 (the latent heat of steam on the Fahrenheit scale), the number of units of water evaporated per unit of fuel is obtained, whether these units be kilos, grams, or pounds.

Thus in the example given :—

$$\frac{7{,}563 \text{ cals.}}{536{\cdot}5} = 14{\cdot}1 \text{ kilos or grams evaporated from and at } 100° \text{ C.}$$

or in B.T.U.—

$$\frac{13{,}615}{965{\cdot}7} = 14{\cdot}1 \text{ lbs. from and at } 212° \text{ F.}$$

Amongst engineers the Fahrenheit scale is still in most cases retained, and the evaporative value is often calculated from the percentage composition by the formula—

$$0{\cdot}15\left(C + 4{\cdot}28\left(H - \frac{O}{8}\right)\right) = \text{lbs. from and at } 212° \text{ F.}$$

which is constructed on the basis that hydrogen has approximately 4·28 times the heating value of carbon, whilst the factor 0·15 is obtained by dividing the calorific value of the carbon in B.T.U.'s by the latent heat of steam multiplied by 100—

$$\frac{14{,}647}{966 \times 100} = 0{\cdot}15.$$

Certain calculated and evaporative values are open to objections. In the first place there is the difference in heating value given by various observers for the same combustible. Again, the process of analysis requires expert skill in order to obtain accurate results, any errors becoming largely multiplied in the calculation. As already pointed out, heat is required to break down most forms of chemical combination, and as to the amount of heat used up in this way we have no actual knowledge in reference to most fuels, but recent researches show that coal is slightly exothermic, and that any heat required to break it down may be practically disregarded. Close agreement is obtained between calculated and determined values with a large number of coals, but occasionally one meets with considerable differences, which are quite inexplicable, and therefore cast a doubt upon calculated values generally.

The most satisfactory method for finding the calorific value of a fuel is undoubtedly by direct determination of the heat evolved during combustion in a calorimeter.

In all forms of calorimeter the principle relied on is tc burn the fuel to be tested in a vessel entirely surrounded by water, and to calculate its heating power from the increase in temperature of the water.

Many forms of calorimeter have been devised, but they may be classified into the following types :—

(1) Where combustion of the fuel is effected by admixture with a solid oxidising agent, as is done in the Lewis Thompson calorimeter.

(2) Combustion with oxygen at constant pressure—

(*a*) Where the temperature of the escaping gas is undetermined, as in the William Thomson and Darling calorimeters.

(*b*) Where the temperature of the escaping gas is under control, as in the Fischer calorimeter.

(3) Combustion with oxygen at constant volume, as in the Berthelot, Mahler, Mahler-Donkin, or Mahler-Krocker bomb.

Of these various types of calorimeter undoubtedly the best and most accurate is the bomb, the chief drawback to it being the expense of the apparatus, whilst the least accurate and most used is the Lewis Thompson, which has gained popularity amongst engineers owing to its ease of manipulation.

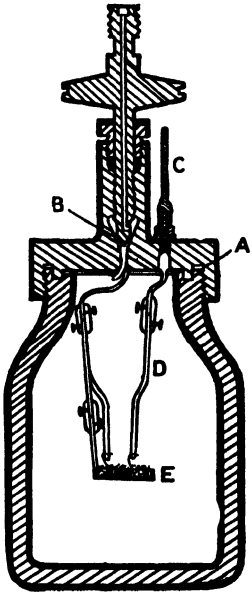


FIG. 1.—Mahler bomb (section.)

In Mahler's calorimeter the combustion of the material takes place, in a closed bomb or cylinder of steel, in oxygen under a pressure of twenty-five atmospheres. The bomb is of the shape shown in Fig. 1, and is coated internally with a thin lining of porcelain[1] in order to resist the corrosive action of the trace of nitric acid formed during combustion. The cover of the bomb screws down on to a leaden washer (A), placed in a groove in the rim, thus ensuring a tight joint, whilst a tube through the cover serves for the admission of oxygen and is fitted with a screw-down conical valve (B). Through the cover also passes an insulated rod C to the lower end of which a platinum rod D is fastened by means of a clamp. Attached to the

[1] See note (5) on p. 83.

cover and in electrical contact with it is a second platinum rod, to which is clamped another, carrying the platinum capsule E, in which is placed the substance to be burnt. The two ends of the platinum rods can be connected by a fine iron or platinum wire, which is caused to rest on the combustible material, and serves to ignite it when the wire is raised to incandescence by the current from a battery.

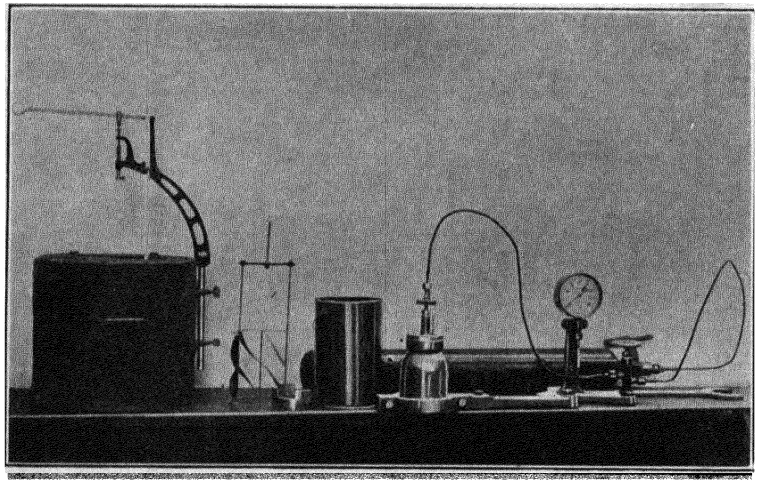


FIG. 2.—Mahler bomb with fittings.

The bomb is placed in the calorimeter vessel, which contains about 2·25 litres of water, the volume of water being capable of thorough agitation by means of vanes on a frame worked by a lever through a rod on which a spiral thread is cut, thus causing the vanes to have a reciprocating circular motion. The standard carrying the agitator is also fitted with a small clamp for a thermometer, graduated to read to hundredths of a degree.

In actual working the charge of combustible is weighed into the platinum capsule, which is then clamped on to its rod, and a fine wire is attached to the platinum rods so that

it rests on the charge. The cover is screwed down firmly on to the bomb, a wrench being applied to the cover whilst the bomb is held in its special clamp. The connecting tube from the oxygen cylinder is attached to the tube in the cover, and oxygen is slowly admitted until the pressure gauge shows 25 atmospheres. The valve is then screwed down, and the oxygen tube removed.

The bomb is placed in the calorimeter, which has been previously filled with the required amount of water, and the water is thoroughly stirred to obtain a uniform temperature. Observations of the thermometer are taken at frequent intervals for a few minutes to determine the rate of change of the temperature of the water, and the charge is ignited by touching the insulated rod in the cover and any part of the bomb with the two wires from a battery. The agitator is kept at work during the whole time, and the temperature of the water is taken at regular intervals until it reaches a maximum and then falls regularly, and for another five minutes to ascertain the rate of cooling. The bomb is now removed from the water, the valve opened, and the cover unscrewed, after which the interior is rinsed out with distilled water to collect any acid formed during combustion, which is then estimated by analysis.

The result can then be calculated from the observed rise in temperature of the water, which is corrected for radiation; the weight of the water equivalent of the bomb, accessories, and gas being added to the weight of the water originally taken.

An example of the calculation of the calorific value of a fuel is given below from an actual determination.

The formula used is as follows:—

D = observed rise in temperature
a = correction for radiation

P = weight of water in calorimeter
p = equivalent in water of the bomb and accessories
x = calories due to nitric acid formed
y = ,, ,, sulphuric acid formed
W = weight of coal taken

then

$$\text{Calories per gram} = \frac{(D + a)(P + p) - (x - y)}{W}.$$

The nitric acid is estimated by titrating the washings from the bomb after combustion with standard alkali containing 3·706 grams of sodium carbonate (Na_2CO_3) per litre. One cubic centimetre of this solution is equivalent to ·0044 gram of nitric acid, the heat of formation of which is one calorie, so that the number of calories can be ascertained directly from the number of cubic centimetres of standard alkali used. In the same way the sulphuric acid in the washings is precipitated with barium chloride, and the weight of the barium sulphate formed, multiplied by 100, gives at once the number of calories to be subtracted.

The correction for cooling is based on Newton's law which gives results sufficiently accurate for technical work.

1. The decrease of temperature observed after the maximum has been attained represents the loss of heat before the maximum and for any given minute if the mean temperature of the minute so determined does not differ more than one degree from the maximum temperature.

2. If the temperature of the given minute differs by more than one degree, but less than two degrees from that of the maximum, the number that represents the law of decrease at the moment of maximum less 0·005 will give the desired correction.

Taking now an actual example—
Readings per minute in degrees C.

	Minute.	Reading.	Minute.	Reading.
Maximum.	0	19·343	5·0	22·180
	1·0	21·840	6·0	22·170
	1·30	22·200	7·0	22·155
	2·0	22·280	8·0	22·145
	2·30	22·215	9·0	22·135
	3 0	22·200	10·0	22·120
	4·0	22·195		

Fall in 8 minutes from maximum = ·16, or ·02 mean per minute.

Having thus obtained the necessary factors for the calculation we have—

$$\begin{aligned} D &= 2{\cdot}877 \\ a &= 0{\cdot}020 \\ P + p &= 3{,}000 \\ x &= 21 \\ y &= 5{\cdot}6 \\ W &= 1{\cdot}0048 \end{aligned}$$

and these give us

$$\frac{((2{\cdot}877 + 0{\cdot}020) \times 3{,}000) - (21 - 5{\cdot}6)}{1{\cdot}0048} = 8634{\cdot}5 \text{ calories}$$

per gram.

The Darling calorimeter is based upon the principle of combustion in a current of oxygen gas at constant pressure, and the apparatus is a modified and improved form of the well-known William Thomson calorimeter. Fig. 3 shows its essential parts. A small nickel or platinum crucible, 1½ inches high by 1 inch in diameter, is held by brass arms in the centre of the perforated brass base-plate of the apparatus. A flanged glass bell-jar, provided with a rubber cork carrying a brass oxygen supply pipe and two copper conducting wires, is

clamped to the base-plate by means of rubber rings, and by a brass ring plate held in position by screws and nuts. It is advisable to use a rubber ring above and below the glass flange on the bell-jar to avoid breaking this when tightening the milled head screws. A brass gauze ring is shown in position on the bell-jar in Fig. 3, but this is an addition to the original apparatus. The ignition is by a thin spiral of platinum wire, heated electrically as in the case of the bomb type of calorimeter. In another form of the Darling calorimeter the brass oxygen supply tube is replaced by a tube of hard potash glass, widened out to form a cup at its lower end, and connected above to the oxygen cylinder or gas holder by a glass T-piece. In this second form of apparatus (Fig. 4), ignition occurs by means of a small piece of glowing charcoal (·01 to ·02 gram), which is dropped down the oxygen supply tube by removing the small cork which closes the vertical end of the glass T-piece. This method of ignition is preferable to that recommended by Darling, as the use of sulphur for igniting the charge has many disadvantages. In both forms the water and air jacket casings employed with bomb calorimeters (Fig. 5) must be used if accurate results are to be obtained.

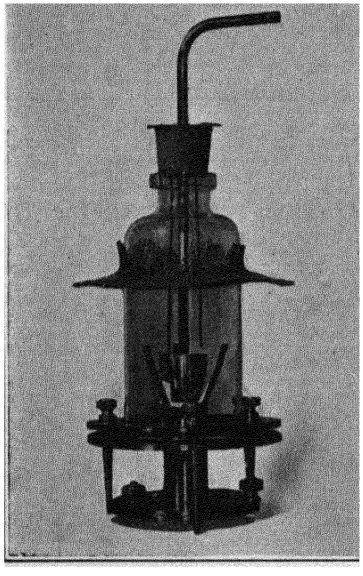


FIG. 3.—The Darling calorimeter.

The method of carrying out a determination with the Darling calorimeter is as follows :—

One thousand four hundred grams of water are measured carefully into the glass containing-vessel, using a one-litre

flask and graduated cylinder for this purpose. From half to one gram of the dry sample of fuel is weighed out into the crucible; this is placed in its holder, and the apparatus is clamped together. If electric ignition is to be employed, the ends of the two copper conducting wires are joined by a short piece of very fine platinum wire, the loop of which is made to dip under the surface of the fuel contained in the crucible. It is wise to try the effect of the current on this wire before clamping up the apparatus for each test. The oxygen supply tube is connected to the gas holder or cylinder containing oxygen, and a slow but steady current of oxygen is passed through the apparatus, which is now ready for immersion in the vessel containing the water.

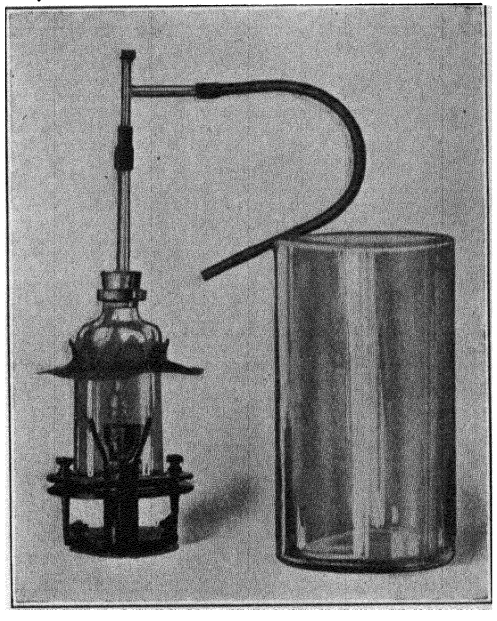


FIG. 4.—The Darling calorimeter.

When immersed, the water should reach up to the neck rim of the bell-jar but not above it, and the air which is being displaced from the interior of the apparatus by oxygen should bubble up through the water in small bubbles from all portions of the perforated brass plate. The temperature of the water is next taken at two-minute intervals, and when the thermometer has become stationary, the stream of oxygen is made much more rapid, and the coal is ignited. If charcoal be used

for ignition, the small weighted particle is held over a lighted match until it commences to glow, when it is dropped down the oxygen tube. If the coal contains much volatile matter, there is some danger of explosion during the early part of the combustion, and considerable skill and experience in the management of the apparatus are necessary to obtain perfect combustion. It is advisable, therefore, to start with the lower end of the oxygen supply pipe high up in the bell-jar, and to have a very rapid current of oxygen when the coal (as shown by the approximate analysis) contains over 30 per cent. of volatile matter.

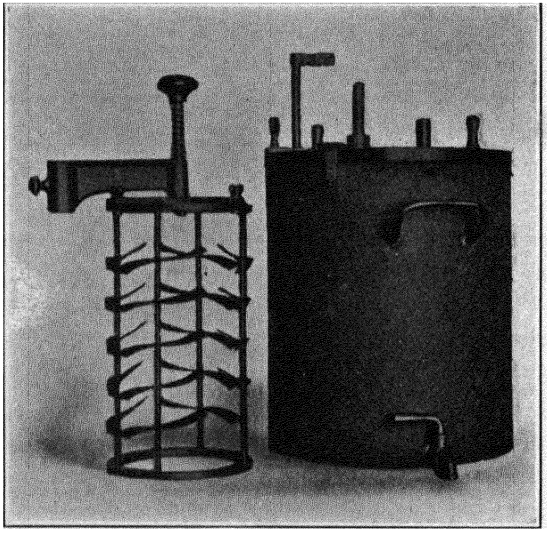


FIG. 5.—Insulating vessel and mechanical stirrer for calorimeters.

When the greater portion of the volatile matter has been distilled and burnt, the oxygen tube can be pushed down gradually until it is below the crucible rim. The combustion can be finished with the lower end of the oxygen supply tube nearly touching the glowing residue in the crucible. The combustion is finished when the residue in the crucible ceases to glow; the crucible itself should become red-hot during the combustion, and in order to avoid premature loss of heat it is advisable to support the crucible upon an asbestos tray. The current of oxygen gas through the apparatus is then slackened, and the temperature

of the water is noted every half-minute until a fall occurs. The calculation is made as already described for the Mahler bomb.

The Darling calorimeter yields entirely satisfactory results with fuels low in ash and in volatile matter. When fuels containing a high percentage of volatile matter are burnt, there is a tendency for some of the volatile hydrocarbons to escape unconsumed; and when fuels high in ash are tested, there is a tendency for portions of the fixed carbon to remain unburned in the crucible.

The first of these difficulties may be overcome by mixing one-third of its weight of china clay with the fuel before burning in the calorimeter. This remedy, however, is only partial, for it increases the amount of ash and therefore the risk of some of the fixed carbon remaining unconsumed.

The second difficulty can be overcome by making small pellets or briquettes of the fuel sample, and using these for combustion in the calorimeter in place of the finely-powdered sample. Very bituminous fuels can be moulded without adding gum arabic; but in other cases a few drops of a 1 per cent. solution of this binding agent will be found useful in preparing the briquettes.

When fuels containing less than 10 per cent. of volatile matter are tested, some difficulty will be met with in the absence of an electric current in causing them to ignite, for neither charcoal nor sulphur will always suffice to start the combustion. The best plan in such cases is to use a small weighed portion of some previously tested bituminous coal, as ignition charge. The calorific value of the added fuel must, of course, be allowed for in calculating the result of the test.

By using only half a gram of fuel with 3,500 grams of water, the time required for burning the fuel and the gain in temperature can be reduced very considerably, and the errors due to radiation losses correspondingly diminished. When working with this small amount of fuel and large volume of water,

however, very careful and accurate weighing and temperature measurements are required in order to obtain reliable results.

The combustion of the fuel can also be effected much more quickly when the fuel is in briquette form, since the current of oxygen gas can be increased greatly without danger of blowing the fuel out of the crucible. The oxygen used in working the Darling apparatus should either be stored in a gas holder over water, or should be passed through a glass tower filled with pumice soaked in water, in order that it may take up before use all the moisture it can carry at the temperature of the laboratory. It is also useful to have a wash-bottle, through which the oxygen bubbles, inserted between the oxygen gas holder or cylinder and the calorimeter, since in this way the speed of the gas current can be more easily noted and controlled.

When used with the precautions described above, the Darling calorimeter yields accurate results with all classes of fuel.

The above forms of calorimeter are all designed for solid fuels, and the only one in which the calorific value of a liquid fuel can be determined is the Mahler bomb. In practice, it has been recommended that the liquid fuel should be soaked up by a pellet of absorbent cellulose, and the pellet and oil burnt together, but the objection to this is that the heat of combustion of the pellet has to be allowed for, and it is difficult to get its exact weight owing to its hygroscopic properties. The best method is to fill the platinum crucible or holder with kieselguhr, and to drop the oil on to this. No trouble is experienced in igniting the oil in the bomb, and no allowance has to be made for added cellulose.

To determine the calorific value of a gas, the exact content of the bomb must be ascertained. It is filled with the gas, and the pressure is reduced to a few millimetres of mercury by an air pump, when the bomb is again filled

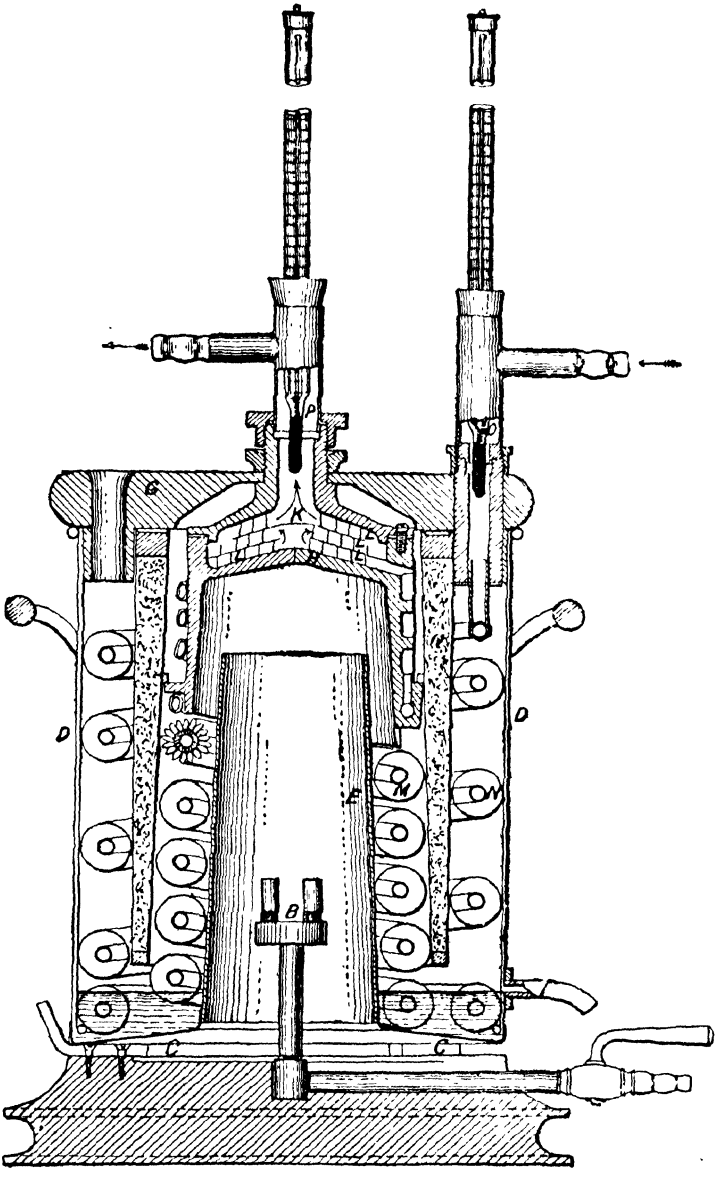


FIG. 6.—Boys' calorimeter (section).

with gas under atmospheric pressure and at the ordinary temperature. It may be then taken that the bomb is filled with the pure gas. Care must be taken that the gas is not diluted too greatly with the oxygen, as otherwise combustion will not be secured. With illuminating gas a pressure of 5 atmospheres of oxygen is sufficient, whilst with a poor combustible like producer gas, half an atmosphere only is needed.

For the determination of gaseous fuels, however, the simplest and best form of calorimeter is that of Boys, in which the heat caused by the combustion of the gas from a suitable burner is transmitted to a current of water flowing at a constant rate. Measurements are taken of the quantity of gas burnt, the quantity of water passed through the apparatus, and the difference in temperature of the water at its inlet and point of outflow.

The calorimeter is shown in section in Fig. 6, and the following description is drawn from Boys' paper before the Royal Society in 1906.

A circular base A carries the gas pipe and tap, terminating in a pair of No. 3 union jet burners B. The top surface is protected from radiation by a disc of bright metal, which is held down by the screws which fix the three centering blocks C. In the base a governor may be inserted, or an ordinary balance governor may be used instead, to counteract the variations in pressure resulting from the working of the meter.

On the three centering blocks C rests a vessel D of sheet brass with a central chimney of thick sheet copper E. On one side, 1 inch from the bottom, a side tube F is fastened, so that condensation water may drip from this into a measure placed to receive it. The vessel D may be turned round so that the drip tube lies in any direction with respect to the gas inlet.

Attached to the lid G are the essential parts of the calorimeter. Beginning at the centre, where the outflow is situated, there is a brass box which acts as a temperature equalising

chamber for the outlet water. Two dished plates of thin brass KK are held in place by three scrolls of thin brass LLL. These are simply strips bent round like unwound clock springs, and no attempt should be made to prevent all leakage from one spire to the next, as a little will be advantageous in encouraging temperature equalisation. For the same reason a little leakage from each spire to the one above may be allowed. The lower or pendant portion of this box is kept cool by circulating water, the channel for which may be made in the solid metal as shown on the right side, or by sweating on a tube, as shown on the left. Connected to the water channel at the lowest point by a union are six turns of copper pipe, such as is used in a motor car radiator. A helix of copper wire is wound round this pipe and sweated on to the same in order to promote its action in absorbing the heat of the gases. A second pipe and helix of similar pattern surrounds the inner one, and is connected to it at the lower end by a union. This terminates at the other end in a block, to which the inlet water box and thermometer holder are secured by a union as shown at O. A similar outlet water box P and thermometer holder are similarly secured above the equalising chamber H. The lowest turns of the two coils M and N are immersed in the water, which in the first instance is put into the vessel B.

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

The narrow air-space between this and the vessel D also serves to prevent interchange of heat between the calorimeter and the air of the room.

The two thermometers for reading the water temperatures, and a third which may be added for reading the temperature of the outlet air, are all near together and at the same level. The lid may be turned round into any position relatively to the gas inlet and condensed water drip that may be convenient for observation; also the inlet and outlet water boxes may themselves be turned so that their branch tubes point in any direction. The instrument is convenient also in its small height, the thermometers being comfortably read when the instrument is standing on an ordinary table.

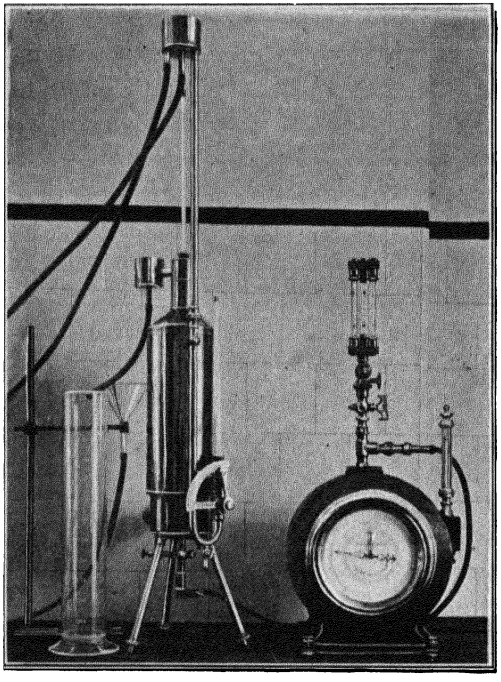


FIG. 7.—Junker calorimeter.

For regular testing purposes, there is no need to use different rates of flow of water at different times. An overflow water funnel may therefore be fixed on the wall at a convenient height, and connected by indiarubber tubes with a supply tap from the main and with the inlet O of the instrument. A uniform rate of flow is most easily attained by the use ot a diaphragm in the supply pipe which has been reamed out to

allow the desired flow to pass through the instrument with the given head. There will be no occasion afterwards to adjust this.

The flow of air to the burner is determined by the degree to which the passage is restricted at the inlet and outlet. If the three centering blocks are made of material $\frac{3}{16}$ inch thick and the gas escapes by five holes $\frac{5}{8}$ inch in diameter in the outer portion of the lid, the flames burn well, do not smoke, and an unnecessary excess of air is prevented from passing through the instrument. A sixth hole may be provided for a thermometer, so placed as to measure the temperature of the outlet gases.

In order to prevent corrosion of the metal surfaces by the continued soaking action of very dilute sulphuric acid and dissolved oxygen, the whole of the coil system can be lifted up out of the vessel D when the measurements have been made, and placed in a jar containing a very dilute solution of carbonate of soda.

Any deposit of lime that may be formed in the pipe system and equalising box can be removed by passing very dilute hydrochloric acid through, and washing out with water.

The water contents of the coil and equalising box of the Boys' instrument is only 300 c.c., and of the vessel D, up to the overflow, 400 c.c. The designer justifies his inversion of the usual arrangement of a small gas space and of large water space by stating that the latter leads to irregular outlet temperatures. In his opinion the gases should have sufficient space to pass slowly through the calorimeter, while the water should be taken rapidly through every channel, strictly in series, with the complete avoidance of parallel flow. The small water pipe used in his own design of calorimeter, fortified with heat collecting ribs or wires, carries sufficient water to absorb the whole of the heat present in the hot gases.

Tests are given showing that the form of construction advocated yields variations only of ·01° or ·02° C. with a total rise

of 24° C., and that in from 10 to 15 minutes after lighting up, the calorimeter is giving uniform readings.

The calculation of the calorific value of the gas is made by multiplying the volume of water flowing per minute, measured in litres (1 litre = 1,000 c.c.), by the rise in temperature, measured in degrees Centigrade. The product is then divided by the volume of gas burnt per minute, measured in cubic feet or in cubic metres (1 cubic foot = 28·31 litres; 1 cubic metre = 1,000 litres).

The above is the "gross" value of the gas, *i.e.*, includes the latent heat of the steam formed by the combustion of the hydrogen in the fuel, which heat is not used in firing boilers or in the internal combustion engine, as the steam escapes uncondensed. To determine, therefore, the actual available heat, this latent heat must be deducted from the gross value, and the result gives the "net" value. The amount of condensed water in cubic centimetres per cubic foot of gas consumed collected in the measuring cylinder, multiplied by 0·6, will give the calorific value of the latent heat of the steam.

To take an actual example:—

Gas consumed—

Meter at start . . . zero.
Meter at finish . . . 0·25 cubic feet.

Temperature of the water—

	Inlet Thermometer.	Exit Thermometer.
	10·2	28·5
	10·2	28·6
	10·2	28·5
	10·2	28·4
	10·2	28·5
Average	10·2	28·5

Increase of temperature = 28·5 − 10·2 = 18·3° C.

Water collected . . . . 2 litres.

Gross heating value of the gas—

$$\frac{2 \times 18{\cdot}3}{{\cdot}25} = 146{\cdot}4 \text{ calories per cubic foot.}$$

Condensed water collected in measuring cylinder—

51 cc. from 2 cubic feet of gas.

The latent heat of the condensed water, therefore, is

$$\frac{0{\cdot}6 \times 51}{2} = 15{\cdot}3 \text{ calories.}$$

Deducting 15·3 from the gross value, 146·4, the net value is obtained.

$$146{\cdot}4 - 15{\cdot}3 = 131{\cdot}1 \text{ calories per cubic foot.}$$

To obtain the value in B.T.U., multiply the results by 3·968, then—

CALORIFIC POWER OF THE GAS.

	Calories.	B.T.U.
Gross	146·4	580·9
Net	131·1	520·2

In the Simmance-Abady calorimeter, which differs considerably from the Boys, the gas to be tested is burnt in a bunsen burner, and the products of combustion are made to pass downwards through a number of tubes set in a vessel through which a constant flow of water is kept running in the opposite direction. The outside of the vessel is lagged with wood to prevent loss by radiation. The thermometers for recording the temperatures of the water at the inlet and outlet of the supply are brought close to one another at the top of the calorimeter, whilst an open glass tube at the outlet serves as a gauge for detecting any changes in the "head" of water passing through the instrument. A thermometer is placed at the exit for the cooled products of combustion. The outlet pipe of the water is provided with a tilting bucket, by means of which the stream of water can be directed either into the measuring cylinder or into the waste funnel.

Water is allowed to flow through the calorimeter and run to waste, and the gas to be tested, after passing through a governor and meter, is burnt in the special burner in the stand under the calorimeter. The outlet shutter at the exit of the products of combustion is adjusted till the thermometer there shows that practically all the heat has been extracted from them. When all the thermometers show a fairly constant temperature and the hand of the gas meter passes zero, the flow of water is directed by means of the tilting bucket into the measuring cylinder, and kept in that position until the meter hand has made one revolution, when the water is again allowed to run to waste by releasing the bucket. The difference in temperature between the inlet and outlet thermometers multiplied by the volume of water collected in the measuring cylinder and divided by the quantity of gas consumed will give the calorific power of the gas.

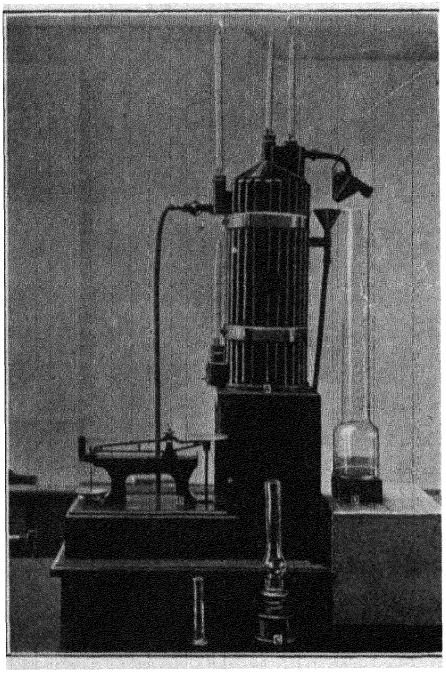


FIG. 8. – Simmance-Abady calorimeter.

The Simmance-Abady calorimeter is easily modified for determining the calorific power of light oils, alcohol, etc. Instead of the gas burner and meter, a small lamp is used, which fits on a sensitive balance. The lamp is charged with the liquid

hydrocarbon to be tested, and whilst water is passing through the calorimeter, is lighted and placed on the balance with its flame or chimney central under the calorimeter. When all the measuring cylinder, a small measure is placed under the outlet for condensed water, and a gramme weight added to the lamp pan, which will cause it to fall again. With the combustion of the oil the lamp will again rise, and as the balance indicator passes the level point, the water is allowed to run to waste. The collected water is weighed and correction applied for temperature, if necessary.

Knowing then the difference in the inlet and outlet water thermometers, the weight of fuel burnt, and the amount of water collected, a simple calculation will give the calorific value of the fuel. The difference in temperature is multiplied by the amount of water in litres and divided by the quantity of fuel consumed, and the result will give the calorific value in grammes per litre.

(5) Platinum is the most satisfactory lining for bomb calorimeters on account of its resistance to heat changes and to acids, although its very high cost has now restricted its use for this purpose and has led to the employment of many cheaper substitutes. Electro-deposited gold is fairly satisfactory, but requires frequent renewal; and enamel or porcelain is liable to develop fine cracks under the heat developed at the moment of combustion, which is often sufficient to fuse the thin platinum wire used for ignition.

A perfectly satisfactory lining for bomb calorimeters in fact has not yet been found.

CHAPTER IV.

LIQUID FUEL.

The discovery of petroleum in America—The Russian oil fields—The distribution of petroleum—The conditions under which it occurs—The nature of petroleum, and the products obtained from it—The amount available for fuel purposes—The flash point, and how it is determined—The Abel test—The Pensky-Marten—The requirements in a fuel oil—Shale oil as a fuel—The shale oil industry—Coal tar, and its composition—Creosote oil—Blast furnace oil—Shipping regulations for oil fuel—Petroleum spirit and its dangers—The testing of atmospheres likely to contain explosive mixtures of petroleum vapour and air—The Clowes-Redwood apparatus.

THOSE districts which now yield so rich a harvest of mineral oil have been celebrated, from the earliest days of which we have record, for the curative powers of certain oils found either as springs or as a scum on lakes and pools. Many hundred years before the American Indians in the valleys of the Allegheny collected the scum from certain pools and streams and used it as a cure for rheumatism, the curative properties of the oil from springs in the Baku district of Russia had been recognised and used by the Persians for sore heads and mangy camels, whilst at even earlier dates the natural gas issuing from the ground not far from the present site of Baku gave the everlasting fire that made this district the principal stronghold of the fire worshippers.

It was in America, however, that the first systematic boring to obtain oil took place, when in 1859 Colonel Drake sank an artesian well on much the same system as had

been previously employed for water. This well was sunk at Oil Creek in Pennsylvania, and oil was obtained at a depth of 69 feet. Although the yield during 1859 only amounted to some 2,000 barrels, yet it led to rapid development, all the available land down the creek and along the Allegheny being taken up, numbers of wells were sunk, and considerable quantities of oil were obtained, although always at a greater depth than had been the case with Drake's well.

In these early wells the oil had to be pumped, but in 1861 a well drilled to a depth of 460 feet yielded oil at such pressure that it rose to the surface and overflowed, and oil to the extent of 300 barrels a day was obtained from it for six months, whilst the Empire well, sunk close to it, yielded 2,500 barrels a day.

The oil fever was now at its height, and oil was prospected for in every direction: wherever found, wells were sunk, and the most wasteful systems of collection and storage being adopted, the loss of oil was enormous. As a rule these wells were only productive for from six months to two years, and mushroom cities sprung up in the neighbourhood of successful wells only to be deserted as the supply failed. Moreover, the glut of oil so created swamped the demand, and prices fell until the barrels were of more value than the oil, and in 1862, in Pennsylvania it is computed that as much as ten million barrels of oil ran to waste.

Western Virginia, Kentucky, Tennessee, Illinois, Kansas, and Texas, all proved to be oil-bearing States. About this time also, in the township of Enniskillen, Canada, at Blake Creek, enormous yields of petroleum were obtained, and wells were sunk in large numbers, but as there was no market for the oil most of it ran to waste down the creek and five million barrels were wasted in 1862. Gradually however, the supply created an increasing demand, and vast quantities of oil being exported, the prices gradually

increased, until in 1872 the great Russian oil fields entered into competition with America for the European trade.

Although it had been well known from the earliest dates that in the Baku district oil existed in great quantities, but little importance had been attached to it, and at this period the oil production of the district was practically a monopoly in the hands of a trader named Meerzoeff: in 1872, however, this concession was withdrawn, and the Russian Government substituted a tax on the amount of oil produced, this change quickly resulting in the oil production of the district being increased tenfold.

At this period the oil wells of the district were mostly dry, and there were no flowing wells, but in 1873 drilling resulted in getting oil not only to flow, but to spout in such enormous quantities as to be entirely beyond control, with an enormous consequent loss, these fountains often rising to a height of 200 to 300 feet.

These enormous deposits were generally tapped at a depth of 400 to 800 feet, and the volume of oil discharged may be imagined from the following description given by Sir Boverton Redwood from a Baku paper:—

"From the town the fountain had the appearance of a colossal pillar of smoke, from the crest of which clouds of oil sand detached themselves and floated away a great distance without touching the ground. Owing to the prevalence of southerly winds, the oil was blowing in the direction of Bailoff Point, covering hill and dale with sand and oil, and drenching the house of Bailoff, a mile and a half away. . . . The whole district of Bibi-Eibat was covered with oil, which filled up the cavities, formed a lake, and on the fifth day began flowing into the sea. The outflow during three days was estimated at 5,000 or 6,000 tons daily. . . . On the eighth day the maximum was reached, the oil then spouting at the rate of 11,000 tons, or 2,750,000 gallons, a day. . . . After the tenth day it began to diminish, and by

the fifteenth day the engineers had so far got it under control that the outflow was only 250,000 gallons a day. Altogether, over 10,000,000 gallons of oil came to the surface, and most of this was lost for want of storage accommodation."

At the present time there is hardly a country in the world that has not yielded small quantities of petroleum, and the recent trial borings in Derbyshire have proved the presence of oil in that county, although it is not yet settled whether the amount is sufficient to create a new industry. The following table shows the relative proportion of oil produced by the various countries of the world in 1912—before the European War had interfered with the normal development of the industry.

Country.	Barrels.	Metric Tons.	Percentage of Total Production.
United States . .	222,113,218	29,615,096	63·25
Russia	68,019,208	9,317,700	19·37
Mexico . . .	16,558,215	2,207,762	4·71
Roumania . . .	12,991,913	1,806,942	3·70
Dutch East Indies . .	10,845,642	1,478,132	3·09
Galicia	8,535,174	1,187,007	2·43
India	7,116,672	989,801	2·03
Peru	1,751,143	233,486	0·50
Japan	1,671,405	222,854	0·48
Germany . . .	995,764	140,000	0·28
Canada	243,614	32,612	0·07
Italy	86,286	12,000	0·02
Other countries . .	250,000	33,333	0·07
Total . . .	351,178,236	47,276,725	100·00

The form of well and method of driving it varies a good deal with the country and the geological strata through which the shaft has to pass, whilst the depth in some cases may be under 100 feet, and in others over 2,000. Nor is the oil confined to any particular geological formation. The oil is mostly found in strata of conglomerate or sand,

and the deposits which have proved commercially successful in working are chiefly comprised within the Silurian and Carboniferous epochs in America, and deposits of the Tertiary period in the eastern hemisphere.

The conditions under which petroleum and natural gas occur are summarised by Mr. Topley as follows:—

1. They occur in rocks of all geological ages, from Silurian upwards. The most productive areas are the Palaeozoic in North America, and Miocene in the Caucasus.

2. There is no relation to volcanic action.

3. The most productive areas for oil in great quantity are when the strata are comparatively undisturbed. Oil, but in less abundance, frequently occurs when the strata are highly disturbed and contorted: but gas is rarely so found.

4. The main requisites for a productive oil or gas field are a porous reservoir (sandstone or limestone) and an impervious cover.

5. Both in comparatively undisturbed and in highly disturbed areas, an anticlinal structure often favours the accumulation of oil and gas in the domes of the arches.

6. Brine is an almost universal accompaniment of oil and gas.

As the crude oil comes from the well it is a mixture of many hydrocarbons, and varies considerably both as regards its physical and chemical properties, according to the source from which it was obtained, the American and Russian oils, upon which the greatest amount of scientific work has been done, differing widely in their chemical composition, although much alike in the physical properties of the products obtained from them.

The researches of Pelouze, Schorlemmer, Warren, and others, all show that the Pennsylvanian oil consists of the methane or paraffin series of hydrocarbons, whilst the Russian oil belongs to the naphthene group ($C_nH_{2n-6} + H_6$), which in empirical composition is identical with the ethylene group (C_nH_{2n}), but which in many properties so

closely resembles the paraffins that in considering the rectification of the oil it will be sufficient to consider the processes employed in dealing with the American oil.

The specific gravity of the oil as it leaves the well varies from 0·77 to 1·00, although either of these extremes is very rarely met with, and the bulk of the crude oil of Pennsylvanian and Russian origin will fall between the limits of 0·844 and 0·899. Where the specific gravity much exceeds this it often means that it is an oil collecting at shallow depths, which has lost most of its more volatile constituents by evaporation, or else that it contains a high proportion of solid hydrocarbon dissolved in it.

The following members of the paraffin series have been isolated from American petroleum :—

PARAFFINS FROM PENNSYLVANIAN PETROLEUM.

Name.	Formula.	Boiling Point °C.	Specific Gravity.	Condition.
Methane	CH_4			Gaseous
Ethane	C_2H_6			,,
Propane	C_3H_8			,,
Butane	C_4H_{10}	0		,,
Pentane (normal)	C_5H_{12}	38	0·628	Liquid
Hexane ,,	C_6H_{14}	69	0·664	,,
Heptane ,,	C_7H_{16}	97·5	0·699	,,
Octane ,,	C_8H_{18}	125	0·703	,,
Nonane	C_9H_{20}	136	0·741	,,
Decane	$C_{10}H_{22}$	158	0·757	,,
Endecane	$C_{11}H_{24}$	182	0·765	,,
Dodecane	$C_{12}H_{26}$	198	0·776	,,
Tridecane	$C_{13}H_{28}$	216	0·792	,,
Tetradecane	$C_{14}H_{30}$	238		,,
Pentadecane	$C_{15}H_{32}$	258		,,
Hexadecane	$C_{16}H_{34}$	280		,,
Octodecane	$C_{18}H_{38}$			
?	$C_{20}H_{42}$			
?	$C_{23}H_{48}$			
?	$C_{25}H_{52}$			
Paraffin (myricyl)	$C_{27}H_{56}$			Solid
,, (ceryl)	$C_{30}H_{62}$	370		,,

The object of the refiner is to obtain from the crude oil the largest proportion of the most marketable product, and in most cases the oil is fractionally distilled, so as to separate from it the various grades of petrol, which is now, owing to the demand for motor spirit, one of the most profitable products, burning oils (suitable for use in lamps), lubricating oil, and solid paraffin.

The proportions in which these products are obtained from American crude oil have been given as—

Petroleum spirit—Gasoline .	1·5	per cent.
C naphtha	10·0	,,
B naphtha	2·5	,,
A naphtha	2·5	,,
Lamp oil	54·0	,,
Lubricating oil . . .	17·5	,,
Paraffin solid . . .	2·0	,,
Loss	10·0	,,
	100·0	

The petroleum spirit and lamp oil after separation have to undergo a process of purification to remove highly coloured traces of tarry matter dissolved in them, as well as other impurities, and this is done by first washing the oil with sulphuric acid, then with water, and finally with caustic soda or sodium hydroxide.

Where oil is abundant the distillation is in many cases only continued until the naphthas and lamp oil have been separated, and the heavy oil left in the still and called in America "residuum" is employed as fuel. In Russia especially, where the crude oil contains a comparatively small proportion of the volatile hydrocarbons, and where there is a good market for the residue, called "Astatki," this is done.

The crude Russian oil yields on an average—

Petroleum spirit . . .	6 per cent.
Lamp oil	20 ,,
Solar oil	6 ,,
Astatki	58 ,,

This at once shows the difference in value of an oil as a source of fuel, for with the American oil there is only some 20 per cent. of residuum which could be supplied at a price that would make it commercially possible as a fuel, whilst in the Russian oil there is nearly 60 per cent. of the Astatki. In the oil fields which have been discovered since 1900, such as those of Texas, Borneo, and California, the oils are comparatively poor in the lighter hydrocarbons, but yield a high percentage of fuel oil, whilst some of the still smaller sources of supply yield oil so poor in volatile bodies that mere exposure to the atmosphere would fit them for fuel purposes.

Taking all the sources of oil supply, the amount which could be used as fuel in place of coal would be approximately one-third of the total yield.

As has been already stated, the total oil output of the world in round figures is 61,000,000 tons, as against 1,300,000,000 of coal; and if, of this 61 only one-third is available for fuel purposes, we find that there is less than one-sixtieth of the liquid fuel to be obtained that would be necessary if it were to entirely replace solid fuel, as some of its more ardent advocates seem to think it should. It may be urged that the supply of oil has steadily increased since its discovery in quantity, but whilst this is perfectly true, it is also a fact that the increase has been due to increase in the number of wells, and that the oil-yielding districts are becoming rapidly exhausted.[1] This is especially the case in America, and whilst, although less visible in Russia, the last ten years have seen the number

[1] See note (6) on p. 107.

of producing wells more than trebled, whilst the production has been hardly doubled.

It is quite clear that even if oil is still being produced by natural processes in the underlying strata of the earth, it can only be at a very minute rate as compared with the drain that is taking place on the oil stored in the sand strata from which we take our supplies, and that instead of building our hopes on an ever increasing supply of this valuable fuel we should be rather economising the supplies we can get for use in those branches of industry in which liquid fuel has shown itself to be of the greatest economic advantage.

The factor which has cut down our liquid fuel supply to one-third of the total production is the all-important one of safety in transport and use. If it were attempted to use crude oil as obtained from the oil well, those portions which in the rectification of the oil distil over at the lowest temperatures, would evaporate into the air, and with it form an explosive mixture, whilst the vapour, being specifically much heavier than air, would flow from the fuel store to even distant sources of fire, and once ignited the flame would travel back to the oil store itself, hundreds of accidents of this character taking place in the early days of the oil industry before the full danger had been realised.

The temperature at which a sample of oil commences to give off inflammable vapour is known as its "Flash Point."

For oils suitable for domestic use in heating and lighting the flash point used to be determined by heating a small quantity of the oil in a cup or other open vessel, the temperature, as indicated by a thermometer in the oil, being gradually raised until a point was reached at which, when a small flame was passed over the mouth of the vessel, a flash was observed, due to the ignition of the oil vapour given off. The temperature at which this occurred was called the flash point of that particular oil.

This method of testing gave very discordant results, and was unsatisfactory, as it was easily affected by external influences. These troubles were overcome by using a closed vessel to contain the oil, and the type of apparatus which has been adopted in England was designed by Sir Federick Abel, and bears his name. In this instrument a metal cup A of standard size is used for holding the oil, the correct quantity being indicated by a bent wire with sharpened point being fixed inside the cup; a flange near the top of the cup permits it resting in an outer vessel D which forms a water jacket, and which can be heated by a spirit lamp placed below. The cup is provided with a close-fitting cover C, which carries the test flame and thermometer B. In the cover also are cut three square holes of definite sizes, which can be closed or opened by a sliding piece of metal with perforations to correspond. The test flame may be a small bead of gas at the end of a small tube, or the flame from a small oil lamp, but in either case the

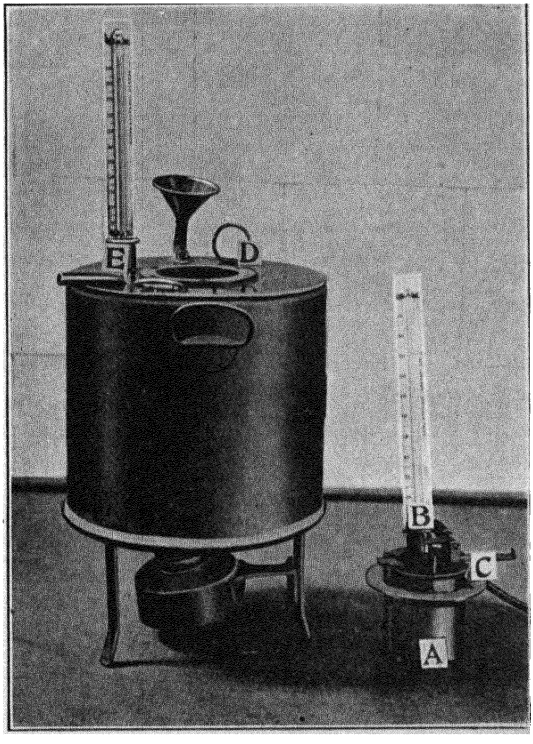


FIG 9.—Abel flash point apparatus.

burner is so arranged on trunnions that the flame can be lowered into one of the cover openings when the slide is drawn back, and resumes its normal position when the slide once more closes the openings. The thermometer is fixed in a slanting position for ease of observation, and is so arranged that when slipped into its tube in the cover the bulb is a definite distance below the surface of the oil in the centre of the cup.

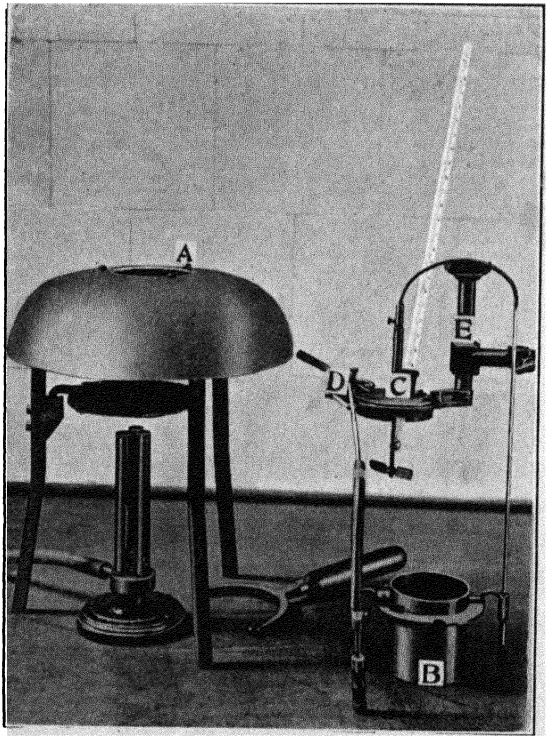


FIG. 10.—Pensky-Marten flash point apparatus.

In use the spirit lamp below the outer water jacket is lighted, and the temperature slowly rises. At regular intervals the slide on the cover is pulled, thus causing the test flame to be lowered into the opening in the cover, and the moment a flash is seen to occur, the temperature is noted, this point being regarded as the "flash point" of the sample under consideration.

If the same oil be tested with the open and the closed cup, it will be found that whereas the oil will flash at, say, 100° F. with the open, the flash will take place at 73° F.

in the closed vessel, the difference being due to various factors, such as absence of draughts, etc.

In Germany the authorised apparatus is the Pensky-Marten, which is a modified form of the Abel, and is used in a similar manner. The oil cup is of porcelain, B, and rests in an outer vessel of iron, A, which contains sufficient sand to raise the bottom of the cup half an inch away from the point of contact with the flame. A mechanical device of a rotating fan attached to the rod C in the oil is used to keep the liquid agitated, and ensure an even distribution of the heat.

For domestic purposes and use on shore the flash point of an oil has to be 73° F. (22·8° C.), whilst for use as a fuel in the mercantile marine it has to be 150° F. (65·5° C.): the flash point of oil fuel for the Navy, however, has been fixed at 175° F. (80° C.).

In considering the requirements for a really good fuel oil, there are several factors that must be taken into account. Many of the more recent oil supplies contain an objectionable amount of sulphur, and if this were all left in the fuel oil, its action upon copper and copper alloys in the injectors and oil-burning fittings would rapidly corrode and destroy them. The oil, however, can be easily purified to a reasonable extent, and there should not be more than one per cent. left in the oil.

The petroleum intended for fuel should undergo filtration or other process to free it from any foreign matters that would be liable to choke the injector whilst burning the oil, and it should be practically free from water, as it has been found that if the oil contains drops of water entangled in it, these will often put out the flame at the burner, and lead to the formation of an explosive mixture of oil spray and air in the combustion chamber.

The flash point allowed for a fuel will, of course, vary with the purpose for which it is to be used, and for locomotives

it might be as low as 73° F. (22·8° C.) if it were to be used in a cold climate; but experience shows that it is far safer not to lower the flash point below 150° F. (65·5° C.), as trouble may arise in the preliminary heating of the oil before being brought to the burner, and an oil tank on fire is so serious a matter even on land that no risks should be taken.

Many samples of oil otherwise fitted for fuel purposes are so thick and viscid that they will only flow sufficiently freely when heated, and as this gives rise to considerable complication in their use, a good fuel oil should be sufficiently fluid to flow through half-inch tubes, even at the freezing point.[1]

Shale Oil as a Fuel.

Although its wide distribution and the quantity of the supply make petroleum the great liquid fuel, yet there are other liquid hydrocarbons, which are locally obtainable in sufficient quantity to be used in the place of coal, and next to mineral oil in importance comes the oil obtained by the destructive distillation of shale.

We have already seen (p. 39) the course of events which led to Dr. James Young attempting the preparation of lubricating oil from the Scotch shales, and although the fact that liquid hydrocarbons could be obtained by distilling coal and other solid hydrocarbons had been known long before, it was undoubtedly Young's experiments that started the shale oil industry as at present it is carried out.

During the early years of the industry the shale mostly employed was the Torbanehill mineral, but since 1862 the Broxburn, Midlothian, and Linlithgow shales have been the chief source of supply. The shales differ from coal in that, instead of being a mixture or compound of carbon with hydrocarbons, they contain hydrocarbons with mineral matter, with the result that when heated to redness in a

[1] See note (7) on p. 107.

retort, they do not form coke, as coal does, but leave 70 to 80 per cent. of mineral matter.

The distillation of the shales takes place in vertical retorts, the upper portions of which are often of cast iron, and here the shale is exposed to a temperature of 900° F. (482° C.), at which the oil distils over; the spent shale then passes down into the lower portion of the retort, which is made of brickwork heated to about 1,300° F. (704° C.), and being kept moving downwards is finally discharged into a hopper at the bottom. The process is continuous, and takes about six hours from feed to discharge, fresh shale being fed into the top of the retort as the spent shale is removed below, and steam is passed through the retort during the whole process, the quantity varying with the character of the shale. The action of the steam is to recover the ammonia from the nitrogen present in the shale. From a ton of shale from 20 to 30 gallons of crude oil and from 40 to 70 lbs. of ammonium sulphate can be obtained.

The crude oil has a specific gravity of from 0·860 to 0·890, and has a dark green colour; during the process of refining this yields approximately—

Naphtha	6 per cent.
Burning oil	32 ,,
Heavy oil	24 ,,
Paraffin scale	12 ,,
Loss	26 ,,
	100

and it is the heavy oil that is used as a fuel.

Tar, formed during the destructive distillation of coal for the production of coal gas, is also used as a liquid fuel, but in its crude condition contains so much solid matter that it can only be employed with very unsatisfactory furnace arrangements.

Tar derived from ordinary bituminous coal is a black, somewhat viscid liquid, varying in specific gravity from 1·1 to 1·2. London tar, made from coal alone, or at most with an admixture of only about 2 per cent. of cannel, has usually a specific gravity of 1·2; whilst provincial tar, made from coal with a larger proportion of cannel, is reduced to near the lower limit owing to the greater quantity of light oils yielded by cannel. The ultimate composition of a London tar is approximately as follows:—

Carbon	77·53
Hydrogen	6·33
Nitrogen	1·03
Sulphur	0·61
Oxygen	14·50
	100·00

These elements in tar are built up into about 190 different compounds, traces of which can be identified, but for all practical purposes we may take those given in the table on page 99 as being the chief constituents.

In roughly considering the proportion in which the main constituents occur in coal tar, we can still further simplify the composition, and look upon it as containing benzene, naphtha, naphthalene, anthracene, carbolic acid, and pitch; and if this tar be carefully redistilled, we find it can be separated into these constituents, which distil over at various temperatures.

First, light oils pass over, from which benzene and its homologues can be obtained; then heavy tar oil, from which carbolic acid is made; and pitch is left, from which a substance called anthracene can be separated. The benzene obtained is the source from which aniline is prepared, and it is from aniline that most of the coal-tar colours are derived.

	Neutral Hydrocarbons.	Boiling Point °C.	Formulæ.	Specific Gravity.
Liquid .	Benzene	80	C_6H_6	0·88
	Toluene	110	H_7H_8	0·87
	Xylene	142	C_8H_{10}	0·87
	Isocumene	170	C_9H_{12}	0·85
Solid .	Naphthalene	217	$C_{10}H_8$	
	Anthracene	360	$C_{14}H_{10}$	
	Chrysene		$C_{18}H_{12}$	
	Pyrene		$C_{16}H_{10}$	
Alkaline products	Ammonia		NH_3	
	Aniline	182·5	C_6H_7N	1·02
	Picoline	130	C_6H_7N	0·96
	Quinoline	239	C_9H_7N	1·08
	Pyridine	117	C_5H_5N	
Acids .	Carbolic acid	180	C_6H_6O	1·07
	Cresylic ,,		C_7H_8O	
	Rosolic ,,		$C_{19}H_{14}O_2$	
	Brunolic ,,			
	Acetic ,,	118	$C_2H_4O_2$	1·06
	Free carbon			

The heavy tar oil obtained in this way from the coal tar is often called "creosote," and forms a fairly good liquid fuel. It is called also "heavy oil," from the fact that its specific gravity is over that of water, being as a rule about 1·1. In the fractional distillation of tar it distils over between 392° F. (200° C.) and 572° F. (300° C.), and is rich in phenols and cresols, and also contains large quantities of naphthalene dissolved in it, the latter often being separated from it and purified for use in the albo-carbon light, disinfecting tablets, etc.

The oil obtained from blast furnaces is also sometimes used locally for fuel purposes under the name of "Phenoloid," or blast furnace oil, but none of these forms of liquid fuel can be obtained in sufficient quantities to give them any

universal value. Tar oil and blast furnace oil have the great drawback as fuels, that in a closed stokehole they give off fumes, probably of acrolin, which painfully affect the eyes of the stokers, making them smart and water.

Attempts have been made to use alcohol as a fuel and, according to the German Press, experiments were made in 1902 with it on ships, the spirit being injected on to the surface of burning coal in the boiler furnaces in much the same way as oil fuel is frequently used.

If alcohol could be obtained cheaply it would have an advantage in burning without smoke, and as it is made by the fermentation of vegetable matter there would not be the fear that exists with coal and oil of exhausting the supply.

During the early years of the oil trade, when the importance of the flash point, and the use of proper precautions had not yet been learnt, a good many accidents occurred to cargo ships used in the transport of petroleum or using mineral oil as a fuel, and led to Lloyd's Register of British and Foreign Shipping issuing the following regulations with regard to ships burning and carrying liquid fuel.

1. In vessels fitted for burning liquid fuel, the record "Fitted for liquid fuel," will be made in the Register book.

2. The compartments for carrying oil fuel must be strengthened to efficiently withstand the pressure of the oil when only partly filled and in a sea-way. They must be tested by a head of water extending to the highest point of the filling pipes, or 12 feet above the load line, or 12 feet above the highest point of the compartment, whichever of these is the greater.

3. If peak tanks or other deep tanks are used for carrying liquid fuel the rivetting of these should be as in the case of vessels carrying petroleum in bulk. The strengthening of these compartments must be to the Committee's satisfaction.

4. Each compartment must be fitted with an air pipe, to be always open, discharging above the upper deck.

5. Efficient means must be provided by well sparring or lining to prevent any leakage from any of the oil compartments from coming in contact with cargo, or into the ordinary engine room bilges.

6. If double bottoms under holds are used for carrying liquid fuel, the ceiling must be laid on transverse battens, leaving at least two inches air space between the ceiling and tank top, and permitting free drainage from the tank top into the limbers.

7. The pumping arrangements of the oil fuel compartments and their wells must be absolutely distinct from those of other parts of the vessel, and must be submitted for approval.

If it is intended sometimes to carry oil and sometimes water ballast in the various compartments of the double bottom, the valves controlling the connections between these compartments and the ballast donkey pump, and also those controlling the suctions of the special oil pump, must be so arranged that the suctions for each separate compartment cannot be connected at the same time to both pumps.

8. No wood fittings or bearers are to be fitted in the stokehold spaces.

9. Where oil fuel compartments are at the sides of or above or below the boilers, special insulation is to be fitted where necessary to protect them from the heat of the boilers, their smoke-boxes, casings, etc.

10. If the fuel is sprayed by steam, means are to be provided to make up for the fresh water used for this purpose.

11. If the oil fuel is to be heated by a steam coil the condensed water should not be taken directly to the condenser, but should be led into a tank or open funnel mouth and thence led to the hot-well or feed tank.

12. The above arrangements are applicable only to the case of oil fuel the flash point of which, as determined by Abel's closed test, does not fall below 150° Fahrenheit.

The use of petrol or petroleum spirit in large quantities for oil motors, and the necessity for storing it in bulk, have of late given rise to a danger which before only existed to a limited extent.

Petrol is the first distillate from the crude oil as it comes from the oil well, and largely consists of pentane, C_5H_{12}, and hexane, C_6H_{14}, the first liquid members of the great paraffin group of hydrocarbons. This liquid is volatile even below the freezing point, and a pint of it poured on a level surface will cover about 80 square feet with an inflammable vapour, through which, on coming in contact with a light, a flame will spread. One pint of the liquid will also give enough vapour to render 100 cubic feet of air highly explosive. .

These light oils have a wonderful penetrative power, and it is a matter of considerable difficulty to get vessels made for commercial purposes sufficiently vapour-tight to resist the insidious creeping of petroleum spirit. The result is that in stores, cellars, and other places where vessels containing such spirits are kept, slight leakage and evaporation into the air are constantly occurring, and as the evaporation of one volume of liquid petroleum spirit would render 5,000 volumes of air strongly explosive, it is clear that special precautions must be taken in dealing with the storage and use of such spirit.

Mixtures of air and petrol vapour begin to be explosive when there is 2 per cent. of the vapour present in the air, the strength of the explosion increasing with the quantity of vapour up to about 2·6 per cent. and then gradually falling until with 5 per cent. of vapour the mixture is practically non-explosive.

The temperature needed for the ignition of explosive

mixtures of petroleum vapour and air is comparatively high, and experiments made by Colonel Majendie, Sir Boverton Redwood, and Dr. Dupré show that such mixtures were not ignited by the glowing spark on a splint of wood, a red hot coal which had ceased to flame, or a shower of sparks from a flint and steel, and that it needed a temperature of platinum wire raised nearly to a white heat before explosion took place, that is, about 1,200 to 1,400° C. If, however, any inflammable dust is present in the air, even a small spark will cause explosion, as the dust catching fire causes a flame that ignites the explosive mixture.

One of the greatest dangers with the vapour of volatile hydrocarbons is that the great weight of the vapour as compared with air will cause it to creep along surfaces for very long distances, and then on reaching a light the flame flashes back along the vapour to the source from which it sprang.

It may be accepted that the transport and storage of refined lamp oils and residuum are practically free from danger, the only point to be guarded against being the ignition of the liquids in volume, during fires, whilst the real dangers to be guarded against are to be found in the transport and storage of crude oils containing highly volatile constituents, and with petroleum spirit.

In all confined spaces used for the storage of such material, the adoption of the safety lamp, and the constant testing of the atmosphere by the beautiful method devised by Dr. Clowes and Sir Boverton Redwood would go far towards ensuring safety.

In the early days of the last century, when the introduction of coal gas gave rise to an increased demand for coal, explosions in mines became of such frequency that attempts were made to safeguard the miners' lives. As the result of the labours of a Royal Commission appointed

to enquire into the subject, and the experimental researches of Sir Humphrey Davy and George Stephenson, the safety lamp was installed in all fiery pits. Long before this period, however, the miners themselves had utilised a rough test for detecting the presence of the dread fire-damp in anything approaching dangerous quantities. It was well known that even a small percentage of fire-damp in the air of the pit gave rise to the appearance of a small flame-cap above the flame of the burning candle, and as the miner went down into the workings with the candle fixed at the end of his primitive candlestick—a wooden lath—in front of him, he would shade his eyes from the glare of the flame, and watching its tip would blow out the flame for very life the moment that the ghostly cap appeared. This flame-cap not only gave an indication of the presence of fire-damp, but according to its length also indicated roughly the proportion that was present, and it is upon a modification of this principle that our most modern and successful methods of detecting explosive gaseous mixtures and roughly estimating the proportion of explosive gas present have been based.

With the introduction of the safety lamp it was still found that the flame served to indicate the proportion of combustible gas even when still below the explosive limit, the change in the appearance of the flame giving a very fair guide to an experienced man of the proportion of fire-damp present, whilst when the dangerous limit in the atmosphere had been reached the fire-damp would burn within the lamp, and by its products of combustion rapidly extinguish the flame.

In those early methods of judging the nature of an atmosphere that might be explosive by means of a flame-cap it is clear that the flame employed being luminous, and the cap of a faint shadowy nature, the glare of the luminous portion of the oil or candle flame might seriously interfere

with ease of observation. As it was gradually realised that this phenomenon gave the simplest and most convenient method of testing, the apparatus was improved from time to time with a view of making it more accurate, and by the replacement of the gauze in the lower portion of the safety lamp by glass, and by shielding the direct light of the lamp from the eye, considerable advances were made, but it was only when the luminous flame was replaced by a non-luminous hydrogen flame, and mechanical devices were adopted for setting the test flame to an accurate height and maintaining it at this point, that the method attained any degree of accuracy. The miner's test lamp, as devised by Professor Clowes, has been adopted almost universally in mines.

When it became clearly evident that the development of the carriage of crude petroleum in bulk, and the carriage and storage of petroleum spirit necessitated analysing the atmosphere in tanks and stores, this method of testing naturally suggested itself, and Sir Boverton Redwood succeeded in devising a special modification of the lamp, and also an apparatus for collecting samples of the atmosphere in which petroleum vapour was suspected, and testing them under uniform conditions.

The apparatus consists of the lamp, the cylinder of compressed hydrogen, and a sampling vessel. The base of the lamp is fitted with two inlet tubes, one for the sample of atmosphere, and the other for the hydrogen, the latter being provided with regulating tap and jet. Immediately above the tube for the inlet of the vapour-laden sample is a series of baffles, on the top of which are three discs of very fine wire gauze, which regulate the flow of gas and prevent any flashing back of the flame into the sampling vessel. The hydrogen jet is partially enclosed by a metal tube, the front of which is removed, and over this slides a chimney, partly of metal and partly of glass, the metallic portion

being blackened inside. In the window are lines corresponding to various heights of flame-caps.

The collecting vessel consists of a compression pump fitted with a metallic piston fixed inside a strong metal cylinder, which is furnished with a pressure gauge and valve, and also has connections and taps for collecting and delivering the sample. About thirty strokes of the pump suffice to charge the cylinder to a pressure of 30 lbs. to the

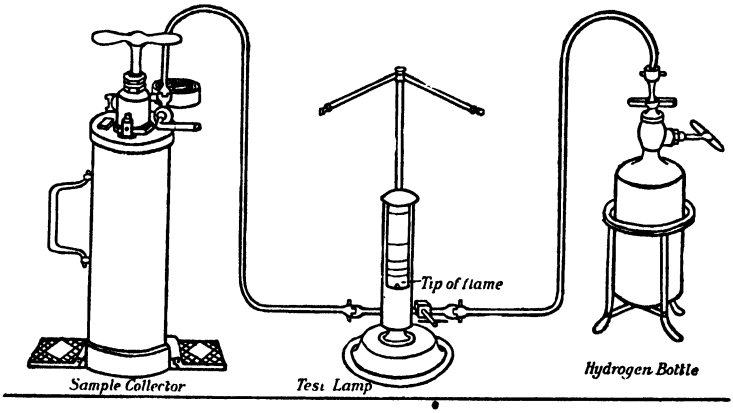


FIG. 11.—The Clowes-Redwood testing lamp.

square inch, when it will contain one-third of a cubic foot of the atmosphere sampled.

In using the apparatus, the hydrogen cylinder is connected to the lamp, and the sliding chimney being raised, the hydrogen is turned on and lighted. The supply is adjusted to give a flame of slightly more than 10 millimetres in length, and the apparatus is left for a few minutes to warm up, so as to drive off any condensed moisture from the surface of the chimney. The collecting vessel is attached to the other inlet of the lamp, the chimney is closed completely, and the hydrogen flame finely adjusted by the regulating valve till the tip of the flame is just hidden when the eye of the operator is on a level with

the bottom of the window. The lamp and head of the operator are then covered with a light-tight cloth, and the tap of the collecting cylinder turned on. Even with a proportion of vapour that is too small to give an explosive atmosphere a cap of a greyish-blue appears on the flame. As the proportion of vapour increases the flame-cap becomes better defined, followed by considerable enlargement of the cap, this feature occurring before the atmosphere contains sufficient vapour to render it inflammable.

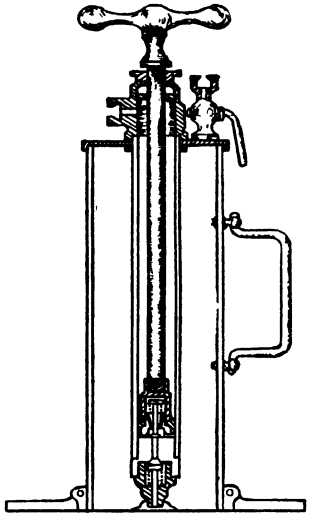


FIG. 12.—Clowes-Redwood sample collecting apparatus.

When petroleum spirit has once taken fire it is most difficult to deal with, as, being far lighter than water, even when great volumes are poured upon the fire the spirit rises to the surface and continues burning, whilst the vapour given off prevents any cooling of the liquid from proving efficacious. Sand or fine mould is the best thing for extinguishing a petrol fire, and if this is not at hand in sufficient quantity, the next best thing is to let the fire burn itself out, and devote one's whole attention to protecting surrounding property.

(6) The increased production of the more recently developed oil fields of Mexico, Persia and of Mesopotamia will no doubt balance for a time the diminishing output of the American and Russian fields, but there seems little doubt that the mineral oil supplies of the world will be exhausted long before the coal measures are worked out, and that the present tendency to replace solid by liquid fuel will be of short-lived duration. The recent estimate by Polk and Foley, that the oil-bearing territories of the U.S.A. will be dry within twenty years at the present rate of production, confirms this view.

(7) Arnold Phillips in British Patent No. 14,778 of 1913, has described the use of naphthalene for reducing the viscosity of thick oils. An addition of 8 per cent. is recommended for this purpose.

CHAPTER V.

THE USE OF LIQUID FUEL.

Oil lamps and the conditions on which their satisfactory working depends—Heating and illuminating power of oil—The history of the use of oil as a fuel—Nobel's troughs—Gasification before combustion—Foote's burner—Simms and Barff process—Eames furnace—Dürr apparatus—Methods of atomising or pulverising oil before combustion—Injectors—Injection under pressure—Körting injector—Swensson burner—Injection by steam—The Holden burner—Rushden and Eeles injector—The Orde burner—Air injection—Furnace arrangements—Conditions of combustion—The formation of smoke—Merits of steam injection as opposed to air or pressure—Furnace space—Liquid fuel for marine use—Advantages for naval use—Employment as an auxiliary to coal—United States Naval Board experiments—Liquid fuel for use in locomotives—Comparative value of liquid fuels in practice.

ALTHOUGH the term "fuel" by custom applies more especially to substances used for heating purposes alone, there are many cases in which liquid fuel at any rate performs the dual function of supplying light as well as heat, and the oil lamp is often in the homes of the poor an efficient stove as well as illuminant.

In order to secure from the oil lamp high illuminating power, together with a smokeless flame and only products of complete combustion, it is necessary to pay strict attention to several factors which play an important part.

In the first place the wick must be so arranged as to supply the right quantity of oil for gasification at the burner head, the flame must be neither starved nor overfed, as if the former is the case great loss of light is occasioned,

whilst the latter, by supplying more hydrocarbons than the air supply to the flame can completely burn, gives rise to smoke and products of incomplete combustion.

The action of the wick depending on the capillary action of the microscopic tubes forming the cotton fibre, nothing but good quality long staple cotton should be employed, and this should be spun into a coarse loose thread with as little twist in it as possible, and from this the wick is built up.

Having obtained a wick of soft texture and loose plait, it should be well dried before the fire, and when put in position in the lamp must fill the wickholder without being compressed; it should be of sufficient length to reach to the bottom of the oil reservoir, and leave an inch or two on the bottom.

Such a wick will suck up the oil in a regular and uniform way, provided that the level of the oil is not allowed to fall too low in the lamp; but it must be remembered that the wick acts as a filter for the oil, and that if any sediment be present it will be retained by and choke the capillaries upon which the action of the wick depends, so that a wick should not be used for too long a time, a good rule being that the wick should, when new, trail for two inches on the bottom of the oil vessel, and should be discarded when these two inches have been burnt off.

When the lamp is lighted the oil burns with a heavy smoky flame, this being due to its not being able to obtain sufficient oxygen to complete the combustion, and not only are soot flakes produced, but products of incomplete combustion, such as carbon monoxide and even petroleum vapour, escape into the air, the first being highly injurious to health and the second offensive to the nose.

In order to supply the necessary amount of air to the flame an artificial draught has to be created which shall impinge upon the bottom of the flame and sweep upwards

over its surface, giving it rigidity, and, by completing the combustion in a shorter period of time than could be done otherwise, increasing the calorific intensity, and thus raising the carbon particles in the flame to a far higher incandescence, so as to secure a greater illuminating power. This in practice has been done in two ways, first, by drawing in the air by the suction of the heated and expanded products of combustion in a chimney fitted over the flame, and, secondly, by creating a draught from a small clockwork fan in the base of the lamp. It is necessary in doing this to break the initial rush of the draught, this being done mostly by discs of perforated metal in the base of the burner, called diffusers, whilst the metal dome which surrounds and rises slightly above the wick-holder serves to deflect the air on to the flame. These arrangements also to a certain extent act as regenerators, the air passing over the heated metal surfaces being warmed before reaching the flame, whilst other contrivances, such as discs, cones, buttons, perforated tubes, inner air tubes, etc., have from time to time been introduced with the object of increasing the illuminating power and completing the combustion.

In the table on p. 111 the results obtained by testing some of the most popular lamps on the market are given.

The amount of heat emitted by our illuminants is a point of importance upon which very little has been said, and which places a distinct limit upon the size and illuminating power of our oil lamps, a lamp such as the 60 line Veritas giving out not only a magnificent illumination, but also an amount of heat which, although acceptable in a cold country chapel on a winter's night, would be unbearable in a dwelling room.

Taking the composition of lamp oil as being 86 per cent. carbon and 14 per cent. hydrogen, the combustion of one

pound would give 20,411 British Thermal Units, whilst 50 grains, yielding one candle of illumination, would give 177 British Thermal Units.

When the idea of using liquid fuel for steam raising first arose, the methods which had served before for the generation of light and heat would undoubtedly be those to which the early investigators would turn first, and on a small

Type.	Name	Grains of Oil per Candle Power per Hour.		Total Candle Power.	
		American.	Russian.	American.	Russian.
Circular Wick.	Veritas, 60 line . .	64·5	112·5	122 5	78·0
	,, 30 ,, . .	42·5	50·0	60·0	60·0
	,, 20 ,, . .	43·75	58·5	40·0	35·0
	Ariel, 12 line . . (centre draught)	52·8	70·9	18·0	18·0
	Reading, 14 line .	97·9	85·4	12·0	12·0
	Kosmos, 10 line .	63·9	97·2	9·0	9·0
	Wizard, 15 line . .	56·9	51·3	18·0	19·0
Flat Wick, single.	Wanzer, no glass .	42·6	48·3	17·0	15·0
	Solid Slip . . . (gauze and cone)	84·4	84·4	8·0	8 0
	Old Slip, fixed gauze	60·9	89·3	7·0	7·0
Duplex.	Feeder Wick . .	56·2	55·7	20·0	22·0
	Ordinary . . .	51·2	46·6	20·0	22·0

American Oil: Specific Gravity, 0·7904; Flash Point, 110° F.
Russian ,, ,, ,, 0·823; ,, ,, 83° F.

scale wicks were employed in the combustion in order to draw up and gasify the oil. These soon proving inadequate, the next step was to make the bed of the furnace of porous material, and saturate that with the oil which was allowed to percolate through it. Such a method was introduced in 1864 by J. C. Richardson, and was slightly improved in 1866 by using steam to aid the action. The method, however, is only of historical interest, and the results obtained by it were of a poor character.

The next step was to burn the oil from a series of open troughs, so arranged that the unburnt oil flowed downwards from trough to trough. This system was generally known as "Nobel's troughs," and gave good results in practice, an evaporative efficiency of as high as 14½ lbs. of water being

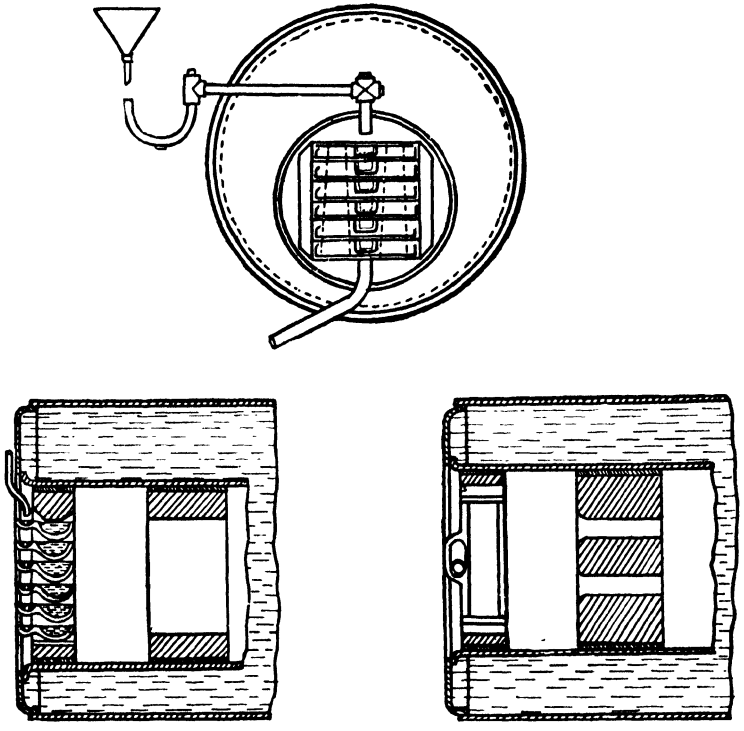


FIG. 13.—Nobel's troughs.

obtained in stationary boilers. The troughs are generally fitted at the mouth of the boiler, and a strong draught draws the flame together with the requisite quantity of air into a mixing chamber, whence it passes with more air through the furnace, combustion chamber, and flues. This method of burning the oil has also been applied frequently

to metallurgical and other furnaces with considerable success, but it must be remembered that such an arrangement would be almost impossible to use with oils of the high density it is necessary now to employ as fuel, and that complete combustion would be very difficult to attain.

As early as 1863 the methods which now are most extensively used began to be introduced, and consisted of bringing the oil into the combustion chamber either as a gas or in such a condition of finely divided spray as to ensure its rapid and complete combustion.

It is well known that if oil be subjected to the action of heat it can be converted into a gas rich in hydrocarbons with simultaneous formation of tar and deposition of more or less solid carbon, and the various oil-gas processes which have from time to time been introduced for the manufacture of illuminating gas give us a fairly complete insight into the actions taking place, and the best conditions for obtaining gaseous from liquid hydrocarbons.

The idea of first gasifying the oil before burning seems to have originated with Colonel Foote, of the United States. The United States gunboat *Palos* was in 1867 fitted for burning liquid fuel by him, and on her trial trip ran over 14 knots, whereas 8 knots per hour had been her previous best record with coal. It was also found that instead of twenty firemen required with solid fuel, the stokehold staff could be cut down to three.

The liquid fuel consisted of petroleum, which was carried in two large iron tanks placed on deck, and from the description given these were fitted with a vent-pipe on top to allow the escape of vapours, so that it is evident that crude petroleum and not residuum was being used. The oil was allowed to flow by gravity through half-inch pipes to a retort placed some little distance inside the furnace, where it was gasified, and the oil-gas was led back towards

the furnace mouth by pipes filled with apertures and giving a large flame which swept back over the retort, keeping it heated to the necessary temperature to continue the decomposition of the oil. The oil-gas so formed was diluted with hydrogen, made by passing steam through tubes filled with

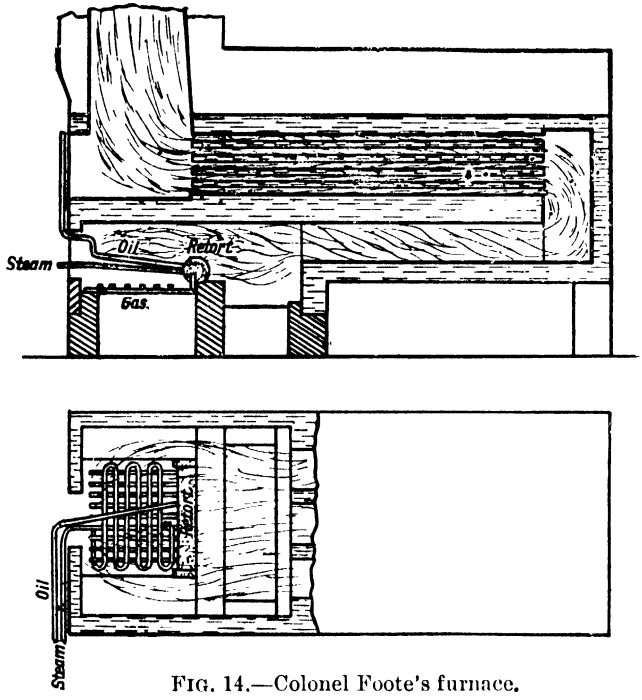


FIG. 14.—Colonel Foote's furnace.

heated iron filings, and the flame was fed with air forced in with an air pump.

The combustion is recorded as being very intense and perfectly smokeless, but nothing more was heard of the system, this being probably due to the costly method of diluting the gas and the trouble from choking of the retort and tubes with carbon. which must inevitably have taken

place. There are certain points of interest in the experiment, however, which are well worth notice, and will be discussed later on.

Soon after, a system of a similar character was patented by Simms and Barff, the oil being injected and vaporised in a retort placed in the furnace, and although satisfactory results were obtained, it was found that considerable trouble was experienced with the retorts, which, being exposed to a very high temperature, had a very short life.

Several systems of this kind have been proposed, and

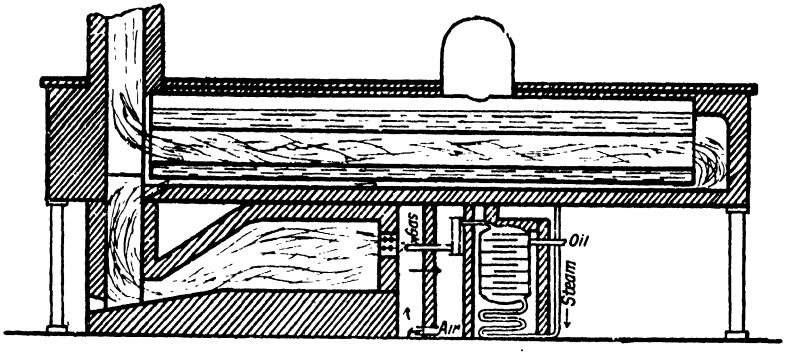


FIG. 15.—Eames' oil furnace.

also others in which the vaporisation of the oil should take place in retorts external to the fire-bars. The best known of these are those processes patented by C. Eames in 1875, and by Dürr. In the Eames system the oil was fed into an externally heated cylindrical retort with round ends, in which it flowed downwards over a series of horizontal iron plates whilst superheated steam was passed upwards, and being decomposed by the hydrocarbons at the high temperature, formed a mixture of what was practically oil-gas and water-gas, which was burnt as it issued from the vaporiser at suitable burners.

In the Dürr apparatus the oil is supplied by air pressure

through a heated retort in which it is vaporised, and the vapour is then gasified in a chamber in the mouth of the furnace heated to a high degree. The gas is led straight for combustion into the furnace.

It is, however, quite evident that for the successful use of liquid fuel auxiliary apparatus and sources of heat must be done away with and the furnaces made practically self-contained if anything approaching success is to be attained,

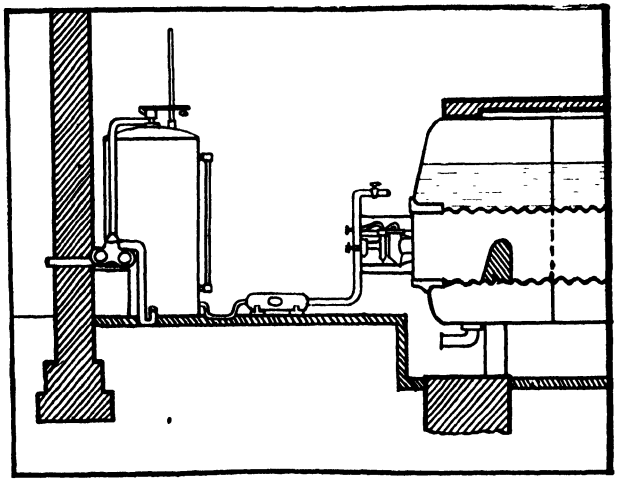


FIG. 16.—The Dürr system.

as it is upon simplicity, ease of working, and freedom from complicated parts that the claim of liquid fuel for supremacy over solid is largely based.

The direct atomising of the oil so as to drive it direct into the furnace chamber in a spray sufficiently divided to act almost as a gas is the method now practically universally adopted. This pulverising or atomising action may be brought about either by forcing the oil out from a jet at considerable pressure, or by injecting it with steam or air, or by a combination of the two.

The system of direct atomising, *i.e.*, by pressure, is perhaps the latest and most promising method of consuming the oil. Körting's injector or burner is the best known arrangement for this purpose, and has been employed with great success on ships of the Hamburg-American line. The oil is heated to a temperature of 130° C., and is then forced into the injector under an air pressure of 50 lbs. on the square inch. In the injector the oil flows into a chamber feeding the jet, and into this jet is fitted a spindle carrying a spiral screw. The oil, at the pressure of 50 lbs., is forced down this spiral, and acquires a centrifugal action which sprays it out of the jet in a very finely divided condition.

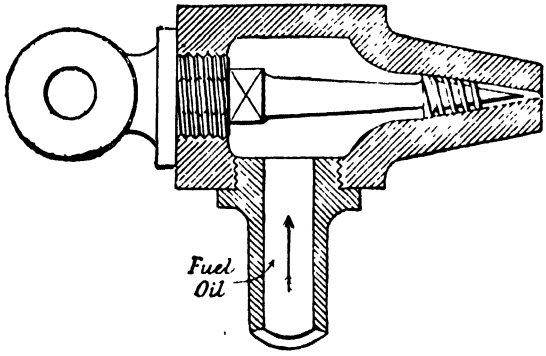


FIG. 17.—Körting's injector.

Another form of burner, the action of which also is merely dependent upon the pressure, is the Swensson, in which the oil under pressure is heated in a steam-jacketed tube, and is then forced out from a fine jet on to the point of a V-shaped metal cutter, which has the effect of atomising it into a very fine spray.

Perhaps the best known and most used of the burners are those in which the oil is atomised by steam, a method that was first used by Messrs. Aydon, Wise, and Field in 1865-7, the general principle being that the oil is led down to the injector by gravity, and there meets a steam jet, which drives it out from the nozzle of the injector with high velocity and in a fine state of division, whilst

the outrush of the steam and oil is usually made to suck in air around the jet to aid the combustion in the furnace.

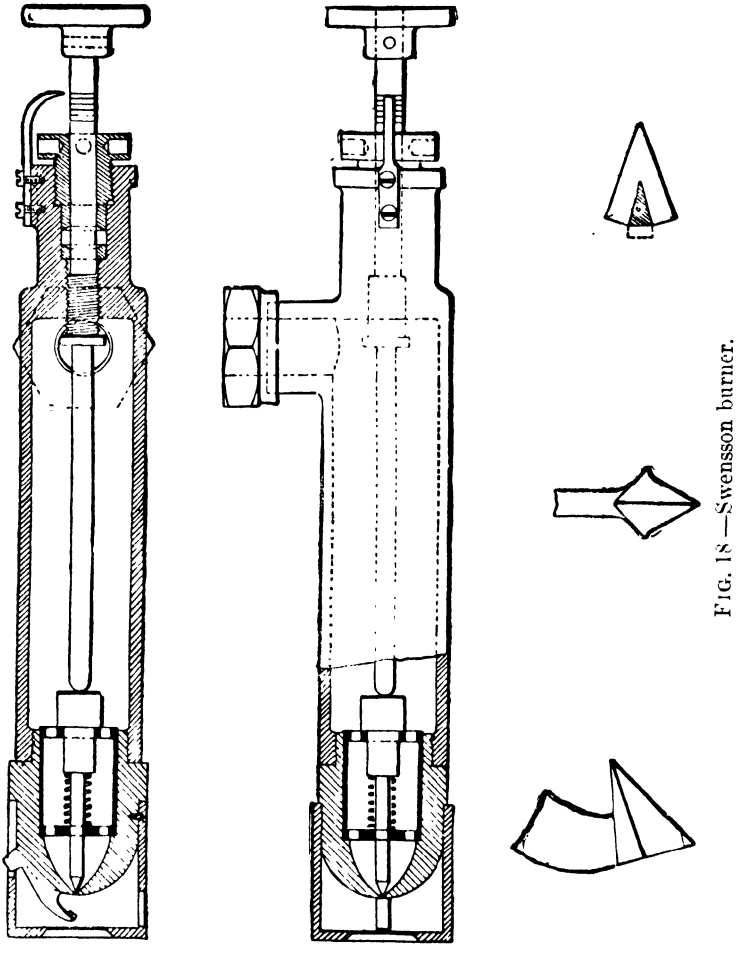


FIG. 18.—Swensson burner.

Of these burners perhaps at the present time the best known are those of the Holden type, and it is a form of these that is employed in the highly successful installations of liquid fuel that Mr. Holden has fitted up, and which

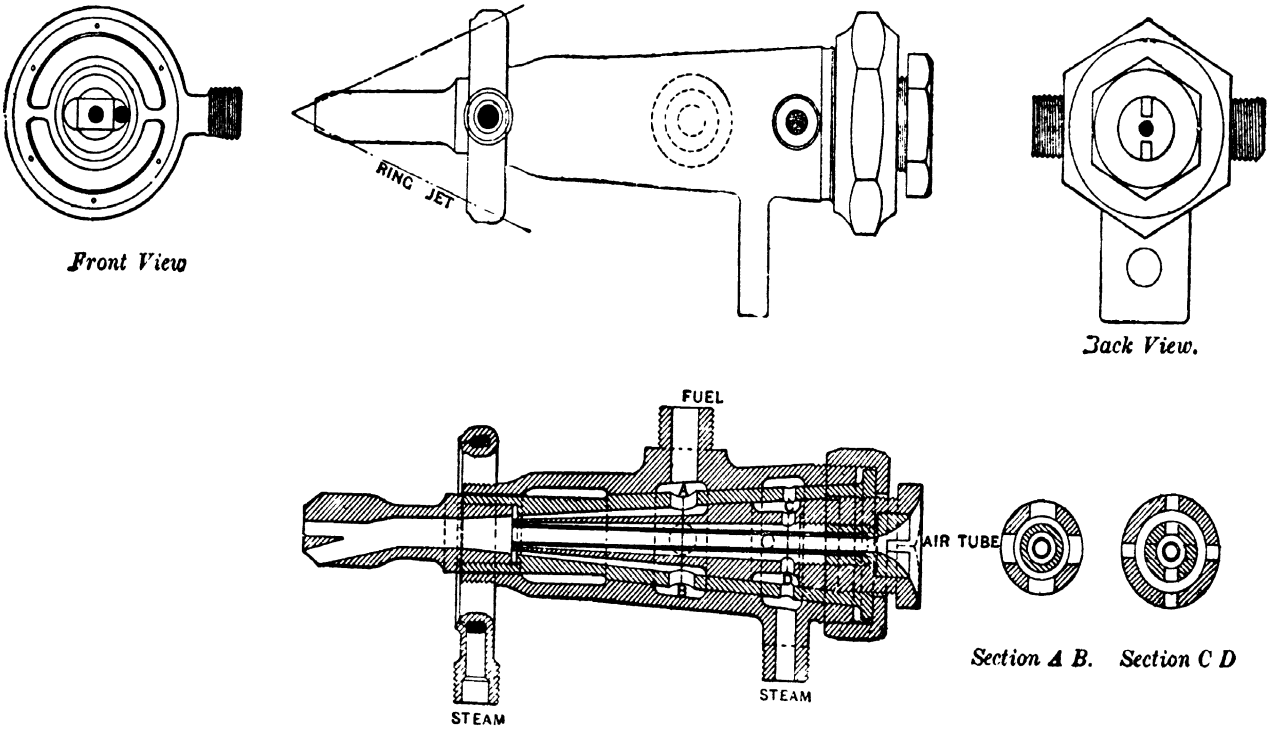


FIG. 19.—Holden injector (locomotive).

have shown themselves to be of a most satisfactory character. One form of the injector or burner is that used on locomotives, which is made to serve the double purpose of injecting the fuel and also maintaining the vacuum necessary for the brakes. In a second pattern, however, arranged for marine work, valves are designed to supply the oil in two portions to the steam injector, in order that if a change from half speed to full speed, or *vice versa*, be desired, the supply of fuel can be arranged without any alteration in the steam consumption. At the mouth of the burner an ingenious arrangement of a steam ring performs the important function of allowing jets of steam at various angles to catch the oil spray as it leaves the burner and to more evenly distribute it throughout the furnace, the steam ring also serving to draw in air for the primary combustion.

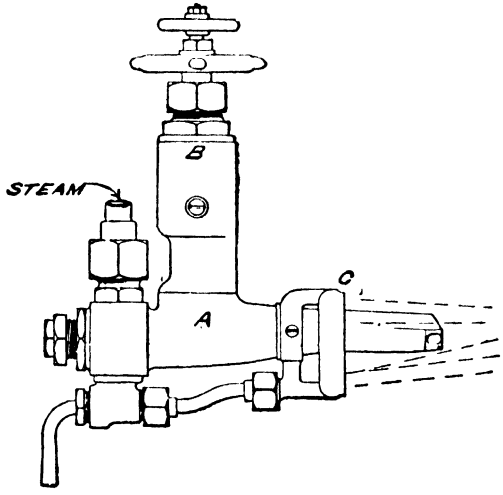


FIG. 20.—Holden's injector (marine type).

Another form of steam atomising burner which has been largely used in practice is that designed by Messrs. Rushden and Eeles. This excellent burner has shown itself very successful in working, and is the burner employed on the vessels of the Shell Transport Company. The oil, after having been heated by a steam-jet, is sprayed out by the steam; and as the burner is made so as to allow of separate adjustments of

the steam and oil jets, the consumption of the fuel can be accurately adapted to the work which it has to do. The burner used by Messrs. Armstrong, Whitworth & Co. is that designed by Mr. E. L. Orde. In this burner highly-superheated steam is employed, 600° F. being probably the temperature at which it works best. The steam inlet is arranged to sweep out and spray the oil with a very high velocity, and

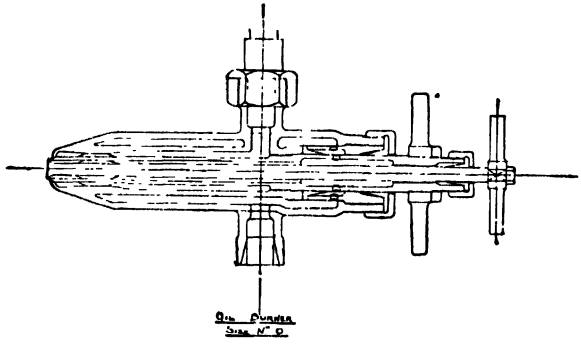


FIG. 21.—Rushden-Eccles burner.

to induce a current of heated air, this being found to help the combustion of the jet of steam and oil.

Although there have been many other forms of burner employed, these types may be taken as fairly covering the most successful methods of bringing the oil to the point of ignition, and it will now be well to see the arrangements which have been found necessary for the successful use of these burners in practice.[1]

When the liquid fuel has been atomised by the injectors and ignited, the burning rush of vapours in most cases is brought in contact either with a layer of fuel or brickwork near the mouth of the furnace; whilst in some cases, as in the Körting system adopted by the Hamburg-American Line, the furnaces are bricked right round. In building in

[1] See Appendix for description of latest types of liquid fuel burners for boilers and furnaces.

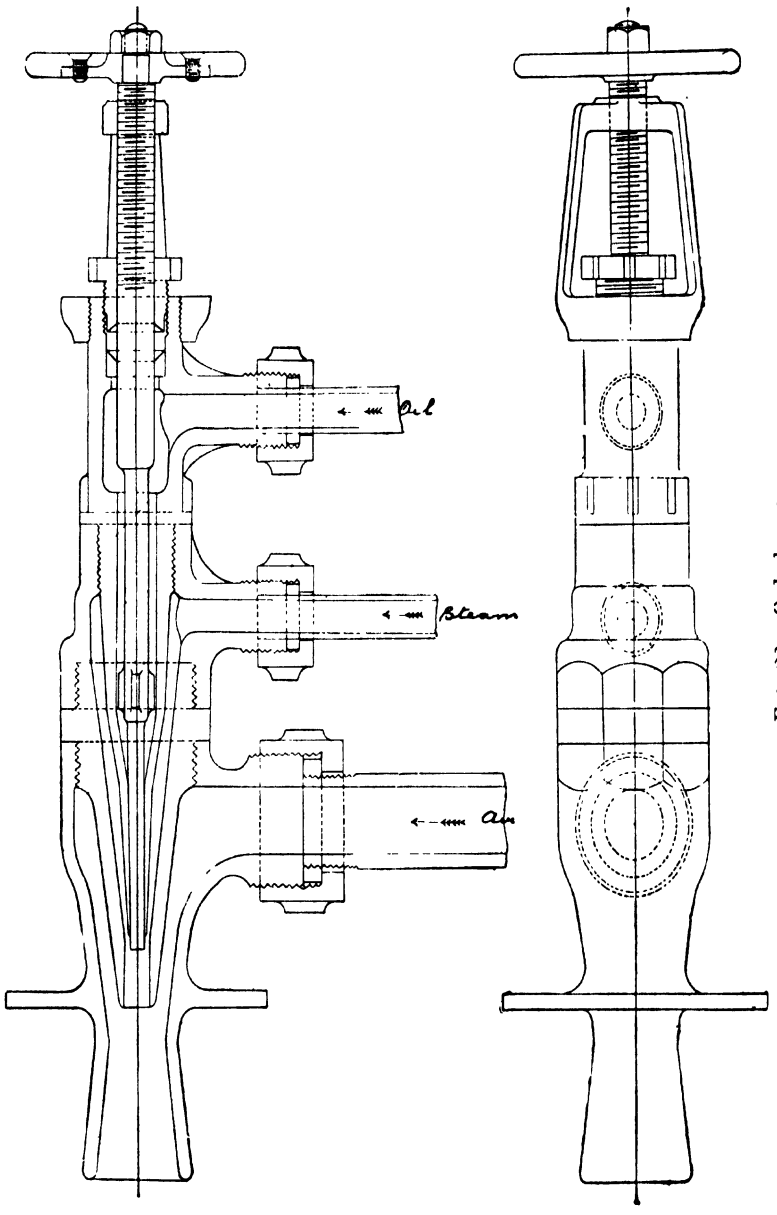


FIG. 22.—Orde burner

brickwork to the furnace, it should be so jointed as to leave plenty of play for expansion, as otherwise at the high temperatures obtained it buckles and the projecting surface fuses.

The best bricks for use in this way are the Scotch Glenboig firebricks, which, although less refractory than several other kinds of firebrick, stand better the constant changes of temperature found in the furnaces when in intermittent working.

The brickwork under these conditions can be made to fulfil several requirements. In the first place it becomes heated to a very high temperature, and serves to ignite the oil vapour and air coming into the furnace; and in the next place, if the oil jet is made to dash straight against it, it serves to disintegrate and gasify it, and also prevents the burning oil and flame being driven too rapidly through the furnace, and saves the plates from the direct impact of the flame. For these latter purposes also various forms of brick baffle are frequently employed.

The Holden injector has already been referred to as one of the best in practice, and the methods used in the engines on the Great Eastern Railway fitted for liquid fuel are somewhat as follows:—Steam is first raised in the boiler by a wood and coal fire, and when 30 to 40 lbs. pressure has been attained, the fire is levelled over and covered with a layer of broken fire brick; a few pieces of wood or oily waste are then thrown in to make a flame, and the oil injector is started. Combustion is imperfect at first, and smoke is formed, but after a few minutes, the necessary temperature having been attained, the ring steam jet is turned on and induces the necessary air current to complete the combustion, when the fire clears and all smoke ceases.

Among the many important questions which have yet to be solved is the best way in which to carry out the

combustion taking place in the furnace, and we must remember that our present methods of burning coal are the outcome of a century of practice and experience, and it cannot be expected that the small amount of work as yet done with liquid fuel should in any way approach perfection.

When coal is burnt in a furnace a large proportion of the heat transmitted to the water takes place by radiation, and it is clear that in our method of burning oil it will have to be determined whether it is better to so arrange the air supply as to produce almost non-luminous flames, such as those given by the atmospheric burner, or whether the air supply should at first be limited so as to give a highly luminous flame, and the air needed to complete the combustion only added when the combustion chamber is reached. A non-luminous flame gives but little radiant heat, whilst the incandescent particles in a luminous flame give a very considerable amount. It is probably best in order to facilitate the transmission of a portion of the heat as radiant heat that the flame in the furnace itself should be luminous, and that the combustion should be completed by the addition of more air at the entrance to the combustion chamber before the tubes are reached.

The transmission of heat from a non-luminous flame in the furnace to the water in the boiler is but small, as the contact of the surface of the furnace crown extinguishes the flame, and leaves a layer of badly conducting gases between the metal and the flame. This is one reason why, when the mass of radiating fuel on the furnace grate is done away with, and is replaced by the flame of burning hydrocarbons, it becomes necessary to use firebrick or other refractory material in the furnace in order that it may become highly heated, and by its radiation aid the transmission of heat to the water in the boiler.

In burning oils there is always a risk that there may be present small particles of solid matter, which may choke the injector, and also water, the latter being present when the oil has been stored in the double bottoms and ballast tanks of the vessel, and also in crude oil. It has been found that the presence of drops of water in the oil is apt to extinguish the flame at the injector nozzle, and if that were to take place, and the finely divided oil spray or oil-gas were to get into the furnace mixed with air in any large quantity, it would give rise to an explosion.

In order to get rid of solid particles and water the oil is pumped into settling tanks, fitted with a steam coil, which can be used to raise its temperature, the necessity for this being found in the fact that the specific gravity of the oil generally used as a fuel is only a little below that of water, and that therefore the separation would be very slow, but when slightly warmed the oil expands at a much greater rate than the water, and the separation takes place with much greater rapidity.

In some cases two settling tanks are employed, each capable of containing 12 hours' supply, and the one which is out of use, after standing 12 hours, has the water drawn off from the bottom, whilst the oil is pumped out through a wire gauze filter. In other forms of settling tanks a filtering cage of wire gauze is employed, which is kept by a float near the surface of the oil, whilst a steam coil is used as before to aid the separation.

The oil is nearly always heated before reaching the injector or atomiser in order to facilitate its flow and disintegration into minute particles. But this preliminary heating must be kept below the point at which the oil generates vapour or decomposes, as otherwise the formation of a break in the column of liquid owing to the generation of gas or vapour might extinguish the flame at the injector nozzle.

One of the points with regard to the methods employed for atomising the oil before combustion is the relative merits of mechanical injection and disintegration, or the utilisation of steam as the injecting and atomising power.

If steam be used for injecting and atomising the oil 0·2 lb. of steam per I.H.P. per hour is required, which on a service vessel could not be obtained without extra boilers, and this of course is a strong point in favour of injecting by pressure.

There is another side to the question, however, which must not be overlooked, and that is that it is necessary to dilute the oil gas as far as possible during combustion in order to prevent the deposition of carbon, which once formed is very difficult to reburn and is one of the chief causes of smoke. If the effect of the steam were merely the mechanical one of injecting and afterwards diluting the oil gas, and no chemical action took place, the advantage would decidedly be entirely on the side of such injectors as do their work by pressure and not by steam; but it must be remembered that as the oil spray is heated in the furnace space in presence of the steam, chemical action takes place and greatly simplifies the decomposition of the hydrocarbons.

It may be roughly taken that the petroleum residue chiefly employed will approximate to $C_{12}H_{26}$, that is to say, will be a mixture of hydrocarbons the composition of which is around this point, and if this be brought in contact with sufficient steam in the hot furnace space, the action, if complete, would result in the formation of carbon monoxide and hydrogen—

$$C_{12}H_{26} + 12\ H_2O = 12\ CO + 25\ H_2$$

whilst under ordinary working conditions, the proportion of steam being far less than this, the result would be hydrocarbons of a simpler molecular structure diluted by hydrogen

and carbon monoxide, such a mixture being comparatively easy to burn without formation of smoke, whilst the rich oil gas and oil tar vapours formed by the heating when no steam is there to aid the chemical interactions are excessively difficult to burn without considerable formation of smoke.

Some observers have tried to argue that the utilisation of steam for direct pulverisation of the oil adds enormously to the heating effect by producing in this way hydrogen and carbon monoxide, but this of course is an utter mistake, as it takes just as much heat to break up the steam as is evolved by the after combustion of the products formed, that is to say, the balance of heat will remain unchanged whether the oil be burnt alone with air or whether it be decomposed by steam and the products then burnt, the great advantage of the steam being to facilitate the combustion of the oil without the formation of smoke, and this is the only way in which the steam can act to give increased heat by preventing the escape of unconsumed products.

When oil is driven by pressure from an injector of proper construction it spreads out as an inverted cone, and in this condition should be so atomised as to be only one degree removed from a vapour. When this is done in the open air the particles are so minute that they continue to float for some moments after the velocity acquired at the mouth of the injector has practically ceased to act. When this jet of oil is ignited close to the injector mouth it burns for the first few feet with a bright and excessively hot flame, and over this area gives no smoke, the reason being that the velocity at which the oil particles are travelling is sufficient to drag in with them from the surrounding area a considerable amount of air which is sufficient to complete the combustion of the outer portion: the radiation from this bakes the oil particles in the interior, where no combustion is going on, into gases and vapours.

As the circumference of the flame gets larger and larger, and the velocity decreases, the cooling influence of the outer air begins to tell, and the carbon particles within the flame gradually begin to show themselves as black smoke on the exterior. This action being increased the more the flame is cooled, dense black clouds of smoke are produced, a result which always ensues with such a method of combustion in the open air, whilst unburnt oil vapour and oil-gas from the interior of the mass form a bluish white line of smoke, showing up in marked contrast to the black mass of carbonaceous smoke. The cooling of the flame therefore before combustion is complete gives rise to—

(1) Black carbonaceous smoke.
(2) Oil gas.
(3) Oil vapour.

When the injector is fitted in the furnace front and the combustion of the oil takes place in the furnace and combustion chamber, the air supply is drawn chiefly from the front of the furnace, passes in alongside the jet of oil, and being heated to a considerable extent before being utilised for combustion, the cooling effect is not nearly so great, but the upsuck of the chimney and the pressure under which the air is in the stokehold, by accelerating the rush of air, also lengthen the combustion area, and the formation of smoke is therefore thrown further from the injector, and with ordinary types of boiler probably takes place to the greatest extent in the combustion chamber.

With any rich hydrocarbon gas the carbon particles, when once formed and cooled to the condition of smoke, are excessively difficult to again burn up by air or even oxygen, but steam is far more effective for this purpose, as it acts on the finely divided carbon with enormous rapidity as long as the temperature is near or about 1000°C. The heat taken by the decomposition of the steam by the carbon is

again recovered by the combustion of the hydrogen so formed to water vapour once more, whilst the heat which would otherwise be lost owing to the escape of unconsumed carbon where smoke is allowed to form, is now rendered available by the combustion of the carbon monoxide.

In the combustion of oil in the various forms of furnace and combustion space found in different types of boiler, the great point to bear in view is that the cause of the smoke is cooling before combustion is complete, and that the arrangements made should prevent the contact of the flame with surfaces capable of cooling it before the carbon has been so far consumed as to prevent smoke formation. It is not necessary that before a cooling surface is reached complete combustion should have taken place, but that before that point the carbon should have been burnt to carbon monoxide, which is incapable of yielding smoke in its further conversion into carbon dioxide. In many attempts to ensure smokeless combustion too much air has frequently been added, which is even worse than too little, as its admixture cools the exterior of the flame, whilst the excess of escaping gases takes away so much heat as to seriously reduce the evaporative power of the fuel. As far as fuel goes the blackest smoke only means a loss of about 1 per cent. of the fuel value, whilst it is easy to reduce the evaporation by 15 or 20 per cent. by using undue volumes of air.

The only advantage of the uneconomical method of using steam instead of direct pressure injection is that the steam present can act on the carbon particles as soon as they are liberated, but it could never be so effective in preventing smoke as the use of a tenth or a twentieth of the quantity of steam injected into the flame at a later period, as the large volume going in with the oil spray begins to act on the oil even before the carbon begins to be liberated. So endothermic is the reaction that takes place that a serious cooling of the flame is brought about, whilst the formation

of a large volume of carbon monoxide and hydrogen tends to prevent proper access of air to the flame in its earlier stages. Nor could such a high efficiency be got from the combustion, as when by the direct injection of oil under pressure the oil spray is burnt at its best during the first few feet of ignition, and is emitting an enormous amount of radiant heat. This in the furnace is largely transmitted to the water, whilst the steam injected at the moment when smoke would otherwise begin to form then fulfils its functions under conditions which do not detract from the efficiency.

With land boilers the use of oil has great advantages, but for use on board ship the advantages are greater still. When coal is used it has to be got into the bunkers, meaning an enormous amount of extremely hard labour, everything on the ship being made filthy by the coal dust, necessitating cleaning and polishing up afterwards. As regards the advantages of oil in this direction, there can be no reasonable doubt. Taking the oil in from big storage tanks alongside the wharf, it can either be run into the portion of the ship reserved for storage by gravity, or it can be pumped in, and instead of having the bunkers, as one is obliged to for coal, above the level of the stokehold, the storage tanks for the petroleum, or whatever liquid fuel it may be, may be in practically the ballast tanks, and as the oil is used it can be replaced by water, thus giving an enormous increase in capacity to the vessel. If it be a ship of the mercantile marine, it gives a large amount of cargo room, which means of course greater earning power for the ship; if it is a man-of-war, it does more—it gives the power of storing a much larger amount of energy in the same space as coal would have occupied.

Liquid fuel is far in advance of coal as a steam raising agent, as it is found that one ton of oil is about equal to 1·5 of coal, and the result is that for the same weight an amount of fuel can be carried which will give a very much

greater radius of action, which at the present time in the Navy is a factor of the greatest possible importance. Again, in the feeding of the oil to the furnaces, instead of needing a very large number of stokers for trimming the coal in the bunkers and keeping up the fires, the use of oil will reduce that number to about one-fourth, whilst there being no ash, cinder, and clinker to clear out of the furnaces and throw overboard, another economy in labour is effected.

Many of the apparent discrepancies to be found in experimental results with liquid fuel are caused by the different conditions of use. For instance, the results obtained by such vessels as the *Murex* and the *Strombus*, over very long periods of steaming with coal and with oil, give respectively the ratios of 25 to 16 and 42 to 30 as the relation by weight of coal to oil consumed to give the same I.H.P. and speed to the vessel.

The working of the Hamburg-American Co.'s steamer *Ferdinand C. Lainer* gives a ratio of 3 to 2, and many other vessels could be cited giving even better results. In the Service these results were not at first so easily attained, and this is due to the fact that the conditions existing in the boilers of the Navy and the merchant service are so utterly different that no comparison can be made between them.

In the combustion of liquid fuel the oil is practically entirely converted into gas, vapour, and floating particles of finely divided carbon before combustion begins, or at any rate before any large amount has been consumed. This requires a large combustion area, as the volume of air needed to complete the action and prevent smoking is very great, whilst with coal the combustion of the largest proportion of the fuel takes place on the furnace grate, and it is only the escaping gases distilled out of the coal and formed by incomplete combustion that have to be burnt in the crown of the furnace and combustion chamber.

The result of this is that plenty of combustion space becomes one of the important factors in a furnace for liquid fuel, and with the vessels that have given the best results in the merchant service the combustion of 2½ lbs. of oil per cubic foot of combustion space will give them full steam power, whilst under the conditions of combustion area existing in the naval boilers, a far larger quantity per cubic foot of space would have to be consumed to give the desired result.

The question of combustion area and air supply needed for the use of liquid fuel is made clear when one considers in figures the work which has to be done. With a Service vessel under full steam, if the best Welsh coal is used there will be little or no smoke, showing that combustion has been fairly complete, whilst one knows that if a Newcastle or Durham coal be taken there would be abundant black smoke from the funnel, showing that already the combustion area and air supply were insufficient to deal with the work that had to be performed. If the actions taking place with a bituminous coal be regarded as representing the maximum efficiency of combustion that could be obtained by that particular arrangement of boiler and furnace, the efficiency would certainly be overstated and not understated.

The action of the heat from the fire in the grate when coal is first charged in very closely resembles the actions that take place in the gas maker's retort, as the red hot fuel below is raising the fresh fuel above to a temperature of about 1000° C., and is preventing any large amount of air from getting through the bed of incandescent carbonaceous material to it. Under these conditions a ton of bituminous coal would yield 10,000 cubic feet of gas and 10 gallons of tar in the condition of vapour, whilst 75 per cent. of the weight of the coal would be left to burn on the fire grate, a certain proportion of which by incomplete

combustion would yield carbon monoxide to add to the body of gas to be burnt up in the crown of the furnace and the combustion chamber.

On the other hand, when a ton of ostatki is converted into gas, on being injected into the furnace it yields double this quantity, *i.e.*, 20,000 cubic feet of gas and about 12 per cent. only of residual tar in the form of vapour and carbon particles. Not only is the volume of gas thus yielded twice as great in the case of oil fuel as in the case of coal fuel, but it is a gas which, being far richer in hydrocarbons, requires a far greater volume of air for its complete combustion than was the case with the gas developed rom the coal. It can easily be understood, therefore, that, without considerable alteration in the draught arrangements, a furnace with its combustion area and air draught arranged for coal cannot be expected to deal with nearly the same weight of liquid fuel.

It must be borne in mind that the area over which the combustion spreads is governed by the length of travel of the combustible gases before they find the necessary amount of atmospheric oxygen for their complete combustion, and that the conditions of air supply mean, to a great extent, regulation of combustion space and rate of travel of the burning vapour.

During the last few years a large amount of attention has been given to the burning of liquid fuel by the naval authorities of all the first class Powers, and it is now firmly established as an auxiliary to coal in the English, German, French, Italian, and American Navies.

From the evidence given by the late Sir Gordon Miller before the Royal Commission on Coal Supplies, the Admiralty take about 1,000,000 tons of steam coal annually from the 24 collieries on the Admiralty list, and this quantity would be much increased in time of war, so that the amount of liquid fuel available would be far too small to admit of its being used alone.

In every case the limitation of the supply of liquid fuel has led to its being fitted as an adjunct to coal, and not as the sole fuel, as it has been realised that until its supply in large quantities is placed upon a more reliable basis than at present, it would be incurring a grave risk to fit a large battleship for burning liquid fuel only, although with smaller vessels, such as destroyers, it is permissible to do so.[1] As an auxiliary to coal it has very great advantages, for with a fleet manœuvring at half speed it gives the power of suddenly increasing to full steam by the mere turning on of the oil supply to the injectors, and it is with this object in view that all the newer English, German and French battleships and cruisers have been fitted for burning coal or a mixture of coal and oil.

Many European critics are distinctly adverse to this method of consumption, as they point out that if the furnaces of a vessel are so arranged as to give the best results with coal, it is clear that the conditions will not allow of sufficient air supply to properly consume the oil and develop its full advantages, whilst a dense flame of oil burning above the coal will keep air away from it and deaden the surface combustion. This is perfectly true as far as it goes, but there is not the least doubt that the results obtained are sufficiently good to justify its adoption for this purpose and that, burnt in this way, it has proved and will prove of the greatest value.

In the United States many experiments have been made with liquid fuel in the mercantile marine, especially when the opening up of the Texas fields seemed to promise an enormously increased supply, whilst the naval authorities also carried out an extensive series of experiments in 1902, for the full details of which the reader is referred to Mr. W. H. Booth's valuable work on Liquid Fuel, but the conclusions arrived at may be stated as follows:—

(*a*) That oil can be burned in a very uniform manner.

[1] See note (8) on p. 140.

(*b*) That the evaporative efficiency of nearly every kind of oil per pound of combustible is probably the same.

While the crude oil may be rich in hydrocarbons, it also contains sulphur, so that after refining the distilled oil has probably the same calorific value as the crude product.

(*c*) That a marine steam generator can be forced to even as high a degree with oil as with coal.

(*d*) That up to the present time no ill effects have been shown upon the boiler.

(*e*) That the firemen are disposed to favour oil, and therefore no impediment will be met in this respect.

(*f*) That the air requisite for combustion should be heated if possible before entering the furnace. Such action undoubtedly assists the gasification of the oil product.

(*g*) That the oil should be heated so that it could be atomised more readily.

(*h*) That when using steam higher pressures are undoubtedly more advantageous than lower pressures for atomising the oil.

(*i*) That under heavy forced draught conditions, and particularly when steam is used, the Board has not yet found it possible to prevent smoke issuing from the stack, although all connected with the tests made special efforts to secure complete combustion. Particularly for naval purposes is it desirable that the smoke nuisance should be eradicated, in order that the presence of a warship might not be detected from this cause. As there has been a tendency of late years to force the boilers of industrial plants, the inability to prevent the smoke nuisance under forced draught conditions may have an important influence upon the increased use of liquid fuel.

(*j*) That the consumption of liquid fuel cannot probably be forced to as great an extent with steam as the atomising agent as when compressed air is used for this purpose. This is probably due to the fact that the air used for atomising purposes, after entering the furnace, supplies

oxygen for the combustible, while in the case of steam the rarefied vapour simply displaces air that is needed to complete combustion.

(*k*) That the efficiency of oil fuel plants will be greatly dependent upon the general character of the installation of auxiliaries and fittings, and therefore the work should only be given to those who have given careful study to the matter, and who have had extended experience in burning the crude product. The form of the burner will play a very small part in increasing the use of crude petroleum. The method and character of the installation will count for much, but where burners are simple in design, and are constructed in accordance with scientific principles, there will be very little difference in their efficiency. Consumers should principally look out that they do not purchase appliances that have been untried and have been designed by persons who have had but limited experience in operating oil devices.

The use of liquid fuel for steam raising in locomotive boilers has received a large amount of attention, and various grades of oil, tar, and tar by-products have been exhaustively tried with most successful results by Holden, on the Great Eastern Railway, and by Urquhart, on some of the Russian Railways, and their classic researches on the subject have led to its introduction for this purpose in every part of the world. The engineering details of such installations are beyond the scope of the present work, and may be found in full in Booth's work on Liquid Fuel.

The liquid fuels generally employed do not show as wide a difference in their calorific value as determined by the bomb calorimeter as might be expected, but in practical work such oils as the blast furnace and heavy tar oils, owing to their chemical nature and the difficulty of decomposing them, give lower evaporative results than the petroleum oil. The general run of these differences may be seen

from the following table, and gives the practical results obtained with the same boiler :—

LIQUID FUELS.

Description.	Specific Gravity.	Flash Point.	Calorific Value by Bomb.		Actual Evaporative Power in practice, from and at 212° F.
			Calories.	B.T.U.	
American Residuum	·886	350	10,904	19,627	15·0
Russian Ostatki	·956	308	10,800	19,440	14·8
Texas	·945	244	10,700	19,242	14·79
Burmah	·920	230	10,480	18,864	14·5
Barbadoes	·958	210	9,899	17,818	14·2
Borneo	·936	285	10,461	18,831	14·0
Shale Oil	·875	288	10,120	18,217	13·8
Blast Furnace Oil	·979	206	8,933	16,080	12·0
Heavy Tar Oil	1·084	218	8,916	16,050	12·0

The best results obtainable with this type of boiler fired with coal would have been an evaporative duty of between 9 and 10 lbs. of water from and at 212° F., when using the best Welsh steam coal.

It must be borne in mind that such evaporative values as have been given here are considerably below many that have been claimed, and it is said that Messrs. Thornycroft have obtained the high evaporative value of 18·95 lbs. of water per pound of oil fuel, but if this is so the boiler must have been a wonderfully perfect instrument for converting heat into steam.

A good sample of oil fuel on analysis gives the following percentage composition :—

Carbon	87·80
Hydrogen	10·78
Oxygen	1·24

and the evaporative power calculated from the analysis is

$0{\cdot}15\ (87{\cdot}8 + 4{\cdot}28\ (10{\cdot}78 - \frac{1{\cdot}24}{8})) = 19{\cdot}9$ lbs. from and at 212° F. Its calorific value taken in the Bomb is 18,831 B.T.U., and by dividing this by 966 (latent heat of steam in °F.) we obtain 19·5 as its evaporative power, so that it is safe to assume that under theoretically perfect conditions the evaporation per pound of oil would be about this quantity.

Taking a good sample of coal, analysing it, and calculating the evaporative effect we obtain 14·1 lbs., whilst by determination in the Bomb we get 14 lbs. from and at 212° F. Now we know from years of experience with boilers and furnaces specially made and adapted for burning this coal, that an evaporation of 9·5 lbs. of water will be the most we shall ever get under the very best circumstances per pound of coal, the difference between the 9·5 found and the 14 calculated being due to the heat losses inseparable from the system.[1] On the same basis it is hard to understand why one should expect to get a greater pro rata duty from the oil, and if a calculated 14 gives an actual 9·5 lbs. evaporation, then our calculated 19·5 for oil should only give an evaporation of 13·2 lbs. If, however, the loss is, as it were, a fixed charge of 4·5 lbs. per pound of fuel due to the personal equation of the boiler, then our calculated 19·5 lbs. evaporation would give in practice just about the 15 lbs. evaporation obtained with this oil in the particular boiler used, and it seems unlikely that when the full steaming power of a boiler has to be developed over a considerable period that this evaporative efficiency will be much increased, although under conditions when smaller quantities of oil can be used to give the required steam power, careful nursing may develop better results for a short period.

Where oil fuel is abundant it is also used for smelting ores and other metallurgical operations, for which the comparative freedom from sulphur of most kinds of oil

[1] See note (9) on p. 140.

specially fits it, whilst for many forms of furnace, rivet heaters, etc., its ease of application and the high temperature obtainable by its use make it a convenient and in some cases even economical form of fuel.

Internal combustion engines using heavy mineral oil of much the same character as that used for fuel are rapidly finding favour not only on land but for marine purposes; in these the oil is introduced into the combustible cylinder as the finest attainable spray, and is there exploded with highly compressed air, the heat generated during compression being an important factor in the successful ignition of the charge.

In a valuable paper read before the Institution of Civil Engineers by Mr. J. T. Milton in January, 1907, the author thus tabulates the special conditions to be satisfied by marine internal combustion engines if they are to be successful for large vessels:

(*a*) The engine must be reversible.

(*b*) It must be capable of being stopped quickly and of being started quickly either ahead or astern.

(*c*) It must be capable of being promptly speeded to any desired number of revolutions between dead slow and full speed, and of being kept steadily at the required speed for any length of time. "Dead slow" ought not to be faster than one quarter of full speed, and should be less than this in very fast vessels.

(*d*) It must be capable of working well, not only in smooth water, but also in heavy weather in a seaway in which the varying immersion of the propeller causes rapidly changing conditions of resistance.

(*e*) All working parts must be readily accessible for overhauling, and all wearing surfaces must be capable of being promptly and easily adjusted.

(*f*) The engine must be economical in fuel and especially so at its ordinary working speed.

In small engines condition (*a*) is not complied with; the engines are always run in one direction, the reversing of the vessel being provided for either by a reversing-bladed propeller, or by the intervention of toothed gearing. Condition (*b*) also, in small engines, is fulfilled by means of a friction clutch arrangement which permits the engine to be kept running while the screw-shaft is stopped. For large sea-going vessels, however, condition (*d*) practically puts movable-bladed propellers, clutches, and toothed gearing entirely out of question, and necessitates a reversing engine, with a direct drive on to the screw shaft, and a fixed propeller.

In large engines also conditions (*b*) and (*c*) prohibit the use of a heavy flywheel, and necessitate a fairly equable turning-moment at all working speeds.

It must be remembered, however, that for the high powers necessary in large sea-going vessels, and especially in warships, the internal combustion engine for heavy oil is as yet in a purely experimental stage, but for smaller craft it is a distinct success, and all submarines and torpedo boats are now equipped with it.

(8) Soon after this paragraph was penned by Professor V. Lewes, the British Admiralty ensured its safety, as regards the supply of liquid fuel for the Navy, by obtaining a controlling interest in the development of the Persian oil fields; and the *Queen Elizabeth* class of battleships burning only oil fuel was planned and was ready for the Great War. The experience gained in the course of the various naval engagements fought in the period 1914—1918, have proved the wisdom of the British Admiralty's policy, and so long as any oil-field remains unexhausted, liquid fuel is certain to play a leading *rôle* as a propellant for naval vessels. For submarine work it is of course indispensable, since the large engines of the internal combustion type used on these vessels all use heavy fuel oils.

(9) Some of the figures obtained by Brownlie in his examination of typical steam-raising plants in the United Kingdom show that efficiencies of 75 per cent. and 80 per cent. are being attained in well-designed and well-managed boiler installations burning solid fuel in this country, although the average efficiency is, of course, far below this percentage.

CHAPTER VI.

THE MANUFACTURE OF COAL GAS.

The history of coal gas—Murdoch, Lebon and Winsor—The coals used in coal gas manufacture—Gas retorts and carbonisation—Retort settings—Charging and drawing—Sloping and vertical retorts—Crude coal gas and its purification—Ammonia liquor—Sulphur compounds in gas—The effect of sulphur in gas on its use for domestic lighting—Lime and ore purification—The composition of coal gas—Illuminating standards—Steaming of retorts—Sale of gas on heat units basis—The cause of luminosity in flame—The chemical changes taking place in a gas flame—Gas burners.

THE ease of application and cleanliness in combustion of gaseous fuel, together with the recognition of the importance of the gas engine as one of the most economical sources of power, have led to a considerable amount of attention being paid to the subject during the last thirty years, and for convenience and efficiency, if not for cheapness, coal gas claims the first place amongst this important class of fuels.

The fact that an inflammable vapour could be obtained from coal by the action of heat was known as early as 1691, but it was William Murdoch who, in the closing years of the eighteenth century succeeded in showing how it could be made a valuable aid to the advance of civilisation. It was in 1779 that Murdoch, a hard-working young Scotch engineer, went to Cornwall as superintending manager to Messrs. Boulton & Watt, in order to introduce their pumping machinery and engines in the tin mines, which were then in their zenith. Having a certain amount of

leisure time he occupied it in trying to work out a number of ideas which had occurred to him in his earlier days, and had it not been for the opposition and obstacles thrown in his way by Watt, he would undoubtedly have perfected the locomotive many years before Stephenson; indeed he did construct a sort of motor tricycle which was the cause of great alarm to the surrounding country.

Amongst other experiments tried by him was that of obtaining gas from coal and using it for lighting purposes. Making coal gas in a simple form of retort in his back yard he led the gas into the front office of his house in Cross Street, Redruth, and there exhibited the wonderful properties of the gas flame to admiring audiences. It must be remembered that at this period the only sources of artificial light were candles and lamps, and to the mind educated by centuries of such forms of illumination it seemed scarcely possible that an illuminating flame could be obtained without a wick, and Murdoch's wickless flame was looked upon in those days with as great wonder as we have bestowed upon Röntgen rays, liquid air, and radium.

In the year 1798 Murdoch left Cornwall, and returned to Messrs. Boulton, Watt & Co.'s engine works at Soho, near Birmingham, where he lighted up their principal buildings and made many experiments on the best form of retort to use for the distillation of the coal.

These experiments occupied until about 1802, when a great public display was made of gas lighting by the illumination of Messrs. Boulton & Watt's factory in honour of the Peace of Amiens, and it was at this period also that many shops in the neighbourhood of the factory were lighted up by coal gas.

Murdoch, however, was not destined to reap the reward of his discovery, and in 1799 a Frenchman named Philippe Lebon took out a patent in Paris for making an illuminating gas from wood, and gave an exhibition of it in 1802, which

excited a considerable amount of attention on the Continent. It was seen by a German, named Winsor, who made Lebon an offer for his secret process for Germany. This offer was, however, declined, and Winsor returned to Frankfort determined to find out how such a wondrous effect as making common smoke burn with greater beauty than wax or oil had been brought about. Having quickly succeeded in finding out how it was to be done, he in 1803 exhibited before the reigning Duke of Brunswick a series of experiments with lighting gas made from wood. Looking upon London as the happy hunting ground for the accumulation of wealth, he came over to England, and at the commencement of 1804 boldly took the Lyceum Theatre, where he gave lectures on gas lighting, or rather had an assistant to read the lecture whilst he looked after the experiments. He then proceeded to float a company, and in 1807 the first public street lighting took place in Pall Mall, whilst in 1809 he applied to Parliament to incorporate the National Heat and Light Company, with a capital of half a million.

This application was opposed by Murdoch on the ground of his priority in invention, and the Bill was thrown out, but, coming to Parliament for the second time in 1810, Winsor succeeded in getting it passed in a very much curtailed form, a charter being granted in 1812, and the company was called the Chartered Gas Light & Coke Co., and was the direct forerunner of the present Gas Light & Coke Co. From that day to this the great gas industry has never looked back, and is at the present moment certainly one of our most important industrial assets.

We have seen the wide differences which exist in coal (p. 32), and the coals employed for the manufacture of illuminating gas are all of bituminous character, such coals as the Welsh steam coal or anthracite being useless as a source of gas.

The districts yielding coals best fitted for gas making are

the Northumberland, Durham, South Yorkshire and Derbyshire fields, and the ultimate composition of such coal may be gathered from the following table:—

	Carbon.	Hydrogen.	Sulphur.	Nitrogen.	Oxygen.	Ash.	Moisture.
Newcastle gas coal .	82·16	4·83	1·00	1·23	6·82	3·20	0·76
Durham gas coal .	84·34	5·30	0·73	1·73	4·29	2·42	1·14
South Yorkshire silkstone . . .	80·46	5·09	1·66	1·67	6·79	3·30	1 03
Derbyshire silkstone .	76·96	5·04	2·39	1·77	6·92	3·28	3·64
Barnsley gas coal .	75·64	4·94	2·84	1·65	7·25	4·28	3·40

For enrichment purposes, cannel or "parrot" coal was largely employed.

As before pointed out, our knowledge of the composition of the hydrocarbon compounds present in coal is so limited that the ordinary analysis of a coal affords but little indication of its value for the production of illuminating gas; but there is one point which is highly suggestive, and which has received but a small amount of the attention it deserves. In a report made by M. Ste. Claire Deville in 1886 upon a series of experiments, extending over 12 years, which were carried out at La Villette (Paris) with 59 different kinds of coal, he clearly established the fact that as the amount of oxygen in the original coal—oxygen in combination with hydrocarbons—increases, so does the total amount of volatile matter present in the coal rise in quantity, whilst the density and illuminating value of the gas produced also increase, and he comes to the conclusion that the best gas coals are those containing from 7·5 to 9 per cent. of oxygen. Less oxygen than this in the coal means that the coke will be plentiful, but the gas poor: whilst if the oxygen is above the standard, the coke is bad. This fact seems to point to

the valuable hydrocarbons for gas production in the coal being oxygenated bodies, which, like fatty acids or alcohols, would decompose with formation of ethylene, methane, hydrogen, and oxides of carbon at the temperature of the gas retort, and not, as has been more ordinarily supposed, bodies like paraffins.

The effect which the combined oxygen has upon the composition of the gas obtained from the coal is also instructive.

Percentage of oxygen in coal	5 to 6·5	6·5 to 7·5	7·5 to 9	9 to 11	11 to 12
Composition of gas—					
Carbon dioxide	1·47	1·58	1·72	2·79	3·13
Carbon monoxide	6·68	7·19	8·21	9·86	11·93
Hydrogen	54·21	52·79	50·10	45·45	42·26
Benzols	0·79	0·99	0·66	1·04	0·88
Methane	34·37	34·43	35·03	36·42	37·14
Ethylene	2·48	3·02	3·98	4·44	4·76
Density of gas	0·352	0·376	0·399	0·441	0·482

It will be seen from the table that the proportion of oxides of carbon increases with the rise in the oxygen, as also does the ethylene, whilst the hydrogen decreases.

In ordinary gas practice the coal is heated out of contact with air in elliptical or D-shaped retorts, set in groups of five, seven, nine, or even more and heated by the same furnace, and the products of distillation are then led off by an ascending tube from the mouth of each retort. This tube, called the ascension pipe, after ascending above the level of the bench of retorts, bends over and descends into a trough-shaped tube, which is about half full of tar; and into this the delivery tube or dip pipe from the retort just dips, the tar closing the mouth of it gas-tight. This collecting main runs horizontally over the whole of the front of the bench

of retorts and is called the hydraulic main, and all the retorts discharge into it by means of their ascension-and dip pipes, each of which is sealed by the tar, kept at a constant level by means of an overflow syphon at the end of the hydraulic main.

Each retort is fitted at the end which projects from the furnace with a mouthpiece and lid, which can be removed to allow of the coke being withdrawn and the fresh charge of coal inserted, and the vertical ascension pipes which lead up to the dip pipe and hydraulic main start from the top of the mouthpiece. The reason why these pipes are sealed by dipping under the surface of the liquid in the hydraulic main is that the gas from the other retorts cannot escape down the ascension pipes, as would be the case if they simply opened into the main, and this enables any of the retorts to be opened for recharging, whilst the others are still giving off gas, and also prevents leakage from the whole bench of retorts should one accidentally crack. A large quantity of volatile products escapes as vapour with the gas into the hydraulic main, where much condenses as tarry products and ammoniacal liquor (consisting of ammonia, carbonate and sulphide of ammonium, etc., in solution), and these run off through the overflow syphon to the tar well, where they are collected. The gas passes down from the hydraulic main to the atmospheric condensers, a series of tubes which are exposed to the air, thus cooling down the gas as it passes through them, and causing a further deposition of tar, ammoniacal liquor, and any easily condensable hydrocarbon which may be present. There is also generally an arrangement for artificially cooling the condensers in hot weather by means of water. After leaving the condensers the gas next passes through the scrubbers, which consist of towers built of iron plate and filled with coke or brushwood, over which water or diluted ammoniacal liquor is sprayed and trickles down, meeting the gas which

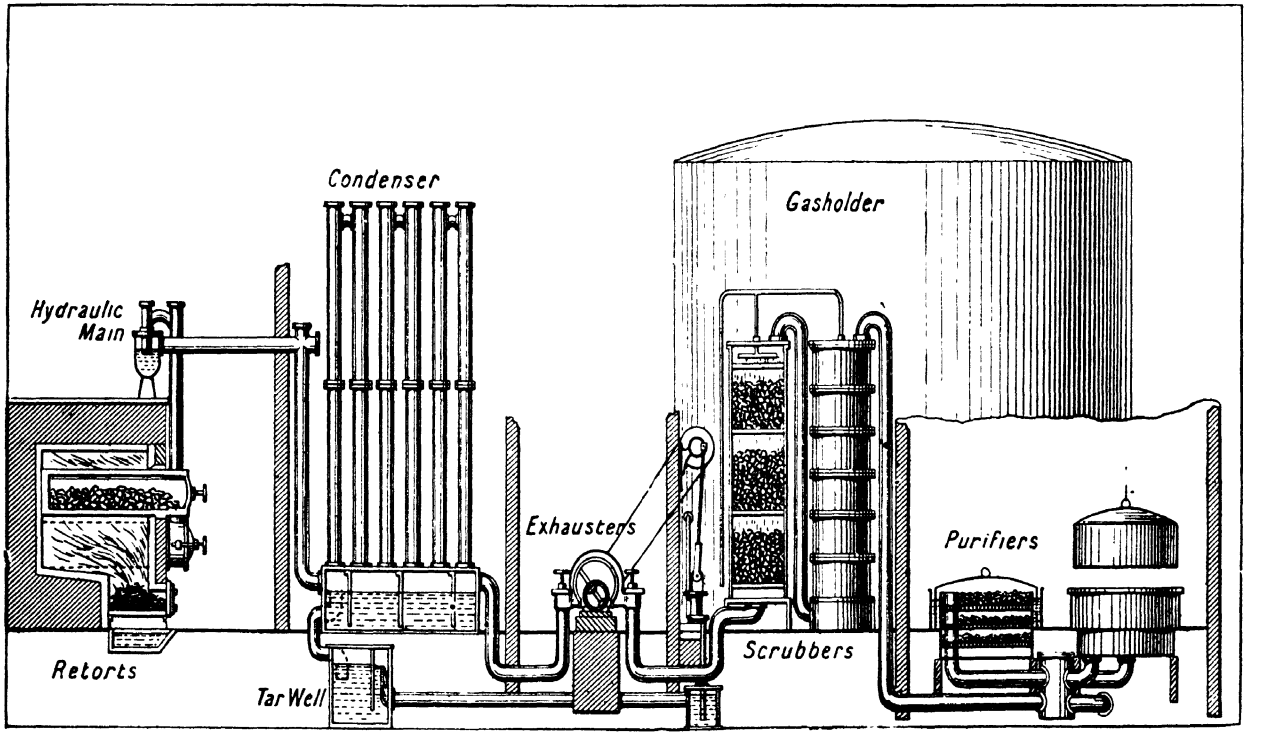


FIG. 23.—Small gas works.

is made to pass up them. The alkaline liquor absorbs some of the sulphuretted hydrogen and carbon disulphide present in the gas, and also removes the last traces of tar and ammonia; the gas, still containing some sulphuretted hydrogen, carbon disulphide, and carbon dioxide, then passes on to the purifiers.

When Murdoch first made gas at Redruth, he employed a cylindrical cast iron pot with a rounded bottom, sunk in the furnace. But it was soon found that the removal of the coke left by the carbonisation of the 15 lbs. of coal employed caused inconvenience, and in 1802 he constructed a horizontal retort. A little later on, in 1804, he reverted to the vertical pot form, but added a tubulure at the bottom for removing the coke, and it was about this period also that he made an inclined retort with lids at either end. The form of the retort, however, soon settled down to the horizontal. This early period was richer in experiments on the subject of carbonisation than almost any we have had since, as when once the horizontal retort gave satisfactory results, the only alteration made during the next 70 years was in material shape and setting. Since then the "sloper" has been once again introduced, with all its mechanical improvements, and has brought gravity to the aid of labour in charging and discharging, with results that need no discussion. Rotary retorts have also had some short trial, and the vertical retort has been developed by Dr. Bueb in Germany, and Messrs. Settle & Padfield, Woodall & Duckham, Dempster & Toogood, and Glover & West in England.

The forms of retort now most in use are made of fire clay: in small country works these are what are termed "single-ended" retorts, and are about 9 feet in length, but in works of any size the more economical double-ended retort is used. The cross-section of the retort has undergone a considerable amount of experiment, but what is known as the "D" form is now generally adopted, as long

exposure to the heat of the furnace does not affect the shape, and it presents a large amount of heating surface on the base. The conditions of working, the heats employed, and other factors affect the life of the retort, but with ordinary care a retort of D section will last about thirty months. At each end of the retort is fitted a cast iron mouthpiece and lid, and into the mouthpiece is fitted the ascension pipe.

A number of retorts, varying from five to twelve, are set together in the furnace, which has the form of an arch, the retorts resting upon the ends of the furnace and upon transverse brick walls built in the furnace. This arrangement of retorts and arch is called a "bed," and a number of beds are set in a row, to which the name of "bench" is given. Each bed has its own furnace for the external heating of the retorts, and the heating can either be by direct or regenerative firing, but the latter system possesses so many advantages that it is rapidly superseding the direct method.

In the regenerative system producer gas, consisting of a mixture of carbon monoxide with nitrogen, is made by passing air over incandescent coke heated in a generator below the bench, whilst a small proportion of steam is added to the entering air in order to form a small proportion of water gas, and so obtain an increased heating effect. The gas so produced contains about 32 to 38 per cent. of combustible gas. The mixed gases pass into the retort furnace at a high temperature, and there meet with a second air supply, in order to complete their combustion, the latter air being heated by having to pass around the exit flue, which carries off the hot products of combustion.

With this system of heating the retorts a considerable saving of fuel, amounting to about one-third, is gained over the direct firing, and the retorts can be heated to a higher temperature, whilst the distribution of heat is more even.

A great improvement and saving in the retort house has been effected during the last thirty years by the introduction of labour-saving machinery. The charging and discharging of the retorts by hand has always been expensive and inefficient, and it is now only to be found in very small gas works, charging and discharging by machinery having taken its place. The machines for this purpose are driven chiefly by electric power, and on a pre-war basis a saving averaging eighteen pence per ton of coal carbonised is effected. The machines in general use are of the projector or push-plate type. The former type operates as charger only, and a separate push-plate machine is utilised for discharging. With the push-plate type the machine is capable of conducting both operations, either simultaneously or separately. Modern practice aims at filling the retort to within a few inches of the top, and this plan of operating shows a material gain in the gas calories obtained from one ton of coal.

Such machines, however, are costly, and wear and tear, both of retorts and machinery, is high, with the result that in order to bring gravity to the assistance of the operation inclined retorts have been reverted to. These retorts are fitted in the furnace at such an angle that the class of coal employed will just slip in them, the angle varying between 28 degrees and 34 degrees. In charging an iron stop is placed in the lower mouthpiece, and the coal is charged in from above by hoppers through a shoot, and running down the slope of the retort is arrested by the barrier at the bottom, and forms an even layer of any desired depth throughout the length of the retort.

When carbonisation is complete the door of the lower mouthpiece is opened, the barrier removed, and on being gently stirred with an iron rod the red-hot coke rapidly discharges itself, and its course is directed by guides to coke hoppers below the working floor.

An idea may be obtained of the appearance of a setting

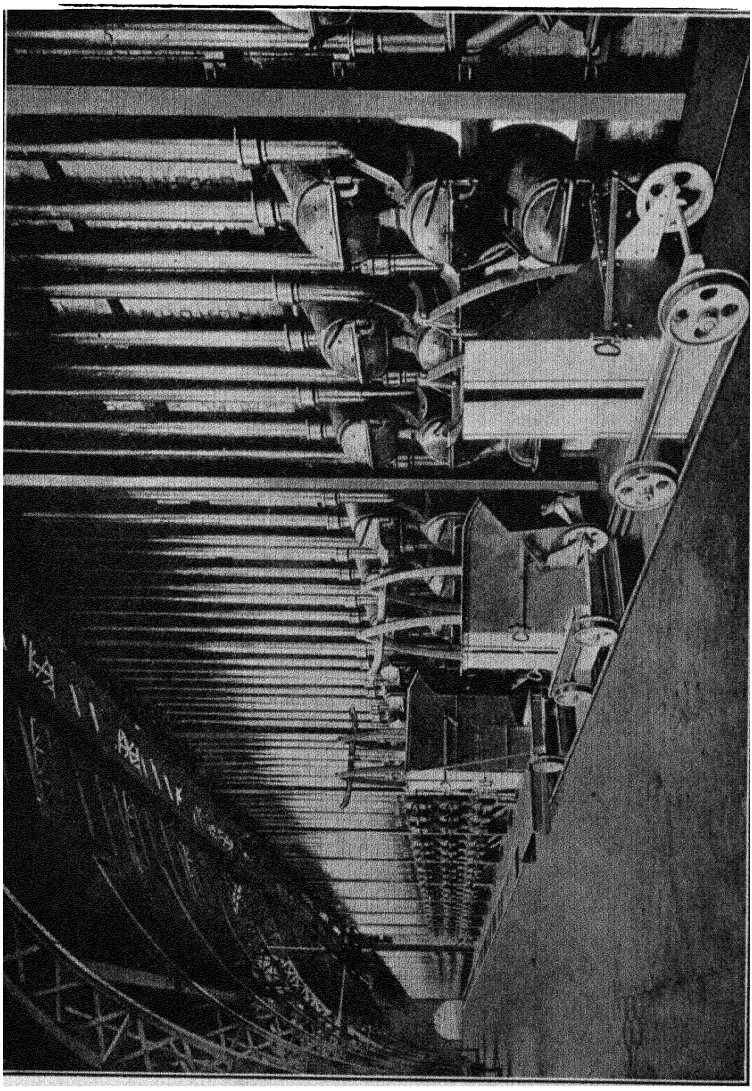


FIG. 24.—Retort house, Granton works.

of these retorts from Fig. 24, which shows the drawing stage in one of the retort houses at the Granton Works at Edinburgh.

One of the earliest retorts tried by Murdoch in his experiments was set vertically in the furnace which heated it, but gave such unsatisfactory results that this form was abandoned. During the last decade the idea has again come to the front, and the disadvantages urged against it have been to a great extent overcome. Several systems of continuous and vertical retorts have in fact now passed beyond the experimental stage, the most successful being those of Glover & West, Dempster & Toogood, Woodall & Duckham, and the "Leeds" intermittent type.

With both the horizontal and sloping retorts the great drawback has always been found in the unequal heating of the gas produced from the coal, the portion near the mouthpiece escaping with but little heating, whilst from the middle of a double-ended retort or the end of a single retort the gas has been exposed to the full baking influence of the hot crown of the retort during its travel to the mouthpiece, this being one of the most prolific causes of naphthalene in the gas.

With a properly arranged vertical retort, into which the coal is charged in small portions, as is done in the Glover-West process, the gas is all evolved at the same rate, and not having to pass through a mass of hot material, which destroys a considerable amount of its illuminating and heating value, can escape direct from the coal, and after exposure to a minimum amount of radiant heat in the upper portion of the retort is withdrawn from the heated zone.[1]

The evil effect of overheating gas is shown by the retort carbon deposited in the crown of the horizontal retort, this carbon having been all produced at the expense of the illuminating and heating value of the gas. Dr. Bueb, who has experimented in this part of the process, gives the following figures as the heating value of gas obtained

[1] See note (10) on p. 183.

from the same coal by different methods of carbonisation :—

Vertical retorts	604	British Thermal Units	per cubic foot.
Inclined ,,	584	,,	,,
Horizontal ,,	570	,,	,,

After leaving the retort and passing through the hydraulic main and condensers the coal gas will still retain impurities which have to be got rid of. The analysis of the gas taken at this point is approximately as follows:—

Hydrogen	47·40
Unsaturated hydrocarbons	34·50
Saturated hydrocarbons	4·75
Carbon monoxide	6·50
Carbon dioxide	1·50
Nitrogen	3·00
Sulphuretted hydrogen	1·50
Ammonia	0·75
Cyanogen	0·07
Carbon disulphide	0·03
	100·00

The last six of these constituents are impurities, and the gas manager as far as possible diminishes them by purification.

Besides the gas the destructive distillation of the coal also yields as by-products—

(1) Solids, the coke and retort carbon.
(2) Liquids, tar and ammoniacal liquor.

The subject of coke has already been dealt with (p. 37), and the composition of the tar has been discussed under liquid fuel (p. 98).

Of the other residues the retort carbon, which forms as a dense layer on the overheated crown of the retort, is carbon in a very pure form, deposited from hydrocarbons decomposed by heat, and on account of its power of conducting electricity, it is much used for making the poles of arc lamps and the negative plates for certain forms of battery.

The second liquid product of the destructive distillation of coal is the ammoniacal or gas liquor, which consists of water partly condensed from the hot gas, and partly added to wash the gas in the scrubbers. It contains as its principal constituents ammonia, partly combined with carbonic acid and sulphuretted hydrogen, forming compounds which are decomposed on boiling with evolution of ammonia gas, and partly combined with stronger acids to form compounds which require to be acted upon by a strong alkali before the ammonia contained in them can be liberated. The ammonia in the first class of compounds is technically spoken of as "free," that present in the latter as "fixed." The following analysis will give an idea of the relative quantities in which these compounds exist in the liquor:—

	Grams per Litre.
Free ammonium sulphide . . .	3·03
,, carbonate . .	39·16
Fixed ammonium chloride. . .	14·23
,, thiocyanate . .	1·80
,, sulphate . .	0·19
,, thiosulphate . .	2·80
,, ferrocyanide . .	0·41

From a scientific point of view, the term "free" is absolutely incorrect, and in using it the fact must be clearly borne in mind that in this case it merely stands for ammonia which can be liberated on simply boiling the liquor.

The ammonia is derived from the nitrogen present in the coal combining with hydrogen during destructive distillation, the nitrogen becoming distributed amongst all three classes of products. The following table will give an approximate idea of the proportions which go to each—

	Per cent.
Nitrogen as ammonia . . .	14·50
,, as cyanogen . . .	1·56
,, free in gas and combined in tar	35·26
,, remaining in coke . .	48·68
	100·00

It might be imagined from the enormous solubility of ammonia in water that the coal gas could easily be freed from this compound by the merest contact with water, but in all purification the dilution of the gas to be absorbed by presence of many hundred times its volume of other gases renders this far from easy. If air containing 5 per cent. of ammonia be bubbled through water, or even strong acid, plenty will be found in the mixture after treatment, whereas if pure ammonia gas had been used, not a trace would have come through.

The gas liquor produced is almost always employed in the manufacture of ammonium sulphate, by a process of great simplicity. The free ammonia is first expelled by means of steam, and when this operation is completed, the residual liquor is treated with lime and more steam, in order to expel the fixed ammonia, which, as we have seen, is the term used to denote the more stable compounds. The ammonia and other gases are passed through strong sulphuric acid in lead tanks, and the crystals of ammonium sulphate forming there as the solution becomes saturated are withdrawn from time to time by perforated copper

ladles. The process is a continuous one, the stream of gas liquor flowing through the apparatus in one direction, whilst steam passes in the contrary direction.

The proportion in which the products are approximately obtained from a ton of gas coal is as follows :—

10,000 cubic feet of gas =	380 lbs.	= 17·0	per cent.
10 gallons of tar	115 ,,	5·1	,,
Gas liquor[1]	177 ,,	7·9	,,
Coke	1,568 ,,	70·0	,,
	2,240	100·0	

The purification of the crude coal gas consists in entirely freeing it from sulphuretted hydrogen, ammonia, and carbon dioxide. Up to the year 1906 the carbon disulphide contained in the gas also had to be abstracted as far as possible, but most of the gas companies have now been relieved from the Parliamentary necessity of doing this, and it was hoped that as a result a cheapening in the production would be possible without the sulphur being increased to a point at which it became detrimental to the consumer.[2]

It was thought that in relieving the companies from these onerous restrictions the maximum amount of sulphur present in the gas as carbon disulphide would not rise above 35 grains per 100 cubic feet of gas, and many gas companies have by a partial purification, or by not using excessive heats in retorting, kept down to the limit, but in other cases the amount has risen to over 51 grains, owing to the high temperatures used in carbonising the coals with the view of obtaining a larger yield of gas.

The formation of the carbon disulphide vapour found in coal gas is due to the direct action of sulphur vapour upon the red-hot carbon. If powdered charcoal or coke be mixed

[1] Liquor condensed from gas alone, without wash water.

[2] See note (11) on p. 184.

with powdered sulphur, and the mass heated, sulphur vapour distils off, and no carbon disulphide is produced, because the sulphur has all volatilised before the carbon is in a sufficiently heated condition to bring about combination; and if the sulphur in the coal were in the free state, the same thing would happen. When coal is put into the hot retort the portions in contact with the sides are rapidly raised in temperature, and the sulphur liberated by the breaking down of the iron disulphide, pyrites, or "brasses," then vaporises and combines with free hydrogen to form sulphuretted hydrogen. By the time the pyrites in the centre of the mass of coal are sufficiently heated to yield sulphur vapour the outer surface of the partly coked mass is at a temperature high enough to form with it small traces of carbon disulphide, and the higher the temperature used the more of the "sulphur compounds other than sulphuretted hydrogen" are produced.

In the following table, obtained from experiments made by Mr. Lewis T. Wright, this is shown very clearly, the yield of gas per ton of coal being taken to give an idea of the temperature, whilst the grains per 100 cubic feet of sulphur compounds in the gas are after purification from sulphuretted hydrogen. The same coal was used in each case :—

Yield of Gas. Per Ton.	Sulphur per 100 Cubic Feet. Grains.
6,893	13·9
8,370	19·1
9,431	26·7
10,772	36·9
11,620	44·1

It will be found that in the crude gas made by most gas

companies the sulphur compounds other than sulphuretted hydrogen will average from 30 to 40 grains of sulphur per 100 cubic feet.

In considering the effect of these sulphur compounds in the products of combustion it must be borne in mind that when coal gas is burnt the sulphur is liberated in the form of sulphur dioxide, and many most misleading statements and ideas have gained ground as to the quantity of this which becomes converted into sulphuric acid in the atmosphere. The experiments of Professor Harold B. Dixon and others all prove that when traces of sulphur dioxide, as minute in quantity as those which are given off in the combustion of gas, are present in the air, they show no tendency to oxidise to sulphuric acid, even though the air be highly charged with moisture, unless the temperature fall to such a point that water is deposited from it. This water then takes up the sulphur dioxide, which slowly becomes oxidised to sulphuric acid. For this reason it is perfectly possible to find traces of sulphuric acid and sulphates upon window panes where the cold air from outside has caused moisture to condense on the windows, and the same action will take place where ammonia or other alkaline substances present in the air or dust can fix the sulphurous acid. But it is manifestly incorrect to suppose that this action goes on unless the temperature of the room has fallen to the condensing point of the water vapour, for, if this did take place, even with a highly purified gas, there is not a sitting room in which the draperies would not become rotted in a very short space of time, as the smallest deposit of sulphuric acid, no matter how dilute, would by slow and cumulative action become sufficiently strong to burn away the fabric. The test of time has shown the fallacy of any such injurious action.

In order to prove the deleterious effects of this hypothetical formation of sulphuric acid, certain observers have

brought forward many experiments to show that, in passing the air through absorbing solutions, sulphates could be detected in them in small and varying quantities. This, however, does not prove that sulphates were present in the air, as directly the sulphur dioxide is absorbed by the liquid the oxidation to sulphuric acid takes place with considerable rapidity. It is this that has given rise to wrong deductions from the observed facts of sulphuric acid, either free or in combination, being found in wetted fabrics or on moistened plates or liquid absorbents exposed to the air of rooms in which gas has been burnt, also on lamp glasses and in ventilating tubes, especially in towns where no limit is placed on the amount of sulphur present in the gas.

Exhaustive experiments made by Dr. Rideal and Dr. Otto Hehner also showed conclusively that the alleged damage due to such quantities as 30 to 40 grains of sulphur per 100 cubic feet of gas was entirely mythical.

In purifying the gas, the crude gas after leaving the surface condensers is sucked forward by the exhauster or pump for pulling the gas away from the retorts and forcing it through the purifiers to the gas holder. These exhausters are of various kinds, but the most usual form is the rotary, in which a revolving fan rotates excentrically in a cylindrical drum. The exhauster is driven by a steam or gas engine, and is kept so regulated as to maintain a slight vacuum in the hydraulic main, the vacuum not exceeding the extent of the seal given to the dip pipes, otherwise air would be drawn into the retorts and mixed with the gas when the retorts were open.

From the exhauster the gas is driven forward through the scrubbers, which are tall towers packed with wooden boards, coke, or brushwood, down which water percolates from a supply on top of the tower, whilst the gas passes upwards. Two or more scrubbers are generally used in series, the first being fed with gas liquor, and the last with

clean water. Instead of "scrubbing" the gas some works employ "washers," which are vessels in which the gas is broken up into fine streams and caused to bubble through water, or else the apparatus is half filled with water, and the rotation of a central shaft, fitted with a number of metal discs, continually presents freshly wetted surfaces to the streams of gas.

The operation of scrubbing or washing the gas serves to extract from it practically all the ammonia remaining in it after passing the surface condensers; the gas still contains carbon dioxide and sulphur in the form of sulphuretted hydrogen and carbon disulphide, and to remove these the gas is forced through the "purifiers," a series of large rectangular boxes with movable lids rendered gas-tight by a seal, and generally eight in number, and charged some with slaked lime and others with ferric hydroxide, the latter in the form of Irish bog ore. The iron removes the sulphuretted hydrogen and when exhausted can be revivified by exposure to the air; the lime removes the carbon dioxide and some sulphuretted hydrogen.

In working, the purifying boxes are arranged to work in couples; the first couple remove the carbon dioxide by means of slaked lime, the second couple contain oxide of iron for extracting the bulk of the sulphuretted hydrogen; in the third couple the bulk of the carbon disulphide is removed with calcium hydrosulphide, whilst the fourth couple act as the final purifying box for the elimination of the last traces of sulphuretted hydrogen. The purifiers are so arranged that they can be worked in five different ways, and allow of any of them being cut out for recharging, etc.

The most generally accepted theory as to the chemical action which leads to the purification of the gas in this part of the process is that, as the gases pass through the lime, the latter first takes up carbon dioxide, becoming calcium

carbonate. Until nearly the whole of the carbon dioxide is removed from the gas the sulphuretted hydrogen is but little acted upon, as the carbon dioxide has under these conditions a greater affinity for lime than the sulphuretted hydrogen; and if sulphide of lime were formed, carbon dioxide and moisture would again decompose it. As soon as the carbon dioxide is all taken up the lime begins to act upon the sulphuretted hydrogen and absorbs it, forming calcium sulphide and other more complex bodies, and liberating moisture; and the sulphides so produced have the power of taking up the sulphur compounds other than sulphuretted hydrogen. In this way they are reduced in quantity, and the sulphuretted hydrogen is almost entirely eliminated; to get rid of the last trace of the latter the gas is generally passed through hydrated oxide of iron.

The compounds which sulphur forms with lime, and which act in absorbing carbon disulphide, are not thoroughly understood, and there is no doubt that there are many factors in purification which are at present outside our knowledge, one of the most important of these being the effect of change of temperature and moisture upon the compounds formed by lime, sulphuretted hydrogen, and carbon disulphide.

In lime purification of the above character there is very little difficulty in keeping the sulphur down to the prescribed limits under normal conditions, especially in the summer, when reduced output allows of a slower flow of the gas through the purifying material; but in the winter the sulphur compounds are liable to sudden rise in quantity, due to causes which, being at present but little understood, are practically beyond the gas manager's control. These sudden rises are more frequent when the limit aimed at is, say, 17 grains than when it is 22 grains.

These unaccountable variations and the nuisance caused to the neighbourhood of the gas works by the removal of

the spent lime made the abolition of the limit for sulphur compounds other than sulphuretted hydrogen a very welcome relief to the gas manager, and at the present time the dry purification of the gas generally consists in passing the crude gas, after leaving the scrubbers, through a sufficient number of purifiers containing slaked lime, to remove all the carbon dioxide and some of the sulphuretted hydrogen, and then through oxide purifiers to remove the remainder of the sulphuretted hydrogen.

The lime used for purification is prepared in large quantities by burning chalk or limestone, both of them impure forms of calcium carbonate, in egg-shaped kilns. The limestone is brought to the mouth of the kiln in waggons in fair sized lumps. In the older kilns large pieces were used to form an arch over the fire grate at the bottom, the rest of the kiln being filled up with the smaller pieces mixed with coal or some other combustible material. The fire is then started and kept going for about two days, after which time the lime is allowed to cool, and is removed. In the modern continuous process, however, the limestone is renewed from the top, whilst the burnt lime is drawn from the bottom ; lime and coal in alternate waggon loads being supplied at the top as fast as the burnt lime is removed from the base. By this method of working fuel is economised, and the smoke, so offensive in the old forms of kiln, is greatly reduced. About one bushel of coal is required for the manufacture of six bushels of lime, although some limestones require less. If a large amount of clay is present the lime fuses very readily, and great care must be exercised in order to keep the temperature below the melting point, otherwise a slag is formed.

When lime is brought in contact with water great heat is evolved, and some of the water enters into combination with the lime to form calcium hydroxide or slaked lime. This calcium hydroxide is a white amorphous powder,

sparingly soluble in water, the solution being known as lime water. This has an alkaline reaction and absorbs carbon dioxide from the air, in like manner to caustic soda. Calcium hydroxide is decomposed at a red heat into water and calcium oxide.

In oxide purification Irish bog ore was generally employed. This contains as a rule about 32 per cent. of hydrated oxide of iron, but only about two-thirds is in a condition in which it can actively absorb sulphuretted hydrogen. The bog ore also contains a large percentage of moisture, sometimes amounting to nearly half its weight, but for successful purification it should not contain more than about 25 per cent. of moisture, as, when the quantity rises much above this it becomes less sensitive, whilst if too dry it gets dusty and works through the grids on which it is placed on the purifiers, and increases the resistance to the passage of the gas. In recent years artificial and chemically prepared iron oxide has been substituted for bog ore with success.

As the crude coal gas passes through the hydrated oxide sulphuretted hydrogen is arrested, and forms with the iron two sulphides, ferrous and ferric sulphide, at the same time liberating water. When the material ceases to absorb sulphuretted hydrogen, its original power can be restored by exposing it freely to the action of the air, when the sulphides deposit all their sulphur in the free state, and the iron, taking oxygen from the atmosphere, is rapidly converted once more into oxide of iron. This process of oxidation is called "revivification," and it is effected by simply spreading the foul oxide on the floor, when it becomes warm and gradually changes from black to its original reddish-brown colour. The material can in this way be revivified about sixteen times, after which the accumulation of sulphur interferes with the action, and the mixture of oxide with about 55 per cent. of free sulphur is then sold to the sulphuric acid manufacturers.[1]

[1] See note (12) on p. 184.

If traces of ammonia and cyanogen find their way into the purifiers, ferrocyanide of iron is formed, which greatly interferes with its effect, and prevents its subsequent revivification, but this trouble rarely arises when lime purifiers are used before the oxide boxes.

After purification the gas is stored in the gas holder, and is ready for distribution.

Gas so made is not a definite compound but a mechanical mixture of several gases, some of which are reduced to the lowest limit in order to develop as fully as possible the light-giving properties of the most important constituents of the gas.

The following analysis gives a fair idea of the composition of an average sample of gas made from coal and without enrichment:—

Hydrogen	52·22
Unsaturated hydrocarbons . .	3·47
Saturated hydrocarbons . .	34·76
Carbon monoxide . . .	4·23
Carbon dioxide	0·60
Nitrogen	4·23
Oxygen	0·49
	100·00

These constituents may be divided into three classes: (*a*) light-yielding hydrocarbons, (*b*) combustible diluents, and (*c*) impurities.

The hydrocarbons, upon which the luminosity of the flame entirely depends, are divided in the analysis into two groups, saturated and unsaturated, according to their behaviour with a solution of bromine in potassium bromide, which has the power of absorbing those termed "unsaturated" but not affecting in diffused daylight the gaseous members of the saturated series of hydrocarbons. They

may be separated in the same way by concentrated sulphuric acid, which has an absorbent effect on the one class, and not on the other.

The chief unsaturated hydrocarbons present in coal gas are:—

Ethylene	C_2H_4
Butylene	C_4H_8
Acetylene	C_2H_2
Benzene	C_6H_6
Naphthalene	$C_{10}H_8$

whilst the saturated carbons consist chiefly of—

Methane	CH_4
Ethane	C_2H_6

The light-giving power of coal gas is undoubtedly entirely due to the hydrocarbons, and the idea held up to sixteen years ago was that the illuminating value depended upon the amount of ethylene present. This, however, is manifestly incorrect, as, if it were true, 4 per cent. of ethylene mixed with 96 per cent. of hydrogen or other combustible diluent should give a 16 to 17-candle gas, whereas a mixture of 10 per cent. of ethylene and 90 per cent. of hydrogen is devoid of luminosity. In 1876 Berthelot came to the conclusion that the illuminating value of the Paris coal gas was almost entirely due to benzene vapour. But here again another mistaken idea arose, owing to a faulty method of estimating the benzene; and there is no doubt but that methane is certainly one of the most important of the hydrocarbons present, when the gas is burnt in such a way as to evolve from it the proper illuminating power, whilst the benzene vapour, small as the quantity is, comes next in importance, and the ethylene last. It is the combined action of the hydrocarbons which gives the effect, not any one of them acting alone.

The illuminating standard of the gas made as described above from ordinary gas coal was from 14 to 16 candles, and this gas up to the year 1910 formed the customary supply by gas undertakings, although in many cases its candle power was increased by the use of cannel coal and by carburetting the gas with volatile hydrocarbons and oil gas, or with other materials of this type.

However, the position was by no means a stable one, for the much better illumination afforded by the incandescent mantle caused the continuous advance of this system of lighting at the expense of the old flat flame burner, and during the period 1909—1913 the three leading London gas companies and a large number of provincial companies applied to Parliament for relief from the out-of-date standard of illuminating value which then governed their statutory powers of gas supply and obstructed real progress in the industry.

In these earlier Bills a double standard was agreed to, namely, one which fluctuated between 12 and 14 candles for illuminating value, and between 522 and 540 British thermal units for heating power.

The granting of this concession to the more progressive companies and undertakings in the gas industry led the majority of the remaining private companies and municipal committees which operated gas undertakings to apply for similar powers ; and when the war broke out in 1914, numberless Bills of this character were before the Parliamentary Committee charged with the consideration of private bill legislation in the gas industry.

The difficulties of maintaining any gas standards at all, however, caused the limits and penalties specified in these various Bills to be entirely in abeyance during the war period, (1914—1918), and it is only to-day that attention is being once again directed to the improvement of the heat value of the gas supplied to the public by the municipalities and private companies. During the last period of the war, in fact,

and especially during the period since the Armistice was signed, great difficulty has been experienced by the managers of gas works in keeping up the supply; for both the output of coal and its quality have fallen far below the pre-war standard, and nearly all gas undertakings have been obliged to manufacture and use water gas upon a much larger scale than before, as a diluent and as an addition to their output by the ordinary retort process. In the majority of gas works, special plants have been erected for this manufacture from a portion of the coke produced by the ordinary process; but in the smaller works the plan of steaming the retorts has been carried out with very noteworthy effects upon the yield of gas obtained per ton of coal carbonised.

The manufacture of water gas in separate producers as a diluent for coal gas is dealt with at length in Chapter VIII., and it is therefore only necessary here to discuss the methods now being employed in the gas industry to produce a mixture of ordinary coal gas and water gas in one operation by steaming the retorts, either continuously or intermittently, during the carbonisation process.

The first experiments, of which full details are available, with the continuous system of steaming were carried out at Macclesfield by G. E. Blundell in 1917, and the results are recorded in a paper read before the Manchester District Institute of Gas Engineers, on October 27th in that year.

The gas-making plant at Macclesfield consisted of an installation of the Glover-West type of vertical retorts, with a normal capacity of 1,000,000 cubic feet of gas per 24 hours; and the production capacity of this plant has been increased at least 20 per cent. by the introduction of the new method of working.

Steam is supplied through a reducing valve to the vertical retorts from Lancashire boilers working at 100 lbs. pressure per square inch; the pressure being reduced at the settings to that required on the plant. The low-pressure steam is

admitted to the coke chamber through a nozzle of $\frac{1}{8}$-inch bore. The results obtained under the ordinary system of working, compared with those obtained by the new method of steaming, are shown in the following table :—

	Average for Year ended March 31st, 1915, without steaming.	Test on June 4th, 1917, with steaming.	Test on August 13th, 1917, with steaming.	Remarks.
Gas made in cubic feet per ton at normal Temp. and Pressure	12,049	15,500	15,477	The average make of gas per ton for the three months ending August 31st, 1917, was 15,358 cubic feet.
Calorific value, gross, in B.Th.U. . .	530	510	508	
Analysis of gas :				
CO_2 . .	2·4	3·0	2 0	
C_nH_{2n} . .	2·4	2·4	2·2	
O_2 . . .	*Nil.*	*Nil.*	*Nil.*	
CO. . .	9·8	10·6	13·6	
CH_4 . .	23·9	21·3	24·1	
H_2 . .	53·2	54·4	49·65	
N_2 . . . (by difference)	8·3	8·3	8·45	
	100·0	100·0	100 0	

Since the results of the Macclesfield experiments and trials with steaming have been published, this system of producing water gas *in situ* without the erection of any special plant has become very generally adopted in the gas industry, especially in connection with the operation of the vertical retorts, which lend themselves readily to this method of working. The yield of gas per ton of coal carbonised has been raised far above the maximum of 15,500 cubic feet obtained in the Macclesfield trials, and the following figures of the carbonising results at Uddingston Gas Works, Lanarkshire, for the five months ending September 25th, 1918, show what remarkable increases in the output of gas can be obtained when this system of working is pushed to its fullest extent.

	1918 (with steaming).	1914–15 (without steaming).
Number of retorts required to make 250,000 cubic feet per 24 hours	4	10
Coal used	1,483 tons.	—
Gas made	37,480,000 cubic feet.	—
Gas made per ton	25,273 cubic feet.	11,450 cubic feet.
Average calorific power of gas	460 B.Th.U. (stripped)	560 B.Th.U. (not stripped).
Total B.Th.U. per ton of coal	11,625,580	6,412,000
Coke sold	633 tons.	—
Coke sold per ton	8·53 cwt.	9·25 cwt.
Tar and light oils sold	36,475 gallons.	—
Tar and light oils sold per ton	24·6 gallons.	14·5 gallons.
Sulphate of ammonia sold	35 tons.	—
Sulphate of ammonia sold per ton	52·86 lbs.	30·5 lbs.
Average cost of coal per ton	24*s.*	11*s.* 2*d.*
Yield from residuals per ton of coal	26*s.* 9*d.*	10*s.*

Comparison by Percentages.	Ratios of Actual Calorific Values.
Quality of gas without steaming	560 B.Th.U. = 100 per cent.
Quality of gas with steaming	460 B.Th.U. = 82 „
Production per ton of coal without steaming	11,450 cubic feet = 100 „
Production per ton of coal with steaming	25,273 cubic feet = 220 „
Total calorific value without steaming	6,412,000 B.Th.U. = 100 „
Total calorific value with steaming	11,625,580 B.Th.U. = 181 „

The volume of gas made in this case was more than doubled by steaming, while the total calorific value of the gas was increased by 181 per cent., and the value of the residuals more than doubled.

These striking figures and results are being equalled or approached by many gas undertakings at the present time, and there is no doubt that the " steaming " process, as applied to gas manufacture, has come to stay.

The only questions in fact now unsettled are whether it is best to apply steam continuously or intermittently to the

retorts, and also whether the older types of horizontal or inclined retorts are more injuriously affected by the steam than the vertical retorts.

As regards the first of these questions, the Dessau or "intermittent" system of steaming has many supporters among gas engineers in this country, and it has been applied in what is known as the *Settle* downward-steaming process, by the makers of the *Leeds* intermittent vertical retort.

The Leeds retort and system of steaming have been adopted at Ossett and Hull, among other places, and at the former place yields of 17,000 to 18,550 cubic feet per ton of coal carbonised have been obtained, with heat values running from 480 to 500 B.Th.U. The production of tar and of the valuable tar oils is also much increased by the downward-steaming process, and the coke is said to be improved both in quality and quantity.

Under ordinary dry distillation, the yield of tar is 10 to 12 gallons per ton, of which 50 to 66 per cent. is pitch, leaving 4 gallons or less of oils, whereas the average of the down-steaming tests is 18·7 gallons per ton, of which less than 40 per cent. is pitch, leaving over 11 gallons of oils. The composition of this tar is as follows :—

Unhydrated tar per ton of coal . .	18·7 gallons.
Specific gravity at 60° F. . . .	1·110

AVERAGE COMPOSITION.

	Per cent.
Water	5·7
Light oils	2·6
Middle oils	32·2
Heavy oils	20·3
Pitch	39·1
	100·0

As regards the effects of steaming upon the life of the retorts, the generally-held opinion among gas engineers is that with

horizontal retorts the effects are bad, and that the steam leads to cracking and reduction of the period of useful service for gas making. In the vertical retorts the conditions are different, and the steam does not come into such intimate contact with the interior surfaces of the retort, but passes up the centre column of fuel. Upon this subject the following remarks by J. E. Blundell, in the paper already referred to, are of interest :—

" With regard to the idea that steaming would have a very deleterious effect on the material of the retort, we can state that this has not so far been borne out by our experience. In considering this question it must be remembered that the conditions obtaining in a vertical retort are very different from those in a water gas generator. In the latter, steam at ordinary temperatures is blown in great volumes and at a high speed into a chamber which has a considerably higher temperature at the point of entry than obtains in the interior of the vertical retort ; and during the run the temperature at this point drops very considerably. This temperature is again very rapidly increased during the period of blow. On the other hand, in a continuously-operated vertical retort, before the steam reaches the point at which water gas is first generated, it has already become superheated to a temperature of 500° to 600° C. by its passage through the hot coke in the regenerator chambers. Also the steam nowhere impinges violently upon the hot sides of the retort; it simply flows through the coke in a slow steady stream distributed over the whole area of the retort, and, owing to the continuity of the process, there is no violent alteration in the temperature of any one portion of the retort."

Both of these methods of steaming—namely, the continuous and the intermittent—are used widely in this country at the present time (1920), and since legislation is now contemplated which will abolish the candle-power standard for gas altogether and substitute a thermal one in its place, there

is no longer any valid reason why gas undertakings should not be allowed to supply a mixture of retort and water gas, containing few illuminating elements, but rich in CO and other heat-producing gaseous elements and compounds, if adequate precautions are taken that this gas shall be up to a definite thermal standard of value.

In this connection, the recommendations of the committee appointed by the Fuel Research Board in 1919 to enquire into this question may be referred to. This committee was set up in reply to a request of the Board of Trade that they, the Fuel Research Board, should advise as to " the most suitable composition and quality of gas, and the minimum pressure at which it should be generally supplied, having regard to the desirability of economy in the use of coal, the adequate recovery of by-products, and the purposes for which gas is now used."

The recommendations of this committee have led to the drafting of a Bill which embodies many of their suggestions, and also authorises the system of charging based upon the thermal units supplied to the consumer in place of the cubic feet. The unit to be adopted as basis of this system of charging will be 100,000 B.Th.U., to be known as the " therm." The total units chargeable are to be calculated by multiplying the number of cubic feet registered by the consumer's meter, by the declared calorific value of the gas per cubic foot. The calorific value is to be continuously measured and recorded by a standard type of recording calorimeter, approved by the Metropolitan Gas Referees, who will also prescribe the method of installing, using and checking the same. The gas delivered is to be free from sulphuretted hydrogen; and during the period of two years subsequent to the passing of the necessary Act is to contain not more than 20 per cent. of inert constituents, this maximum being reduced to 18 per cent. during the succeeding two years, and to 15 per cent. thereafter. The producer is to declare the calorific value of the gas to be

delivered, and will undertake to adjust and, if necessary, replace gratis consumers' burners so that the gas may be utilised with safety and efficiency. A gas undertaking is at liberty to change its declared calorific value, due notice of such change being given to the consumer. The necessary adjustments, if any, of consumers' appliances, are to be prepared during the period of such notice. Within a period of five years gas is to be supplied at such pressure, that under normal conditions the pressure of the gas in any main or service pipe of at least 2 inches diameter is at least 2 inches of water.

By the time these lines are in print, it is probable that the proposals of the Board of Trade as set out in this Bill will have been accepted and passed by Parliament, for both the consumers and the producers of gas are in favour of the new system of charging, and the only opposition that can be expected is concerning the maximum amount of sulphuretted hydrogen and of the so-called "inerts" to be permitted in the supply to the domestic consumer. The fact, however, that a successful method of destroying the sulphuretted hydrogen and other similar sulphur impurities in gas by heat has been worked out and operated upon a large scale by the South Metropolitan Gas Co., and that all the more progressive engineers in the gas industry, are in favour of some restrictions of the permissible amount of the sulphur impurities of gas, indicates that this new restrictive clause in gas legislation will be accepted by the industry, in order to obtain the greater freedom which the clauses of the Bill permit in other respects.

The suggested provisions of the Bill relating to the use of a continuous recording calorimeter for checking the quality of the gas are most valuable from the consumers' point of view, since the checks at present in force relating to thermal value are absolutely worthless as a guide to the quality of the gas supplied over the whole 24 hours, and no gas engineer can be satisfied with them as they stand.

The use of coal gas for illuminating and heating purposes necessitates the consideration of the structure and properties of flame.

When a solid which is incapable of being volatilised burns under ordinary conditions, no flame is produced, but when a volatile solid, a vapour, or a gas undergoes combustion in air, flame is formed.

Flame may therefore be looked upon as the combustion of gaseous matter, and as combustion is merely extremely vigorous chemical combination, it is manifest that the flame can only exist where the coal gas and air meet.

If a jet of hydrogen be ignited in air, the conical flame which is produced consists of a hollow sheath of burning gas, surrounding an inner core of unburnt hydrogen, and flames formed by a simple gas which burns without decomposition and only forms one product from its combustion, all have this simple structure, the sheath of flame being produced where the combining gases meet.

The fact that such a flame is hollow can be at once proved by inserting a tube into the hollow cone, when some of the unburnt gas will pass through it and can be burnt at the other end.

Compound gases, which undergo decomposition during combustion, or gaseous mixtures, give flames with a rather more complex structure, and it is usual to describe the flame of coal gas or of a candle as consisting of three zones. The first of these, A, is the inner non-luminous zone (Fig. 25), in which no combustion is taking place, but where some very important chemical changes are going on; the second, B, is the zone of luminosity upon which the light-giving power of the flame depends, whilst the third, C, is a thin, non-luminous envelope which entirely surrounds the flame, and which is clearly seen if a small piece of card be held in front of the flame so as to shield the eye from the light emitted

by it, and only to leave the edge visible. This latter zone may again be divided into two parts—a small blue portion at the base of the flame and the envelope of the upper part of the flame.

When a candle is lighted the burning wick melts the wax or material of the candle in contact with it, and then by capillarity sucks up the liquid, and the heat of the burning wick in the first instance, and afterwards the heat of the flame, convert the hydrocarbons into a mixture of gases and vapours of much the same character as a rich coal gas.



FIG. 25.—Candle flame.

In each case, therefore, the gases flowing from the wick or the jet contain unsaturated hydrocarbons, methane, and hydrogen as their chief constituents.

These gases when ignited burn, but the lighter they are the more rapidly will they diffuse and so reach the outside of the flame; the result of this is that the hydrogen and the methane are the first to burn, and the heavier hydrocarbons flowing upwards between the walls of flame become highly heated and converted into a mixture of acetylene and methane.

Taking ethylene as the type of the unsaturated hydrocarbons in the gas, the change would be represented by—

Ethylene.		Acetylene.		Methane.
3 (C_2H_4)	=	2 (C_2H_2)	+	2 (CH_4)

and at the top of the inner non-luminous zone 80 per cent. of the unsaturated hydrocarbons present are found to be acetylene. The temperature of the flame rapidly rises the higher the point, and at the spot where the luminosity of the flame commences the temperature is over 1,000° C., and

this causes sudden and extremely rapid decomposition of the acetylene into its constituents—

Acetylene.		Hydrogen.		Carbon.
C_2H_2	=	H_2	+	C_2

Acetylene is one of those compounds termed "endothermic" from the fact that heat is absorbed during their formation, and at the moment of decomposition this heat is again liberated, and having no time to dissipate itself amongst the other gases present, heats up the carbon particles to a temperature far higher than the average temperature of the flame, causing them to become incandescent and so rendering the flame luminous, the incandescence of these solid carbon particles being further aided by the temperature of the flame and by their own combustion, partly by the oxygen of the air and partly by the action of water vapour and carbon dioxide upon them,

	Carbon		Oxygen		Carbon monoxide
(*a*)	C	+	O	=	CO

	Carbon		Water vapour		Carbon monoxide		Hydrogen
(*b*)	C	+	H_2O	=	CO	+	H_2

	Carbon		Carbon dioxide		Carbon monoxide
(*c*)	C	+	CO_2	=	2 CO

and it is the combustion of the carbon monoxide and hydrogen which gives the outer non-luminous envelope to the flame.

The small blue portion of the outer envelope at the base of the flame is caused by the rapid inrush of air, the nitrogen so diluting the hydrocarbon molecules at that point that they are burnt up without being first decomposed, and there being therefore no separation of carbon there is no luminosity, and the same blue colour may be observed when

a gas flame is rendered non-luminous by dilution with nitrogen or carbon dioxide.

This explanation holds good for all luminous hydrocarbon flames, but the combustion of many other substances emits light, such as phosphorus, magnesium, zinc, and arsenic, but in these cases the products of combustion are solid, and in the finely divided condition in which they are formed are rendered incandescent, and, in the case of phosphorus and arsenic, are again volatilised by the heat of their own formation.

Flames which can only contain gaseous matter can be rendered incandescent if a sufficiently high temperature can be obtained: for instance, if hydrogen be burnt in an atmosphere of oxygen under a pressure of several atmospheres, light is developed, but the temperature of such a flame is many times hotter than an ordinary hydrogen flame burning in oxygen, as pressure acts on flame in the same way as on a gas, and at a pressure of several atmospheres several times the amount of hydrogen and oxygen would be consumed as would be the case under ordinary conditions of temperature and pressure.

The luminosity of flame may therefore be stated to be due either to the presence of incandescent solid particles or at a far higher temperature to incandescent gases.

As may easily be imagined, the first burner used for the consumption of coal gas was the end of the tube from which it was issuing, but Murdoch soon saw that the consumption was far too high and the illuminating value far too low to make this a successful method of burning his new illuminant. Casting about to find a method of retarding the flow he fitted an old thimble over the end of the pipe, and this happening to have several pinholes in the crown, he lighted the gas issuing from them to prevent it escaping into the room. He at once found that several small jets gave a far better light than one big flame, besides causing considerable

economy in the consumption of gas. But as his experiments progressed the form of his burner was modified, until in 1807, when fitting up the works of Messrs. Phillips and Lee, in Manchester, he used two forms of burner, the one a rough argand, and the other "a small curved tube with a conical end having three circular apertures or perforations about $\frac{1}{30}$th of an inch in diameter (one at the point of the

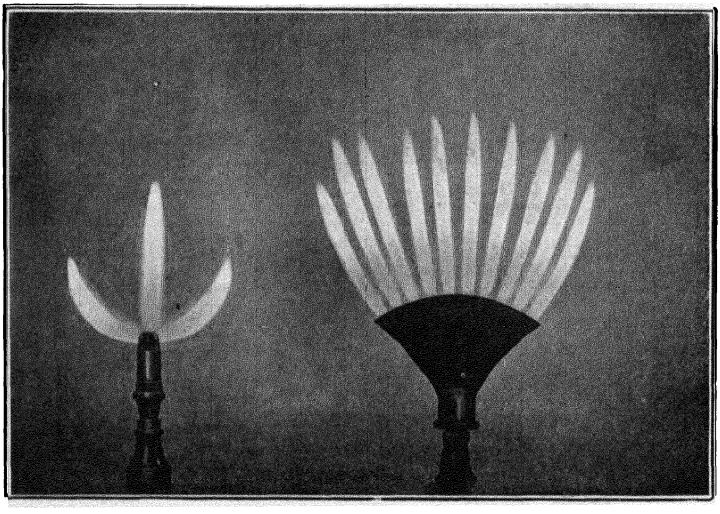


FIG. 26.—Cockspur and cockscomb burners.

cone and two lateral ones) through which the gas issuing formed three distinct divergent jets of flame, somewhat like a fleur de lys." The latter burner, which from the shape of the jet received the name of the "cockspur" burner, gave a light equal to $2\frac{1}{4}$ mould candles of six to the pound, whilst the argands used developed a light equal to 4 candles of the same description. The argand burner had been in use for the consumption of oils for some years before the introduction of coal gas, and in its early form it consisted simply of two concentric tubes

fixed at the required distance apart, the coal gas being fed in between them. Soon however the idea arose of closing the open circular slot by a metal ring pierced with holes, so as to give a circle of small jets; and even prior to 1816 the main principles of our present argands were found to be in the burners in use. It was about 1816 also that the cockspur burner became converted into the "cockscomb," and then the "batswing," thus marking a distinct advance in the method of burning the gas, as by spreading the flame out into a thin sheet, instead of having it in a solid mass as in the jet burner, the air was more readily and uniformly supplied to the burning gas, and the higher temperature of the flame, due to the more perfect combustion, increased the light-giving power of the burner to nearly that of the argands then in use.

In 1820, Nielson, of Glasgow, whose name will always be remembered as the discoverer of the hot air blast in iron smelting, found that by allowing two flames to impinge upon one another an increase in luminosity was obtained; and after several preliminary stages the union jet or "fishtail" burner was produced, in which two holes, bored at the necessary angle in the same nipple, caused two jets of gas to impinge upon each other so that they mutually splayed themselves out into a flat flame, the same result being also secured in the chisel-head burner shown in Fig. 27. The batswing flame was a very wide one, of but little height, whilst the fishtail was much higher and more narrow. Although the service yielded by the fishtail for each foot of gas consumed was no better than, even if it was as good as, that given by the batswing, yet its shape, which made it less affected by draughts and enabled a globe to be used with it, ensured a greater meed of success for it than the batswing burner had secured.

The next twenty years was a period of the gradual improvement and perfecting of the argand and flat flame

burners, the influence of pressure and regulation of the flow of gas to the burner being gradually realised and arranged for, whilst other structural improvements were introduced.

On May 20th, 1853, Dr. Frankland, whilst giving one of the Friday lectures at the Royal Institution, showed, but did not fully describe, an argand burner in which the idea

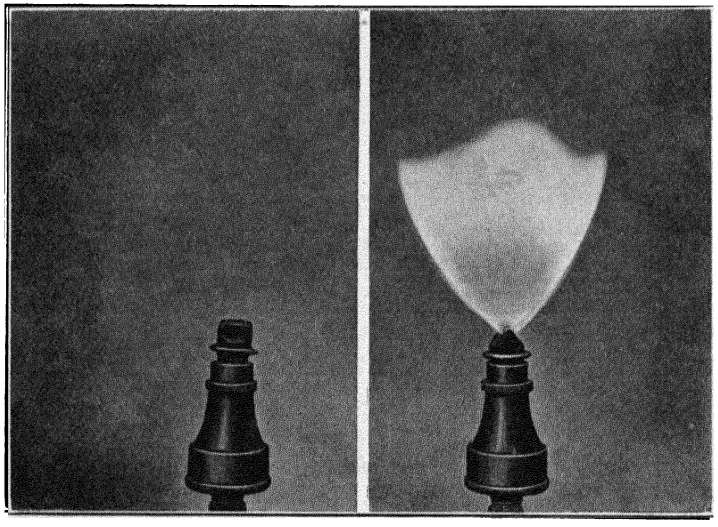


FIG. 27.—Old flat flame burner.

was first adopted of utilising the heat, which otherwise would have been lost, to raise the temperature of the air supply. This burner was afterwards described in "Ure's Dictionary," the article, however, not being published till a year or so after it had been written. The burner consisted of an ordinary argand, but in addition to the usual chimney it had a second external one, which extended some distance below the first, and was closed at the bottom by a glass plate, fitted air-tight to the pillar carrying the burner, so that the air needed to support the combustion of

the gas had to pass down the annular space between the chimneys, and in its passage became highly heated, partly by contact with the hot inner glass and partly by radiation. The temperature of the air finally entering the burner Dr. Frankland considered to be about 500° F. In 1854 the Rev. W. R. Bowditch brought out a burner identical in nearly every respect with the one just described, and as this was brought prominently forward, it attracted considerable attention, with the result that the inception of the regenerative burner has been generally ascribed to Bowditch, whereas that honour is undoubtedly due to Frankland.

In 1879 Friedrich Siemens, of Dresden, brought out his large burner, which, although one of the most effective, was also one of the most unsightly, from its big overhead feed pipe. This burner was really first made for heating purposes, but the light it gave was so far ahead of any effect which had been obtained up to that time that with certain modifications it was adopted for lighting purposes.

During the eighties the regenerative burner was perfected and adapted for general use, and such overhead burners as the Wenham, Cromartie, etc., gave not only an excellent duty per cubic foot of gas consumed, but could also be made powerful engines of ventilation, as, fitted to flues in the ceiling space, they could be made to withdraw an enormous volume of vitiated air from the upper part of the room.

The discovery by Dr. Auer von Welsbach in 1885 of the method of making the incandescent gas mantle, and the further discovery in 1892 of the use of the oxide of thorium with a trace of oxide of cerium for its composition, gave a method for developing light from coal gas which has so far surpassed any other way of burning it that the old forms of burner are now but little used. This system consists of consuming the gas in an atmospheric or bunsen burner, so

as to obtain a non-luminous but very hot flame, and then utilising this to raise to incandescence a mantle made of —

Thorium oxide	99
Cerium oxide	1
	100

a mixture having a far higher power of light emissivity than carbon particles.

The mantles are made by saturating a cotton fabric or stocking with a solution of the nitrates of the two metals mixed in the right proportions. The fabrics are then shaped and dried, and an asbestos loop having been sewn into the top, are burnt in a bunsen flame, the organic matter of the original fabric burning away and the nitrates being converted into oxides, which retain the shape of the original structure. The oxide mantle is then shaped and hardened in a blow-pipe flame, and is rendered sufficiently strong for handling and distribution by dipping it in a solution of collodion. When fixed on the burner the collodion is burnt off, and the mantle of oxides, which just fits the outer zone of the bunsen flame, is heated to high incandescence and emits ten times the light that the same amount of gas burnt in a flat flame burner would have given.

The upright burner incandescent system of illumination has in its turn been displaced by the inverted system, which has two advantages in its favour, namely, (1) the preliminary heating which the gas and air mixture undergoes in its passage to the burner tip, and consequent higher flame-temperature attained at the mantle, and (2) the greater strength which can be given to the inverted mantle owing to its shape. A further advantage is that there is no obstruction offered to the path of the radiated light below the burner level, and the maximum illuminating effect is obtained therefore exactly where it is required.

The disadvantages of the inverted system have been that very often in the past the gas pressure has been insufficient to produce an adequate mixture of air and gas in the mixing tube of the inverted burner without back-firing, and also that the sulphur compounds in the gas have caused unsightly corrosion of the burner-support and fittings. Both of these disadvantages will be minimised, however, if the provisions of the Gas Supply Bill, referred to on p. 171, are faithfully carried out by the supply companies and undertakings.

(10) The principle of the Glover-West system was copied from the continuous vertical retort designed and applied by Young many years before in the shale oil industry. The first experimental vertical retort for coal carbonisation by the Glover-West system was installed in 1907. This retort was successful, and its progress since that year has been rapid and continuous. It is claimed for this system that the retort has not required any radical alterations in design since its first introduction in 1907, and that to-day it is being successfully applied to the carbonisation of all classes of coal, including the highly-swelling coals of the Durham coalfields, and also the difficult coals of the West of England area. It is specially adapted for the application of "steaming."

The coals to be treated are elevated into an overhead bunker, fixed directly over the retorts to be charged. From this point gravitation is allowed to do the work of charging and to assist in passing the charge through the carbonising chamber. The speed at which the charge is allowed to travel through the retort is controlled by a discharging screw set vertically in a chamber at the bottom of each retort. This discharging screw, when driven by its gearing attached outside the chamber, discharges the resultant coke into a sealed hopper.

The Woodall-Duckham system is based similarly upon the continuous descent of the coal through a suitably constructed vertical retort, the heat of which can be closely regulated. The amount of coal fed into the retort and the rate at which the charge descends are governed automatically by the speed of the mechanism which regulates the extraction of the coke from the bottom of the retort. The retorts are heated by bringing the producer gas and heated secondary air in flues across each side of the top of the retorts, the gases burning vertically downwards, and so liberating the greatest heat at the upper portion of the retort. When steaming is resorted to, the retorts are heated by gas admitted lower down the retort, and the steam is also superheated by the waste gases before it is admitted into the retorts.

The Dempster-Toogood continuous feed vertical retort is a development of the "Elland" type of intermittent feed vertical

retort, introduced first in 1908, and is distinguished by its method of adapting the taper of the retort to the change in the volume of the charge of coal, as it passes through the various stages of carbonisation.

Theoretically the taper of vertical retorts should be proportionate to the variously expanding charge. Practically an accelerated taper is adopted, giving the maximum taper at the top where the coal is swelling, and the minimum taper at the bottom where the coke is shrinking. The efficiency of vertical retorts depends also upon the continuity of the descent of the charges; hence an even distillation to prevent tilting of the charge is beneficial. This is accomplished by applying the heat in a perfectly symmetrical manner on each broadside of the retort, which leads to uniformity of distillation of every cross-section throughout the charge, with equal shrinkage and regularity of descent.

(11) Up to the period when the war produced its unwelcome effect upon the costs of fuel and labour this hoped-for reduction in the price of gas to the consumer had been realised.

The enormous increase in the cost of coal, of manufactured materials and of labour since 1916, however, has necessitated a return to the conditions of 1910 and earlier, and as regards the price of gas, all the economic advantages resulting from the progress of the technical and scientific side of gas manufacture during the last decade have now been wiped out and lost.

(12) The decomposition and removal of carbon bisulphide and other sulphur compounds from gas by heat has long been the ideal of gas engineers, and since Heard, in 1806, first suggested this method of purification, numberless experiments and attempts have been made to carry out the process upon a practical scale. The late Professor Vernon Harcourt initiated in 1870 the more modern work upon this subject; but Hall and Papst, in America, were the first gas engineers to attain any success with this method of removing carbon bisulphide from the gas. In 1908—1909 they erected and worked a heat-purification plant at the works of the Portland Gas and Coke Co., and published figures showing a reduction of 71 per cent. in the sulphur content of the gas submitted to the process.

In 1906 the experts of the South Metropolitan Gas Co. commenced their work upon the problem of the more complete and more economical removal of the sulphur impurities of coal gas; and by the use of nickel as a catalyst they managed to make the heat method effective at a much lower temperature than had hitherto been employed (450° C. in place of 900° C.). To Dr. Charles Carpenter and to Mr. G. V. Evans, the chief chemists of the company, belongs the credit for thus surmounting the difficulties of the heat treatment when applied to the purification of gas upon a very large scale.

The published figures for this process, as carried out at the Old

Kent Road Works of the South Metropolitan Co., from January, 1913, up to May, 1914, showed that 2,335 million cubic feet of gas were treated, with an average percentage reduction of sulphur impurities of 79·3 per cent. at an average cost of only ·299*d.* per 1,000 cubic feet. These, of course, are pre-war figures, but they are sufficient to show the success of the process and its applicability to all except the smallest gas plants. When the new legislation relating to the gas industry has been passed, we may expect, therefore, to find the heat-purification method for removing the sulphur compounds of the gas very generally adopted, for otherwise it will be difficult for the gas companies to comply with the provisions of the clause relating to this impurity.

CHAPTER VII.

THE USE OF COAL GAS FOR HEATING AND POWER.

Calorific value of coal gas and its constituents—The relation between illuminating power and thermal value—Effect of enrichment on calorific value—The inception of the atmospheric burner—Early forms of burner—The cause of non-luminosity in the "Bunsen" flame—Ratio of air to gas in the flame—Effect of diluents on the flame—Effect of the specific heat of gases in the flame—The structure of the atmospheric burner flame, and the chemical changes taking place—The temperature of the flame—The Le Chatelier thermo-couple and its use—Gas stoves and their relative efficiency as compared with coal—Methods of heating, and the effect on the air of rooms—Regenerative gas stoves—Flueless stoves—The necessity of leading away the products of combustion—Coal gas in the internal combustion motor.

A good example of the confusion created in the lay mind by scientific utterances is to be found in the calorific value of hydrogen. A pound of hydrogen when burnt evolves more heat than a pound of any other known substance; and as a rule this has given rise to the impression that this gas must be the most valuable of all gaseous fuels. The fact is overlooked, however, that it is also the lightest known element, and that it takes no less than 178·8 cubic feet to weigh a pound, so that the heat value of the cubic foot is only 325 B.T.U. gross, whilst the fact that water is the only product of its combustion lowers the net value to 272 B.T.U., a lower duty even than that of the product of the incomplete combustion of carbon (carbon monoxide), which yields 330 B.T.U. both net and gross, there being no water to vapourise, and no heat therefore rendered latent during its combustion.

Taking the main constituents of coal gas and tabulating them according to their calorific value taken in round numbers, we may state them as follows :—

Description of Gas.	Calories per cubic foot.		B.T.U. per cubic foot.	
	Gross.	Net.	Gross.	Net.
Benzene vapour . . .	938·9	902·5	3,718	3,574
Ethylene	404·8	381·3	1,603	1,510
Methane	258·6	232·0	1,024	919
Carbon monoxide . .	83·3	83·3	330	330
Hydrogen	82·0	68·7	325	272

Taking now an ordinary sample of 16-candle-power coal gas as supplied to London in the city area, and applying these values to its combustible constituents, we have—

Hydrogen . . .	54 per cent.	× 325	= 17,550
Methane . . .	34 ,,	× 1024	= 34,816
Ethylene . . .	3 ,,	× 1603	= 4,809
Benzene . . .	1 ,,	× 3718	= 3,718
Carbon monoxide . .	6 ,,	× 330	= 1,980
			62,873

or 628·73 B.T.U. gross for a cubic foot; whilst if the calorific value be tested direct in the calorimeter, we obtain, as the value of the mean of ten determinations by the Junkers calorimeter, 157 calories per cubic foot, or 157 × 3·968 = 623 B.T.U.

For every reason the experimental determination of the calorific value of a gas is the most satisfactory, the easiest, and the most reliable method. Calculation necessitates an accurate analysis of the gas, which is very difficult to obtain, and not only makes the calculation of the calorific value a most laborious operation, but also leaves loopholes for so many sources of error that the results

are open to grave doubts. Given a good analysis, however, calculation enables one to obtain not only the calorific value under conditions where direct determination would be impossible, but also affords an insight into the cause of any abnormal variation in thermal value which might otherwise be difficult to trace. Taking the calculation of the calorific value just given, it is clear that more than two-thirds of its heating power are due to the hydrocarbons present in it, and that methane is the factor which makes a good coal gas so superior to all other forms of gaseous fuel, with the exception of natural gas.

The calorific value of a coal gas varies enormously with its composition, and the saturated and unsaturated hydrocarbons, which are all-important in endowing the gas with illuminating value, play an equally important part in its heating value. As the illuminating value of a town supply is generally a well-known factor it would be a great convenience to the user of gas for fuel purposes if even an approximate relation between heating and illuminating value could be established. The photometric determination of illuminating values, however, has, until lately, been rendered absolutely fallacious for all qualities of gas, except just about the 16 candle point, by the method employed of burning the gas in a standard London argand at a fixed rate of flow, 5 cubic feet per hour, which properly develops the light from a 16 candle gas, but does a grave injustice to gas of a higher or lower value. Within the last few years, however, a more reasonable, although far from perfect, method has been introduced, and a rough approximation may be arrived at.

It is clear that it is not possible to take a calorific value as indicative of any particular illuminating value, or say that such a candle power gas will have a definite calorific value, because a 16 candle gas may be anything between 575 and 650 B.T.U. gross, and will vary between such limits

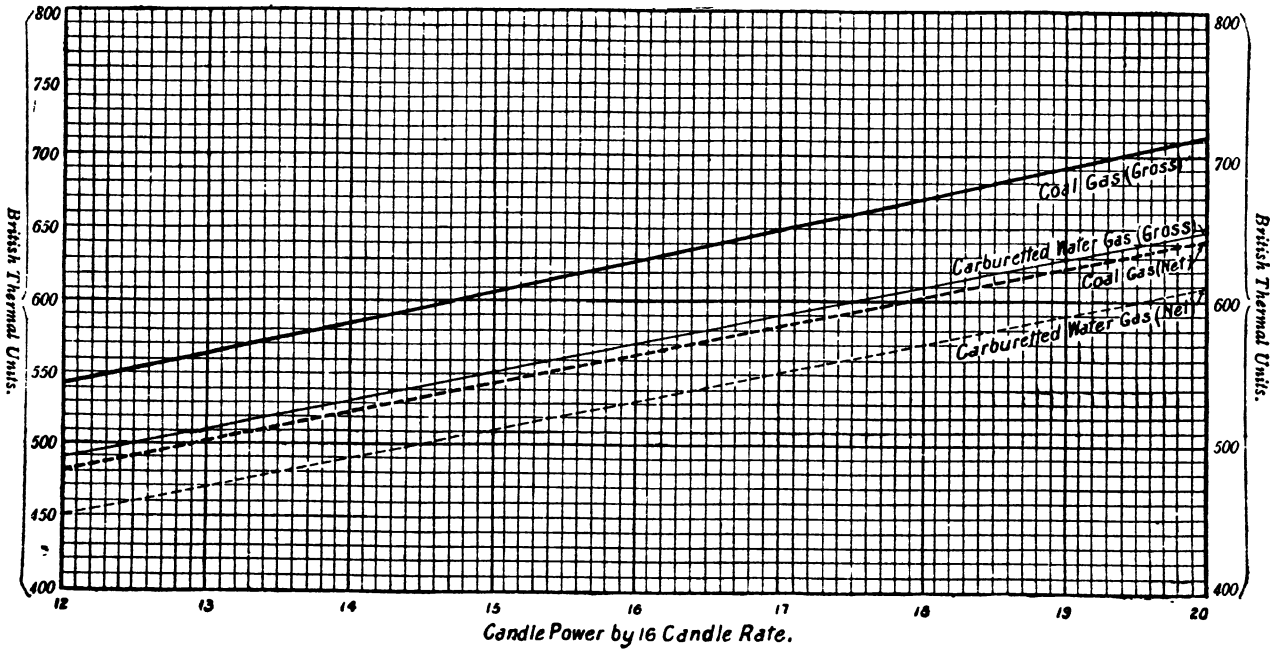


FIG. 28.—Candles and calories.

according to the kind of coal used for its production, or whether it is a pure coal gas or a mixture with carburetted water gas. In fact every alteration in composition is reflected in the calorific value. As, however, calorific tests made on varying grades of coal gas are collected in greater and greater numbers and are entered in diagrammatic form, the more nearly does a line drawn through the centre of the myriad points approximate to a straight line, until now, after several years' testing the calorific value of various grades of coal gas from every part of the country, and made from all sorts and classes of coal, the average relation shown for coal gas, and the second curve for carburetted water gas, in Fig. 28 have been obtained.

Taking the original diagram, the lines appear to run through a haze of spots and are only rendered straight by their equidistance from outlying points; whilst those points distant from the main average lines themselves again fall into secondary lines in the same direction, but on different planes to the main lines, and which represent the curves of calorific value for coals of the same kind. This diagram is merely put forward as the average relation between the illuminating power of a pure coal gas and its calorific power, and the variations from the line may amount to 5 per cent., or even more. With this reservation it gives a definite idea of the relation existing between candle power and calorific value.

Taking now the chart, the average calorific value may be tabulated for each candle power between 12 and 20 as shown on p. 191.

In many of the published results regarding the relation between calorific power and illuminating power the experiments have been rendered useless by the low illuminating power having been obtained by "stripping" the gas, *i.e.*, by taking out the unsaturated hydrocarbons to a greater or less extent by bubbling the gas through

CALORIFIC VALUE OF PURE COAL GAS.

Candle Power.	Calories.		British Thermal Units.	
	Gross.	Net.	Gross.	Net.
12	136·0	120·6	540	480
13	141·0	125·6	560	500
14	147·0	131·2	585	522
15	153·2	136·2	610	542
16	157·0	141·2	625	562
17	162·5	146·2	647	582
18	168·3	151·2	670	603
19	173·3	156·3	690	622
20	178·8	161·3	712	642

CALORIFIC VALUE OF CARBURETTED WATER GAS.

Candle Power.	Calories.		British Thermal Units.	
	Gross.	Net.	Gross.	Net.
12	123·1	113·5	490	452
13	128·1	118·6	510	472
14	132·9	122·8	529	489
15	137·4	127·6	547	508
16	142·4	132·4	567	527
17	147·5	137·4	587	547
18	152·7	142·4	607	567
19	157·5	147·5	627	587
20	162·5	152·5	647	607

petroleum. It is possible, working in this way, to obtain a gas which will remain almost constant in calorific value, whilst the illuminating power descends with great rapidity. This result is due to the fact that the methane, which gives considerably more than half the heating value, remains untouched, whilst the benzene and ethylene, which were the main factors in the illuminating value, are absorbed;

and these representing only a very small percentage of the heat-giving constituents of the gas, the loss is naturally a very slight one as regards the calorific value.

This point also shows the effect which various methods of enrichment have upon calorific value. If the candle power of a pure coal gas rises, it is because a larger percentage of illuminants from the coal is present, and at the same time that one gets an increase in the unsaturated hydrocarbons and a consequent increase in light, a *pro rata* increase is also obtained in the saturated hydrocarbons, such as methane, and consequently a relative increase in the heating value. But if a poor coal gas be enriched by adding to it, say, benzene vapour, the enrichment in candle power takes place without so great an enrichment in heating value. This is at once seen when one considers the relation between the light-yielding and the calorific values of such hydrocarbons as are present in the coal gas.

Description of Gas.	B.T.U.		Illuminating Value per 5 cubic feet.	B.T.U. per Candle.
	Gross.	Net.		
Methane . . .	1,024	919	5·2	984·6
Ethylene . .	1,603	1,510	70·0	114·6
Benzene vapour .	3,718	3,574	820·0	22·6

It is clear from this that if a coal gas be taken in which a large proportion of the illuminating power is due to the presence of methane and ethylene, for any given illuminating power, it must have a higher calorific value than when the illuminating power is due to the addition of benzene vapour.

If no method had been devised for burning coal gas with a non-luminous smokeless flame, little or nothing

would have been heard of coal gas as a domestic fuel, as the carbon deposited when a luminous flame is caused to impinge on a surface at a lower temperature than the flame itself would have been an unsurmountable objection.

In the historical researches which led to the discovery of the principle of the miner's safety lamp, Sir Humphrey Davy noticed that if ethylene or other gaseous hydrocarbon capable of burning with a luminous flame was allowed to escape from a jet placed a few inches below a piece of iron wire gauze, and was then ignited above the gauze, the flame was no longer luminous, and deposited no carbon upon substances held in it. As years passed by and coal gas asserted its position, some attempts were made to utilise it in burners for heating purposes. For scientific work these early burners were warmly welcomed in spite of their many failings, because, bad as they were, they yet had advantages over the spirit lamp, charcoal furnace, and oil lamp upon which the chemist up to that time had been dependent, but up to the middle of the nineteenth century only luminous gas flames were employed for this purpose.

It was at this epoch that Bunsen, the greatest of Heidelberg's great men, was planning and fitting those laboratories which have since then given so rich a harvest to the scientific world, and whilst considering the methods of heating which should be adopted on the working benches, his attention was called by one of his assistants, the late Sir Henry Roscoe, to Davy's experiment with the gauze and gas jet. Seeing at a glance the enormous convenience of such a source of heat, Bunsen brought his marvellous manipulative skill to bear upon the subject, and in a few weeks gave the world its "bunsen burner," a burner which has done more for the gas industry in the past thirty years than almost any discovery or invention connected with it; for it has made coal gas possible and successful for fuel purposes, and has enabled

it, in conjunction with the incandescent mantle, to hold its own against the threatened rivalry of the electric light.

The names of Davy, Bunsen, and Roscoe will always awaken in the mind a long list of benefits which their labours have conferred upon the world; but for practical utility the simple atmospheric burner will always remain one of the most successful achievements to be placed to their credit. Starting from the simple forms left to us by Bunsen, the skill and research of many workers in this branch of industry has given us convenient modifications in form for endless uses; whilst the utilisation of the atmospheric burner as the heat supply for the incandescent mantle has, during the last few years, given rise to many alterations and some improvements in producing the non-luminous flame in the most effective form.

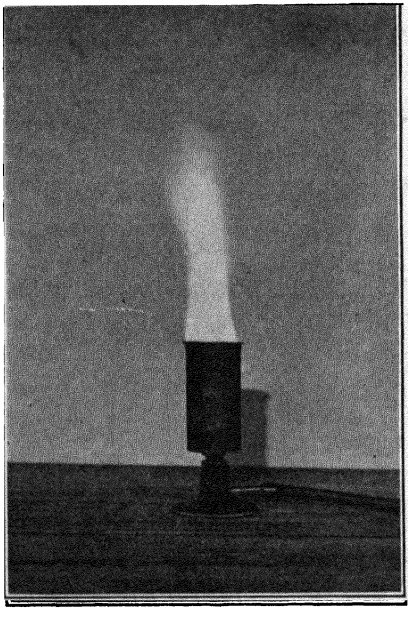


FIG. 29.—Original form of Bunsen burner.

In the early form of burner made by Bunsen the gas issued from either a flat flame or an argand burner head into a metal cylinder open at the bottom and closed at the top by means of a disc of fine wire gauze, so that the gas issuing from the burner head passed upwards through the air in the cylinder and mixed with it, the mixture burning on the top of the gauze. The difference between this class of burner and those which succeeded it was

that the uprush of the gas and its mingling with the air was due simply to the velocity with which it left the burner, and to the fact that the specific gravity of the gas is less than half that of air.

Very soon however it was found that a more rigid flame and one more easily under control could be obtained by utilising the pressure under which the gas was delivered at the burner to produce the effect of an injector, causing the uprush of the gas to drag the air in through side holes arranged in the bottom of a vertical burner tube placed above the gas nozzle. In order to do this a small jet or series of orifices discharged the coal gas into a small chamber surmounted by the upright burner tube, and either the walls of the chamber or the lower portions of the tube were perforated with an opening or openings in connection with the air. On opening the gas tap the coal gas is discharged through a jet with a velocity dependent upon the pressure of the supply, and rushing upwards and impinging upon the sides of the tube above, it acts in the same way as the steam in a Giffard's injector. By drawing up from the chamber the air which is present there it forms in it an area of low pressure, and so sucks in more air through the lateral holes to re-establish equilibrium; this action continuing, and the formation of the mixture of gas and air in the tube going on, as long as the gas continues to flow.

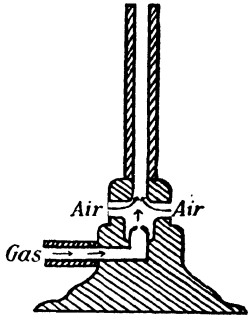


FIG. 30.—Section of Bunsen burner.

In this arrangement it is manifest that by regulating the size of the hole in the gas jet and the lateral air holes it is possible to adjust the mixture of gas and air formed in the tube with the greatest nicety, and to obtain a perfectly non-luminous and fairly rigid flame at the top of the burner.

After burners have been in use for some time, no matter how well they may be regulated at first, the partial stoppage of the injector tip by dust particles, and other causes acting upon the air supply, frequently deranges the ratio of the two supplies, and the result is that in a laboratory or other place where a large number of bunsen burners are used a wide discrepancy can be noticed in the flames given by the burners. In some the gas is burning with a slightly luminous top and the inner zone is barely visible: in others the normal conditions exist, and there is a well-marked violet inner zone and a non-luminous lilac outer zone: in others again the flame is somewhat shortened, showing a distinct greenish tint in the inner zone, with a pale lilac outer zone, and it is generally found that when this point has been reached the flame has more or less a tendency to roar, and will often show a tendency to flash back in the burner tube and ignite the gas as it issues from the jet.

These appearances all mark different ratios between the air and gas in the mixture passing up the tube. When one sees a slightly luminous tip it means that the gas is mixed with less than twice its own volume of air, whilst with the normal conditions obtained with the ordinary 16 candle gas, one volume of gas is drawing in 2·3 volumes of air: the violet inner zone begins to show a tendency to green when the ratio has become one of gas to 2·5 of air, whilst another tenth of a per cent. causes the green to become most marked, and the roaring to commence.

With the ordinary bunsen burner as used in the laboratory it is not possible to push the admixture of air and gas beyond this point, as the admixture of air and gas in the tube is now explosive, and the flame is only prevented from flashing back to the jet below by the rate of propagation of the explosive wave being less than the upward rate of flow of the mixture, and any further increase in the quantity of air present increases the rate of the explosive wave, and so

causes flashing back. If however the head of the burner tube be covered with a layer or layers of fine wire gauze, the power of conduction which the fine metal filaments possess, and the fact that they reduce slightly the area of the tube, and so increase the rate of flow through the orifices of the mesh, prevents the downward propagation of the wave, and under these conditions the ratio of air to gas can be raised to over three volumes of air to the one volume of gas; the green zone shrinks down on to the surface of the gauze, and shows itself as a seething layer in which the green colour has reverted to a very pale blue.

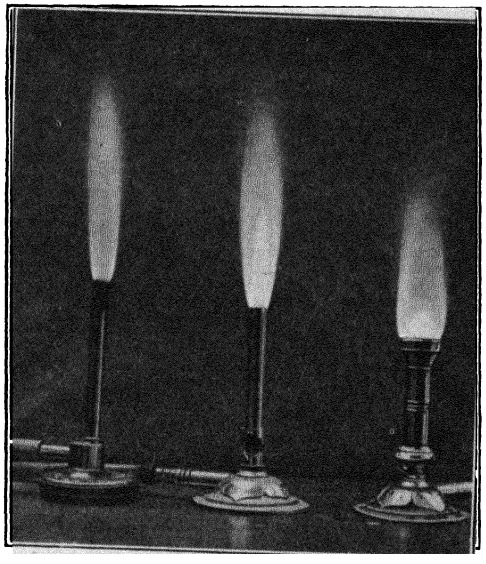


FIG 31.—Bunsen flames.

The importance of the regulation of the ratio between the gases having been recognised, the air holes in most of the burners used for laboratory and heating purposes were then fitted with cut-off rings, consisting of loose rings of metal with holes in them, which could be slid round over the holes in the side of the chamber, so that when the two sets of holes coincided the full air supply could be obtained, whilst by drawing the solid metal of the ring more or less over the under holes, the area of the air supply could be reduced. In this way it was possible to adjust the condition of the flame to the work required of it.

It will be evident that it will be the admixture of air with the coal gas before combustion that causes the production of a non-luminous flame, and the old theory to account for this phenomenon was that the oxygen burnt up the hydrocarbons in the gas before their decomposition set free any solid particles of carbon to render the flame luminous. Knapp and others, however, showed that oxygen was not necessary for the production of a non-luminous flame, but that the luminosity could be destroyed by diluting the gas before combustion with such non-inflammable and inert gases as nitrogen, carbon dioxide, and steam, and the experiments of Blochmann, Landolt, and Heumann showed that nitrogen in the air sucked in by the burner also played a most important part in the action.

The relative importance of the oxygen and nitrogen in rendering the flame non-luminous can be readily determined experimentally by taking a bunsen burner, fitted at the bottom of the tube with two supply pipes instead of the ordinary gas jet and lateral air holes. Each pipe is connected with a small meter, so that the flow of gas and air can be measured. The amount of air required to render the flame non-luminous was found to be 13·5 volumes of air for 6 volumes of gas; and 13·5 volumes of air contain roughly 2·7 of oxygen and 10·8 of nitrogen. When 6 volumes of coal gas are passed into the burner with 10·8 volumes of nitrogen, a flame is obtained which has only a slightly luminous tip, whilst with 2·7 volumes of oxygen and 6 volumes of coal gas a luminous flame is obtained which flashes back unless the burner is provided with a gauze top.

A bunsen burner burning coal gas alone gave on the photometer with 5 cubic feet per hour 5·6 candles, but with the addition of 2·2 cubic feet of oxygen 3·1 candles; using nitrogen, however, in the proportion of 9 cubic feet to 5 cubic feet of gas the luminosity was so feeble that it

could not be read. It follows, therefore, that the amount of oxygen in the air necessary to destroy the luminosity does less than one-half the work. On making another experiment with varying amounts of oxygen, the results obtained are as follows:—

	Candle Power.
5 cubic feet of gas alone	5·6
5 ,, ,, to 1·1 oxygen	5·4
5 ,, ,, to 1·5 ,,	8·0
5 ,, ,, to 2·2 ,,	3·1 (gauze used)
5 ,, ,, to 2·5 ,,	0·0 (,,)

With a coal gas flame burning at the rate of 6·2 cubic feet per hour it is found that 14·2 cubic feet per hour of nitrogen are necessary to bring about complete non-luminosity by dilution only, an amount which is practically the same as that of the air required in the previous experiment.

1 vol. of gas required 2·30 vols. of nitrogen
1 ,, ,, 2·29 ,, of air

This seems to show that the oxygen acts merely as a diluent, but if this were so then mixtures of oxygen and nitrogen containing a larger percentage of oxygen than ordinary air should have the same effect on the luminosity of flame as air, but this is disproved by the results shown on p. 200.

From this it will be seen that until the percentage of oxygen reaches the amount present in air, the diluting influence of the nitrogen overpowers the effect of the oxygen in the destruction of the luminosity, but with 25 per cent. and over of oxygen the retarding influence of the nitrogen has no effect on the activity of the oxygen.

The effect of various gases in bringing about non-luminosity was then tried, but the employment of a wet

VOLUMES OF VARYING MIXTURES OF OXYGEN AND NITROGEN REQUIRED TO RENDER ONE VOLUME OF COAL GAS NON-LUMINOUS IN A BUNSEN BURNER.

Gas Volume.	Volume of Mixture required.	Composition of Mixture.		Volume of Oxygen present in amount required.
		Nitrogen.	Oxygen.	
1	2·30	1	nil.	nil.
1	2·30	5	1	0·38
1	2·27	4	1	0·45
1	2·02	3	1	0·50
1	1·49	2	1	0·50
1	1·00	1	1	0·50
1	0·50	nil.	1	0·50

meter for measuring purposes rendered the number of these limited.

Volume of Gases required to render One Volume of Coal Gas non-luminous.

1 vol. of coal gas	requires	0·50	vol. of	oxygen
1 „	„	1·26	„	carbon dioxide
1 „	„	2·27	„	air
1 „	„	2·30	„	nitrogen
1 „	„	5·11	„	carbon monoxide
1 „	„	12·40	„	hydrogen

So that a combustible diluent which increases the temperature of the flame is required in far larger quantity than a non-combustible diluent in order to render the flame non-luminous.

The varying effects of diluents have been attributed to the influence of density, but it has been shown by Heumann that a flame can be rendered non-luminous by cooling as well as by dilution. If a luminous flame be caused to spread itself over a cold surface it becomes non-luminous, but the luminosity can be restored by heating the surface

over which the flame plays. If, therefore, a diluent had the power of extracting more heat from a flame than another, it would be more active in reducing the luminosity, so that a smaller quantity would be required to render the flame non-luminous. On comparing the specific heats of the gases used in the last experiment the reason for the small quantity of carbon dioxide is at once seen:—

	Specific Heats of Equal Volumes.
Oxygen	0·2405
Carbon dioxide	0·3307
Nitrogen	0·2370
Air	0·2374
Carbon monoxide	0·2370
Hydrogen	0·2359

Experiments show that this is in all probability the true explanation, as in the flames rendered non-luminous by diluents the inner cone for the first $1\frac{1}{2}$ inch is decidedly cooler than in the luminous flame, owing to the cooling action of the nitrogen or carbon dioxide. Above this point, however, the influence of the oxygen begins to be felt, and the non-luminous flame is here hotter than the luminous flame, whilst the hottest portion of the flame is to be found half-way between the tip of the inner and outer cones. With inert diluents, however, the hottest points are found at the side and tip of the outer cone, where the air necessary for the combustion is obtained.

With a bunsen burner in which the mixed gas and air give a green inner cone, although a low temperature, due to the excess of air, is found at the bottom of the inner cone, yet the increased quantity of oxygen causes a rapid oxidation in the upper portion, and a smaller and hotter flame is produced.

From these experiments and also from the researches of

Heumann, it will be seen that several causes aid in the destruction of luminosity in a flame, chief amongst which are oxidation, dilution, and cooling.

The chemical changes taking place in the bunsen flame are far more simple than those which are going on in the luminous flame. Taking an ordinary coal gas having the composition—

Hydrogen	52·16
Unsaturated hydrocarbons	3·50
Saturated hydrocarbons	36·25
Carbon monoxide	3·68
Carbon dioxide	0·00
Nitrogen	4·10
Oxygen	0·31
Sulphuretted hydrogen	0·00
	100·00

It is found that the gas of this composition requires from 5 to $5\frac{1}{2}$ times its own volume of air for its complete combustion When a bunsen burner burns with a blue non-luminous flame, the ratio of air to gas is about 2·3 to 1, less than half the amount necessary to complete combustion' whilst the the green inner cone 2·5 of air mix with 1 of gas. The bunsen flame obtains from the mixture, therefore, only about one-half the air necessary for its complete combustion, the remaining portion being obtained from the exterior of the flame during combustion. This is the cause of the double cone in the flame, the inner cone being caused by the incomplete combustion of the gas with the admixed air, and the outer cone by the combustion of the products of this incomplete combustion by means of the external air. This can be proved by the use of an apparatus devised by Mr. Lewis T. Wright and perfected by Professor Smithells, in which the two parts of the flame can be separated.

The apparatus consists of a glass tube, about 16 inches long and about 1 inch in bore; over the bottom end is a piece of rubber tubing through which slides easily an inner glass tube 20 inches long, kept central with the outer tube by a ring of brass carrying three outspreading springs. Both tubes at their tops are surrounded by a ring of platinum foil to prevent the heat of the flame cracking the glass. The lower end of the inner tube is placed over a bunsen burner, and the gas turned on and lighted at the top of the tubes, the tops of the tubes being level. The flame is much shorter than the ordinary bunsen flame and of a greenish colour. If now the outer tube is raised, bringing its mouth above the top of the inner tube, the outer cone of the flame will be lifted away from the inner, which latter will continue to burn at the orifice of the inner tube. On altering the ratio of either the gas or the air, the inner flame can be made to ascend to the mouth of the upper tube, or recede down the inner tube to the bottom; with increase of gas the inner flame ascends, and with increase of the air supply it descends.

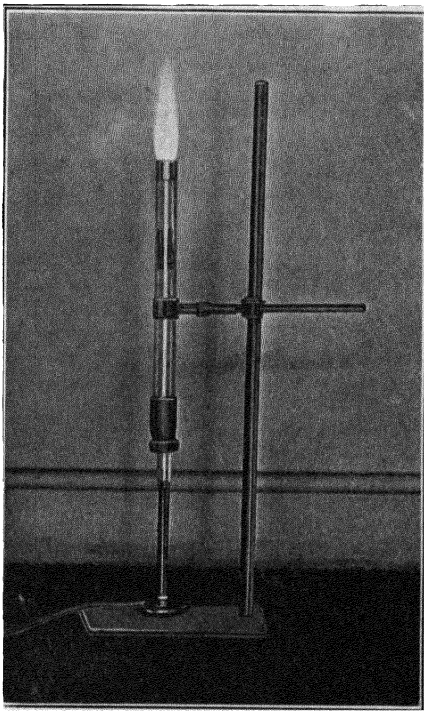


FIG. 32.—Smithells' tube—central cone in position.

The dual action of the flame is practically complete when

the ratio of air to gas is 2·6 to 1, when the green cone is produced. The action of the mixture in the inner cone may be approximately expressed by the following equations :—

Hydrogen.		Oxygen.		Water.
H_2	+	O	=	H_2O

Ethylene.		Oxygen.		Carbon monoxide.		Water.		Hydrogen.
C_2H_4	+	3 O	=	2 CO	+	H_2O	+	H_2

Methane.		Oxygen.		Carbon monoxide.		Water.		Hydrogen.
CH_4	+	O_2	=	CO	+	H_2O	+	H_2

The resulting carbon monoxide and hydrogen in about equal proportions diluted with twice the quantity of steam and the unchanged nitrogen burn at the expense of the oxygen of the external air, forming the outer cone. A small quantity of carbon dioxide is also always found, probably due to the oxidation of some of the carbon monoxide by the steam, and the gaseous mixture which forms the outer cone has the approximate composition of :—

Water vapour	16
Nitrogen	60
Carbon monoxide	9
Hydrogen	10
Carbon dioxide	5
	100

It does not seem possible that such a mixture, containing as it does less than 20 per cent. of combustible gas, should burn and produce the intense heat found in the outer cone of the bunsen burner. But Professor Smithells has shown that under ordinary conditions the heat of the inner cone is added to that of the outer, so that in the combustion the outer cone is always hotter than the inner.

That this is so can be clearly shown by using the Smithells tube, and having widely separated the two cones

of the flame, holding an incandescent mantle in the outer zone. The mantle is not then heated to incandescence, but on now allowing the inner cone to rise in the tube the mantle becomes more and more luminous until the zone has reached its proper position in the centre of the flame, when the mantle gives its full incandescence.

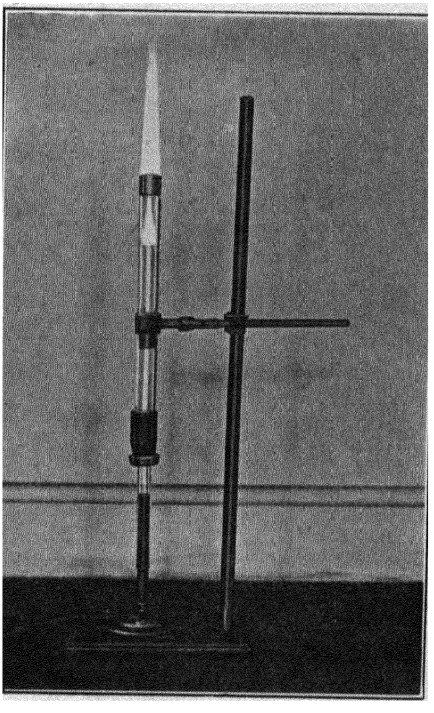


FIG. 33.—Smithells' tube—cones separated.

It is clear that the temperature of the flame must be to a very great extent governed by the degree of oxidation due to air drawn in by the gas, as this governs the size of the flame. A mixture of coal gas and air which is under-aerated forms a longer flame than one which contains more atmospheric oxygen, as the flame has to travel further before it can obtain from the air the surplus oxygen to complete its combustion, and it must be clearly borne in mind that as long as combustion is complete, a cubic foot of gas burnt either as a luminous flame, or an under-aerated, or fully aerated bunsen flame, gives the same total of heat, but the bunsen flame is hotter than the luminous flame because the combustion is quicker, the flame therefore smaller, and the intensity greater.[1]

The best method for measuring the temperature of flames

[1] See note (13) on p. 222.

that is practically available is the thermo-couple, devised by Le Chatelier, and although it is open to certain objections as a recorder of absolute temperature, still when properly used it gives a nearer approximation to the truth than any other method of measurement.

In this instrument the measure of the electromotive force developed by the rise in temperature of a junction of two dissimilar metallic wires is utilised, and affects a "dead-beat" galvanometer in circuit with the couple. The

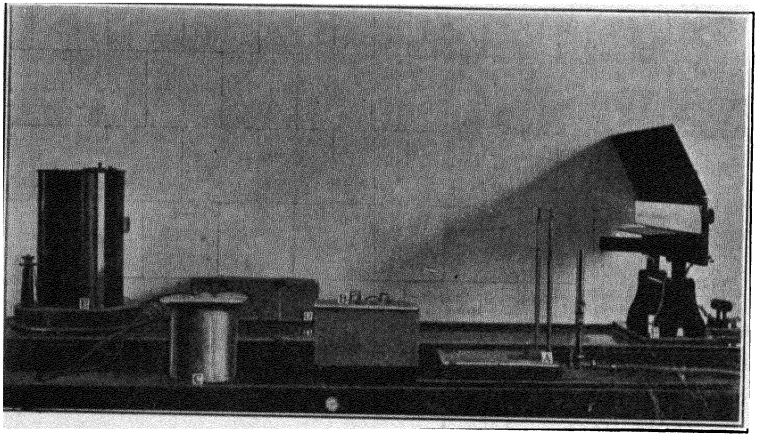


FIG. 34.—Le Chatelier's thermo-couple and arrangement.

wires best suited for the purpose are composed one of platinum and the other of platinum alloyed with 10 per cent. of rhodium, the thickness of each being about 0·4 to 0·5 millimetre. The galvanometer *B* is of very sensitive character, and the moving coil carries a small mirror, which serves to reflect a beam of light from a lamp on to a scale at *F* placed at the focus of the mirror, a distance generally of about a metre. In front of the lamp is a tube with cross wire, so that the shadow of this wire is projected on to the scale in the centre of a disc of light. In this way the smallest movement of the galvonometer coil is magnified

and rendered visible by the travel of the spot of light on the scale. The galvanometer and lamp are so adjusted that when at rest the line of the cross wire rests at zero in the centre of the scale. On subjecting the junction of the wires *A* to heat a current of electricity is generated, which increases with rise of temperature, and this small current affects to a greater or less degree the moving coil of the galvanometer.

The junction of the wires is best made by fusing together the ends in an oxy-hydrogen flame, so as to form a minute bead ; the circuit includes a definite resistance *B* (to keep the spot of light within the limits of the scale) and a reversing switch *C*, the latter being used in order to obtain readings on both sides of the scale from zero, the mean of the two readings being taken as correct. All joints of the connecting wires should be soldered and kept at a uniform temperature, otherwise opposing currents might be set up which would vitiate the results.

To calibrate the thermo-couple various substances are employed whose melting points are accurately known, and from the results so obtained the temperature curve of the junction can be plotted out.

The substances usually employed, together with their boiling or freezing points, are given in the following Table :—

	Boiling.	Freezing.
Water	100°C.	
Naphthalene . . .	218	
Sulphur	445	120°C.
Tin		232
Zinc		419
Silver		962
Gold		1065

In order to protect the couple from any action which the materials used might have upon it the wire and junction

can be encased in thin glass tubes, made by drawing out a piece of wider bore. With substances whose boiling point is desired, the couple is immersed in the vapour above the liquid and out of range of any chance splashings, whilst with metals the material is melted in a small crucible, and the protected couple sunk well below the surface to about the centre of the mass. The heating flame is withdrawn, and the disc of light on the scale carefully watched; the disc gradually descends, remains stationary for some few seconds, and then continues to descend, or makes a sudden rise. The point at which the disc remains stationary is the freezing point of the substance under test. The points obtained by standardising with these materials are plotted on squared paper, and should approximate or fall on a straight line drawn from the lowest to the highest temperature used.

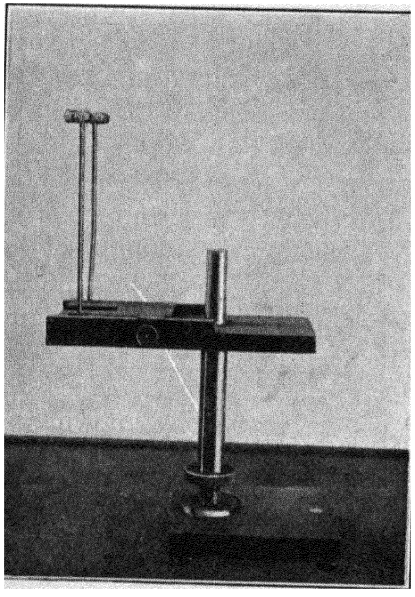


FIG. 35.—Holder for thermo-couple.

In utilising the thermo-couple for the determination of temperatures in various parts of a flame, various corrections must be made and precautions taken, such as allowing for radiation of heat at the junction, whilst in order to avoid as far as possible any disturbance of the flame it is necessary to use wires of the smallest diameter that will stand the heat of the flame. The stand shown in Fig. 35 will be

found of great use for work of this kind. It consists of a stout metal pillar, which is threaded to carry a large milled nut, and over which slides a metal tube having a table fixed to it. On this table are the clamps between which lies the thermo-junction with its wires horizontal, the clamps being mounted on a horizontal slide. In this way the junction can be given vertical as well as horizontal movement, and by attaching scales to the rising table and the clamps - slide any definite point in the flame can be arrived at.

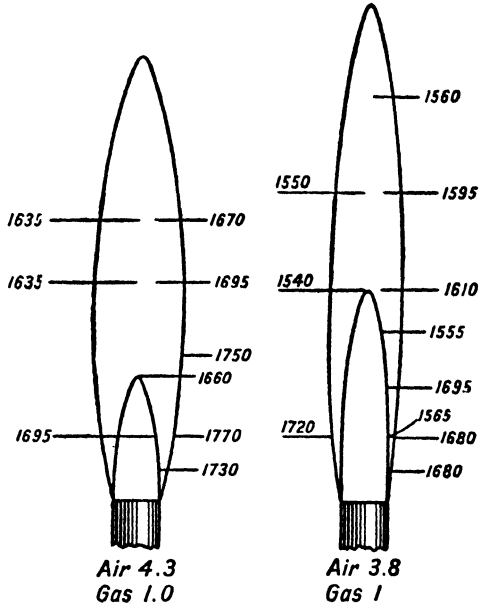


FIG. 36.—Temperatures in Bunsen flame with different aeration.

When the temperature existing in a bunsen flame is mapped out by the Le Chatelier thermo-couple with all possible precautions the general range of temperature is found to vary with the degree of aeration as shown in Fig. 36.

So far only upright bunsen or atmospheric burners have been mentioned, but for cooking and heating many modifications have been introduced, such as ring burners and slot burners, in which the gas is generally injected horizontally, drawing in air from an air port in the under side of the burner tube.

In all forms of atmospheric burner careful regulation of

the air port is one of the chief essentials for successful working, and as the quantity of air required varies with the composition of the gas used, many burners are fitted with ring baffles, by which the air port can be altered to the dimensions necessary to give the best results.

From the point of view of health, cleanliness, convenience and comfort, gas is immeasurably superior to coal for fuel purposes. Not only would the general adoption of coal gas as a fuel do away with the heavy pall of smoke which hangs over a big town and prevents the sun's rays from carrying out the beneficent work which Nature intended them to perform, but it would also reduce to a minimum the number of fogs from which a big town suffers, and would in this way quickly reduce the death rate due to lung diseases.

The only point which militates against the use of gaseous fuel is the assumption that it is much more expensive than solid fuel, and, if the cost of the thermal units developed by ordinary bituminous coal and by coal gas be calculated out, coal has a very substantial advantage.

A good bituminous coal cannot now be obtained in London under ordinary conditions for less than 58*s.* 6*d.* per ton, and at this price one pound would cost 0·313 of a penny, and would have a calorific value of 15,000 B.T.U.

Taking now an average coal gas yielding 450 B.T.U. per cubic foot, and costing 4*s.* 6*d.* per 1,000, it is clear that $33\frac{1}{3}$ cubic feet of the gas will contain the same heating value as one pound of the coal, and will cost six times as much, *i.e.*, 1·8 of a penny for the $33\frac{1}{3}$ cubic feet. It does not by any means follow from this, however, that heating by gas will be six times as costly as heating by coal, for this will largely depend upon the efficiency of the stoves used and the way in which the heat is imparted to the air of the room.

Gas stoves may be classified in three groups—

1. Flueless stoves, in which the products of combustion

either before or after condensation of water vapour are discharged into the air.

2. Radiant heat stoves, in which refractory bodies are heated to incandescence, and the heat is radiated into the room, the hot products and some unburnt gases escaping by flue.

3. Stoves of the same kind as Group 2, but in which by means of air chambers, regeneration, or passing the products through a length of metal pipe, most of the heat is withdrawn from the products of combustion before discharging into the flue.

In the first class of stoves all the heat of the burning gas passes into the air of the room, and practically the whole of the heating is done by hot air and convection.

In the second class of stoves the heat is mostly discharged into the room by radiation, whilst in the third class both radiation and air-heating come into play.

There is not the slightest doubt, from a hygienic point of view, that heating by radiation is infinitely preferable to effecting the heating by warming the air, and this is one of the factors that make the English open fire so superior in comfort to the closed stoves and other air-heating devices so popular on the Continent.

A good gas stove, like the open fire, should not depend too much for its heating effect upon discharging warm air into a room, but should distribute a considerable proportion of its heat by radiation, and so raise the temperature of the floor and furniture in the lower parts of the room.

Radiant heat does not directly raise the temperature of the air, but is radiated to the floor, walls, and furniture of the room, which again slowly part with their heat to the air in contact with them and to the occupants, so that the walls and other solid bodies in the room are at a higher temperature than the air.

Apart from its being much more healthy to breathe cool

than hot air, there is another important point to consider. The normal temperature of the body is 98°F., or 36.8°C., and this temperature is maintained by the slow combustion processes going on in the body. By the laws of radiation a heated surface parts with its heat more or less rapidly according to the temperature of the surrounding bodies, so that if a person be sitting in a room filled with warm air, but near a wall colder than the air, his body will rapidly part with heat by radiation to the wall, and a sensation of chill is the result. But with the open fire this is never the case, as the radiant heat from the fire heats the walls of the room to a temperature higher than that of the air. When however a room is heated by means of warm air the walls not being heated in the same proportion, though the air may feel warm, the walls will remain cold: so that the heat of the body would pass by radiation to the walls and give rise to a chill.

When gas stoves were first introduced the desire of the manufacturers was to as nearly as possible imitate the open stove, and this was done by filling the existing fire-grate with balls made of fireclay, asbestos lumps, or other refractory material, and heating this mass to as high a temperature as possible by means of a series of atmospheric burner flames arranged along the bottom of the front of the grate. This method, however, was found very wasteful of gas, as most of the heat went up the chimney, and the gas stove was then made to stand in front of the grate with a short tube and elbow discharging the products of combustion into the chimney, whilst a row of six or eight atmospheric burner flames played upon asbestos fibre, refractory metal work, or asbestos fireballs in such a way as to heat the material to a temperature at which it would radiate its heat into the room.

Whenever an atmospheric flame is used to heat substances like asbestos in a gas stove, a considerable percentage of

inflammable products of incomplete combustion escape unburned, and that this is so may be seen by disconnecting the stove from the short flue pipe that leads into the chimney, and after the gas has been burning a short time in the stove, and the exit pipe has become hot, the products of incomplete combustion will burn at the exit with a pale blue flame, unless the gas supply has been very carefully regulated, which is hardly ever done by the consumer. The effect of these products on health will be fully discussed under gas cookers and water heaters, but it is now thoroughly recognised that it is impossible to do away with the products of incomplete combustion as long as the heating flame is brought in contact with any surface cooler than itself. In other words, the only way to get complete combustion is to allow the flame to burn itself out without contact with any other body, and the only forms of stove in which this has been attempted were those in which flat luminous flames were burned in the top of the stove, and the light and radiant heat were reflected out into the room by a concave copper reflector placed below the flames. The amount of heat, however, radiated by a luminous flame burning under ordinary circumstances was so small that this form of stove was never very efficient, but when regeneration was also used, a very fine result was obtained.

Many forms of stove which heat the room rapidly depend on either hot air chambers or a certain length of flue between the stove and the flue, in order to utilise a proportion of the heat which would otherwise escape up the chimney, but such stoves have two important drawbacks. In the first place, the thin iron of which the flues or air chambers are made soon gets heated to a high temperature, and under these conditions carbon monoxide, which is the most deleterious of the products of incomplete combustion, freely diffuses through it and escapes into the room, vitiating the air and quickly giving rise to a feeling of oppression

and headache. This principle therefore should only be used for stoves in which flame burns unchecked, and where consequently combustion is perfect. Secondly, the largest part of the heating is effected by warming the air of the room, and not by radiant heat, which is wrong.

Whatever views may be held on the subject, the author feels very strongly that the idea that some forms of stove can be used without being attached to a proper flue is not only dangerous to health, but also militates against the use of gas as a fuel, by encouraging the idea that gas stoves are unpleasant and unhealthy as sources of heat. It cannot be insisted on too strongly that a gas fire whether used for heating or cooking must be connected with a flue, as the products of combustion are just as deleterious, if not so dirty, as those given off by the combustion of solid fuel.

The author has on many occasions protested against the sale of flueless stoves, but freely admits that in spite of protests and preachings they continue to flourish, and have indeed multiplied in number more than any other form of gas heater. Some of these stoves are small stoves of the ordinary types, whilst others, known as condensing stoves, are so arranged as to condense the water formed by the combustion of the gas, and the makers gravely assure the public that this removes all deleterious products. The popular idea of a deleterious product is something that has an offensive taste or smell, or that in a very short space of time seriously affects the health, and if this view be accepted then the makers of these stoves have a modicum of truth in their statement, as the condensing water removes some of the products of the combustion of the sulphur in the gas, and where the gas used is exceptionally foul this prevents a certain amount of discomfort. The ventilation of our rooms, however, is never too perfect during the periods that necessitate the use of the gas stove, and the fact cannot be got away from that each cubic foot of gas burnt forms

half a cubic foot of carbon dioxide, none of which is taken up by the condensing water. This gas moreover is discharged near the floor of the room, and being fairly cooled before leaving the stove mingles with the air in the lower portion of the room instead of rising, as the products from an exposed flame do, straight to the ceiling space.

A long series of experiments was made upon the relative efficiency of a number of gas stoves which experience had shown to be the ones most in demand by the public. To make any such determinations of value it was necessary that the experiments should be carried out with every care as to exactitude in measurement of the gas consumed and of the increase in temperature, and yet to have the conditions such as would be found in practice. The room selected for the experiments was 17 feet 4 inches by 15 feet 7 inches, and 11 feet 1 inch high, giving a cubical capacity of 3,032 cubic feet. It had three windows and one door, the latter being opened twice in the hour to allow the observer to pass in and out during the test, this and all other operations being conducted in such a way as to make the tests strictly comparative.

All stoves with flues tested were fitted exactly as they would be arranged when fixed by an experienced fitter, *i.e.*, the opening of the fireplace was closed by a metal plate through which the elbows from the gas stoves passed, and the thermometers were arranged in different parts of the room, so as to give the temperatures at various distances from the stove from the floor level and at each two feet up to the ceiling.

In testing these stoves the gas supplied to them was carefully measured by an accurate meter, and the temperatures in the room were taken every hour over a period of five hours. Two tests were in this way taken of each stove, but only one test was taken on each day, so as to

allow the temperature of the walls and atmosphere of the room to reach its normal condition again. The tests for each stove were found to differ but little among themselves, and the results taken were the mean of two sets of tests.

The conditions aimed at in the tests were that the stoves should raise the temperature of the room at least 6° F. above the outer air temperature in the first hour, and that there should be a total increase of 13° F. in five hours, every care being taken to so select the time of experiments as to eliminate any differences in outside temperature likely to invalidate the tests.

The first tests made were to ascertain the proportion of heat lost owing to the form of stove used. When a room is being warmed by any form of stove, heat is lost by—

1. Hot products of combustion and unburnt products of incomplete combustion going up the flue.
2. Absorption of heat by the walls of the room.
3. Hot air removed by ventilators and cool air brought in.
4. Leakage from doors and windows.

The last three factors of loss are due to the room itself and will act practically equally with solid or gaseous fuel, whilst the amount of heat escaping up the chimney is largely dependent upon the construction of the stove.

It was found that with the flueless stoves, as might be expected, the whole of the heat was utilised, and that it did not in the least matter whether the gas was burnt in a flat flame or a bunsen burner near the floor level, or whether it was consumed in a regenerative or condensing stove of the most costly and complicated pattern; in all cases the result was the same, and if the user does not mind hot foul air and injury to his health a few bunsen burners on the floor is the most effective form of stove that can be used.

With all the flueless stoves the test conditions were

satisfied with a consumption of 70 cubic feet of gas in the 5 hours, or 14 cubic feet per hour.

It is this high efficiency that accounts for the popularity of this class of stove, but it cannot be too strongly urged upon the public to use them only in halls, passages, or workshops, where ample ventilation can be relied upon, and never under any condition to admit them to the dwelling rooms of a house.

The second class of stove, which did the main portion of the heating by radiant heat, and which from the hygienic standpoint is undoubtedly the best, was next tested, and it was found that in order to get the desired result with the best stoves of this class, the gas consumption had to be raised to 40 cubic feet per hour, or 200 cubic feet in the five hours.

This result, which was amply verified by check experiments, showed such an enormous waste of heat that careful tests were made to see how the heat was being distributed, and it was found that with this class of stove only 35 per cent. of heat found its way into the room, the remainder escaping up the chimney, 49 per cent. as heat in the products of combustion and draught through the grate, and 15 per cent. as unconsumed products of incomplete combustion.

The last class of gas stoves, in which by air chambers, regenerators, and other devices the heat escaping from the incandescent area in the front of the stove is utilised to heat air supplied to the room before the products escape to the chimney, were, as might be expected, found to be the most variable, the worst needing a gas consumption of over 30 cubic feet per hour, and the best 16 cubic feet per hour to fulfil the standard requirements.

Having in this way determined the amount of gas required by the various classes of the gas stove, it was necessary to find how much coal would be used under

normal conditions to give the same thermal results in the test room.

Consuming bituminous coal in a grate of the ordinary construction, and of the kind used in certainly 90 per cent. of our homes, it required an average of 7 lbs. of coal per hour to raise the temperature to the same extent as with the gas stove. We must not lose sight of the fact, however, that with the newest and best forms of open grate using solid fuel, the coal consumption can be reduced from 7 lbs. to 4 lbs. per hour to give the same effect.

It is now possible to contrast the cost of heating by means of coal and coal gas respectively per hour.

Coal Gas at 4*s.* 6*d.* per 1,000.			Coal at 58*s.* 6*d.* per ton.		
	Gas c. ft	Cost Pence.		Coal Pounds.	Cost Pence.
Radiating stove.	40	2·16	Ordinary stove.	7	2·19
Radiating and regenerative .	16	0·86	Newest forms .	4	1·25
Flueless stoves .	15	0·81			

So that, taking London prices in 1920, the best form of gas stove is cheaper with gas at 4*s.* 6*d.* per thousand than the old forms of coal stove.

The initial consumption of coal to give the necessary increase in temperature is greater than with gas; and the saving in waste of fuel secured by being able to turn off the gas when the temperature is too great, or when the fire is done with, practically obliterates the difference in cost even with the radiating gas stove, when intermittent and not continuous heating is required; whilst with rooms used only for an hour or two in the day, gas is cheaper than coal as a fuel.

It must always be borne in mind that the radiating gas

stove, although it utilises only 35 per cent. of the heat of the gas in warming the room, yet like the even more wasteful coal fire, does its work in the right way, and is a powerful factor in ventilation by causing a strong up-draught in the chimney.

The great fault with most of the stoves on the market is the high gas consumption, many of them using from 30 to 50 cubic feet of gas per hour, and this, by unduly swelling the consumer's gas bill, creates a prejudice against the use of gas as a fuel; but there is an immense future for a good stove consuming 12 to 15 feet per hour, and advances are being made in this direction.

In constructing gas stoves, care must be taken not to cool the products of combustion too far before they discharge into the flue, as if the temperature is reduced below the boiling point of water, although a slight increase in heat is obtained, water is condensed, and taking up the sulphur oxides produced from the carbon disulphide vapour in the gas forms a highly corrosive liquid, which rapidly eats away the metal work of the connecting flue to chimney, and corrodes the iron work of the back of the stove.

Gas cookers are daily becoming more firmly established, and the early prejudices against them having been overcome by experience, their convenience and economic advantages are leading to their almost universal adoption. Where they are extensively used a ventilating shaft with a good up-draught should be in connection with a hood a few feet above the stove, for there is one phase in the use of gas fuel which should never be overlooked, namely, that if a cold substance, metal or non-metal, be placed in a flame, whether it be luminous or non-luminous, it will be observed that there is a clear space in which no combustion is taking place formed round the cool surface, and that as the body gets heated this space gets less and

less until, when the substance is at the same temperature as the flame itself, there is contact between the two. Moreover, when a luminous flame is employed in this experiment the space still exists between the cool body and the flame; but you also notice that the luminosity is decreased over a still larger area, although the flame exists.

This means that in immediate contact with the cold body the temperature is so reduced that the flame cannot continue burning, and so is extinguished over a small area; whilst over a still larger space the temperature is so reduced that it is not hot enough to bring about decomposition of the heavy hydrocarbons, with liberation of carbon to the same extent as in the hotter portions of the flame. Inasmuch as when water is heated or boiled in an open vessel the temperature cannot rise above 100° C., and as the temperature of an ordinary flame is over 1,600° C., it is evident that the burning gas can never be in contact with the bottom of the vessel, or in other words the gas is put out before combustion is completed, and the unburnt gas and products of incomplete combustion find their way into the air and render it perfectly unfit for respiration.

The portion of the flame which is supposed to be the hottest is about half an inch above the tip of the inner cone of the flame, and it is at this point that most vessels containing water to be heated are made to impinge on the flame; and it is this portion of the flame also which is utilised for raising various solids to a temperature at which they will radiate heat.

In order to gain an insight into the amount of contamination which the air undergoes when a geyser or cooking stove is at work the composition of the products of combustion was determined, and also of the unburnt gases escaping when a vessel containing water at the ordinary temperature is heated to the boiling point by a

gas flame, the vessel being placed, in the first case, half an inch above the inner cone of the flame, and in the second at the extreme outer tip of the flame.

GASES ESCAPING DURING CHECKED COMBUSTION.

	Bunsen Flame.		Luminous Flame.	
	Inner.	Outer.	Inner.	Outer.
Nitrogen . . .	75·75	79·17	77·52	69·41
Water vapour . .	13·47	14·29	11·80	19·24
Carbon dioxide . .	2·99	5·15	4·93	8·38
Carbon monoxide. .	3·69	nil.	2·45	2·58
Methane . . .	0·51	0·31	0·95	0·39
Acetylene . . .	0·04	nil.	0·27	nil.
Hydrogen . . .	3·55	0·47	2·08	nil.
	100·00	100·00	100·00	100·00

These figures are of the greatest interest, as they show conclusively that the extreme top of the bunsen flame is the only portion of the flame which can be used for heating a solid substance without liberating deleterious gases.

The best forms of geyser and other heaters of water in quantity are those in which the combustion of the flame is completed out of contact with the surface to be heated, and the hot products of completed combustion used to do the heating.

The internal combustion engine, in which the fuel may be either sprayed hydrocarbons, volatilised hydrocarbons, or gases, has made such enormous strides forward during the past quarter of a century that it threatens the very existence of the steam engine; but unfortunately, although coal gas forms the ideal fuel for use in this direction, it cannot compete in price with producer gas as at present made in suction plants for gas engines of large size; but

in cramped manufacturing districts in a big city, and for engines not exceeding 100 H.P., there is so little room available for a producer that coal gas more than holds its own. The consumption for power purposes now bulks largely in the use of coal gas; and if the cost of its production could be reduced so as to bring the selling price for power down to 2*s*. per thousand, it would enter into brisk competition with the true fuel gases owing to the convenience of having it as a constant supply.

(13) This principle is made use of in the patented Méker gas burner, which gives a small but intensely hot flame. The effect is produced by constructing the burner on the usual bunsen principle, but with very much larger air ports or openings at the base of the mixing tube, in relation to the gas openings.

The result is that the gas is fully aerated before it reaches the top of the mixing tube. Lighting back is prevented at this point by a plug of metal, drilled with a number of gas channels and fitting tightly in the mouth of the mixing tube. The heat conducted away by this mass of metal prevents the flame striking back to the gas mixture which is contained in the tube below, even if the pressure should fall below that required to maintain the flow of gas and air through the plug, at a higher rate than the speed of the explosive wave.

The burner is remarkably efficient, and by its use many laboratory fusions, etc., can be carried out, which formerly required a blow-pipe.

CHAPTER VIII.

WATER GAS.

The history of water gas—The European water gas plant—The introduction of carburetted water gas—Thermal considerations in the manufacture of water gas—Blow and run processes—Dellwik water gas—Chemical actions taking place in the generator—The application of water gas—The Kramers and Aarts process—Carburetted water gas—The early forms of plant—The Lowe process and its recent modifications—The Humphreys-Glasgow system—The poisonous properties of water gas—Carburetted water gas as a diluent and enricher of coal gas—Blue gas as an adjunct to coal gas works—Various methods by which it is used—Auto-carburetting—"Tully's C.H. carbonising plant."

THE history of nearly all commercial processes shows us how rarely success is at once attained, the skeleton cupboard of the manufacturer containing many gruesome records of hard-fought struggles and failures before the discovery of some small alteration in the process has elevated it from the depths of mediocrity to the heights of success; and history affords no better illustration of this than the present position of water gas.

The latter half of the eighteenth century, which was so rich in scientific discovery, saw the first recognition of the fact that when steam is passed through red hot carbon in any of its many forms, an inflammable gas is produced. This discovery is generally attributed to Fontana, and the fact was certainly well known to Lavoisier and the brilliant band of scientists whose labours will ever render this period one of the most notable in scientific history, but it was not until 1824 that any attempt was made to adapt the action to commercial requirements. In this year

Mr. Ibbetson conceived the idea that the volume of illuminating gas could be largely increased by passing steam through the red hot coke left in the retorts after the carbonisation of the coal had been completed, the gas so produced passing on and mingling with the coal gas.

It was soon found, however, that the temperature of the carbonaceous matter was too low, and that the large quantities of carbon dioxide produced utterly ruined the illuminating power of the coal gas; and although Ibbetson's process has been patented many times since that date, the same cause has always led, and must alway lead, to failure.

The reason for this is that at a high temperature the action of the steam upon the carbon is to yield a mixture of equal volumes of carbon monoxide and hydrogen, both inflammable gases, whilst the action which decomposes the steam also rapidly reduces the temperature of the carbon, and the moment this falls below a certain point, if the quantity of steam be kept constant, carbon dioxide begins to appear in the place of carbon monoxide, and as this is the most fatal of any known gas to the development of light in flames which owe their luminosity to the separation of carbon particles, its presence in any large quantity must of necessity ruin the quality of the coal gas with which it is mixed.

The value of water gas for all purposes depends upon the carbon dioxide being kept down to the lowest limits commercially possible, and its average composition may be taken as—

Hydrogen	51·89
Carbon monoxide	40·08
Carbon dioxide	4·80
Methane	0·10
Nitrogen	3·13
	100·00

the figures given being the average of many analyses.

Six years after Ibbetson's experiment, Mr. Donovan attempted to make carburetted water gas as a substitute for coal gas, and did so by passing steam through coke heated to a high temperature in a retort, and passing the resulting water gas into a second chamber, where it was brought in contact with crude hydrocarbons, such as tar or naphthalene. Failure attended this attempt, and also many others which were made during the next twenty years, but in 1849 another important step towards success was obtained by Gillard, who at Narbonne introduced a sort of cupola furnace for the manufacture of water gas, and adopted the entirely new idea of raising the temperature of his carbonaceous fuel by blasting it with air instead of heating it in a retort fired from without; having raised the fuel to incandescence by its own partial combustion, he then shut off the air and passed steam through the fuel, until the temperature was so reduced as to necessitate a fresh blowing up by air. It is this process of "blow and run" which has since been employed in all the water gas processes which have had any claims to success.

After Gillard's time numerous other attempts were made to introduce water gas processes, but nothing of importance was done until 1875, when Lowe and Tessie du Motay in America inaugurated the present carburetted water gas systems.

Fuel gas had long been used in metallurgical operations, and had been produced in various forms of apparatus by blowing air through a bed of incandescent fuel, an operation which yielded an impure mixture of carbon monoxide with the residual nitrogen from the air, having the average composition—

Nitrogen	64·5
Carbon monoxide	29·0
Carbon dioxide	4·0
Hydrogen	2·5

As this usually contained only some 30 per cent. of combustible matter, its heating power was very low, and attempts had been made to improve its composition by using soft coal instead of coke, or by mixing a little steam with the air before passing it into the fuel.

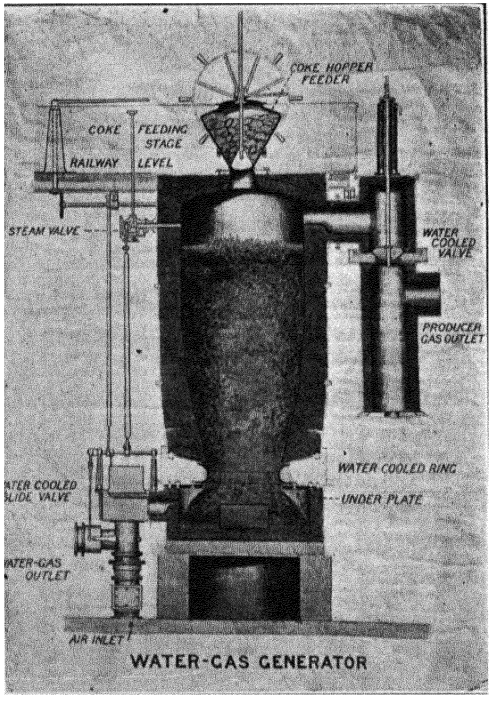


FIG. 37.—"European" water gas generator.

It was not unnatural, therefore, that as processes for the manufacture of water gas appeared to be nearing a commercial status of success attempts should be made to utilise this valuable heating gas for fuel purposes, as by its aid great intensity of heat could be obtained, its heating value being four times as great as the air-coke fuel gas, and from two to three times as great as the improved fuel gases.

With this object in view several Continental works set up plant on the "blow and run" principle, the most successful being the form adopted by Messrs. Schultz, Knaudt, and Company at Essen, who employed the gas largely and successfully for welding tubular boilers and lighting by incandescent devices.

The form of apparatus installed by them, which is still in use, consists of what is practically a cupola furnace lined with firebrick, and with a constriction a short distance above the hearth, the firebrick being protected at this point by a water-cooled ring, the usual size of the generator being about 20 feet in height and 7 feet in diameter. An air blast is admitted below the water-cooled ring, and by blasting for about 10 minutes, the ignited fuel is raised to incandescence. The air blast is then cut off, steam is admitted above the top of the fuel, and passing down through it, becomes converted into water gas, which escapes by the same opening as that through which the air blast was admitted, this being opened and closed by means of a water-cooled valve slide of such construction that it is impossible for any explosive mixture of water gas and air to to be formed. The water gas passes on to the purifiers, which remove sulphuretted hydrogen and carbon dioxide, and the gas is then stored in the gas holders. The fuel is fed into the generator by means of an orifice at the top, which is closed by a cone; the whole of the steam, air, and water gas pipes being governed by an arrangement which renders any explosive mixture impossible.

Hearing of the success of this installation, Mr. Samson Fox, after having the process investigated, acquired the British rights to the patents covering this and the other processes then in use, and erected an installation at the Leeds Forge in 1887, which was started in 1888, and proved as successful for the particular class of work done there as it had been at Essen. This was followed by the exploitation of water gas and the events of 1889 in connection with it, but any chance which water gas had of being made a general success was entirely swamped by the public disgust at the jobbery in connection with the flotation of the water gas companies, and this feeling was accentuated by a deplorable accident at the Leeds Forge consequent on a leakage of the

highly poisonous gas. This chapter in its history ended, therefore, in disastrous failure and heavy loss to the public.

In the meantime, however, events in the gas world had gradually been opening up a field for water gas as an auxiliary to coal gas. Up to the year 1889 the extra candle power needed to enrich a poor coal gas up to the parliamentary standard of illuminating power was obtained by adding to the original coal about 3 per cent of cannel coal for each extra candle with which the gas was to be endowed, and as the price of cannel ruled high this enrichment was somewhat costly. In 1887, 1888, 1889, the price of cannel rose to such a pitch that it was costing the gas companies something like 3d. per thousand per candle to bring the gas up to the standard requirements, and evidence was not wanting that this figure might be largely increased if some other method of enrichment were not obtainable. It was then that the idea of using cheap grades of oil for decomposition into oil gas for the enrichment of coal gas and the utilisation of the vapours of petroleum spirit for the same purpose arose, the employment of oil having one great advantage over cannel, and that was that the deteriorating effect of the cannel on the coke was done away with.

In 1889 an American named Van Steenburgh came over to England and erected in the Humphries Hall at Knightsbridge a plant for the manufacture of what he called "carburetted hydrogen." This plant consisted of a water gas cupola with an arrangement for injecting low flash point oil on the top of the incandescent fuel, and gave with great rapidity a large volume of 22 to 24-candle gas. The plant was visited by several of our leading gas managers, who were immensely struck with the rapidity of make and saving of labour, which made this method of producing gas an ideal one for coping with sudden demands upon the capacity of a gasworks, such as are created by fog, and also for serving as a useful stand-by in case of labour troubles. Hearing that

various forms of water gas apparatus were being employed in the States, Mr. G. C. Trewby, of the Gas Light and Coke Company, went to America and investigated the different systems in use there, and on his return to England had erected at Beckton a generator for carburetting water gas on what was known as the improved Lowe system.

This resulted in the adoption in many works of the gaseous mixture which up to that time had been looked upon as a rival. At the present moment at least one-fifth of the gas supply to London north of the Thames consists of carburetted water gas, whilst most of the large towns in the country have followed the lead of the metropolis.

At this point it will be well to consider the economic conditions which up to 1896 prevented pure water gas from coming into general use, whereas when carburetted it achieved so remarkable a success.

In the formation of water gas the perfect decomposition would be represented by the equation—

$$\begin{array}{ccccccc} C & + & H_2O & = & H_2 & + & CO \\ 12 & & 18 & & 2 & & 28 \end{array}$$

A unit weight of hydrogen in burning to water gives out 34,500 calories, and as 2 units burn to form 18 of water, the heat evolved during its production will be $34,500 \times 2 = 69,000$ calories; when the 18 units weight of water is again decomposed, this amount of heat will be again absorbed. In this case, however, the water has had to be converted into steam, and so contains an amount of heat equal to the latent heat of steam plus the heat used to raise it to the boiling point. It has been seen that the latent heat of steam is 536 calories per unit of water, and to allow for the heat necessary to bring it up to the boiling point, this is generally called 600. In the present case we are dealing with 18 units of water as steam, so the heat present in it will be $600 \times 18 = 10,800$ calories, and the extra heat

used up in decomposing the 18 units weight of water will be 69,000 − 10,800 = 58,200 calories.

The water having been decomposed, the oxygen of it is available to burn the 12 units of carbon to carbon monoxide, and as in doing this one unit of carbon emits 2,489 calories, the 12 will yield 2,489 × 12 = 29,868 calories. If this be deducted from the previous heat deficit, we have—

$$\begin{array}{r} -\ 58{,}200 \\ +\ 29{,}868 \\ \hline -\ 28{,}332 \end{array}$$

or a shortage of 28,332 for the 12 units of carbon, or 2,361 for one. If the units be taken as pounds, we see now that 1 lb. of carbon in decomposing 1·5 lb. of steam to hydrogen and carbon monoxide uses up 2,361 calories. In order to obtain this amount of heat we may burn 1 lb. of carbon to carbon monoxide by an air blast, and so obtain 2,489 calories, so that theoretically it should be possible to get the required balance of heat by burning half the fuel by an air blast to producer gas, and by a steam jet converting the remaining half to water gas.

In practice, however, the loss of heat taking place from the escape of the hot producer gas, radiation, etc., necessitates the air blast being continued until a far higher proportion of the carbon in the fuel has been consumed, and by this process, instead of 50 per cent. of the carbon of the fuel being converted into water gas, the actual amount is nearer 30 per cent.[1]

In making water gas by such processes as those employed at Essen and the Leeds Forge, fuel in the cupola is first raised to incandescence by the combustion of a portion of it under the influence of an air blast, an operation giving as a gaseous product the so-called air-coke gas, an analysis of which has already been given.

[1] See note (14) on p. 257.

Before the temperature of the fuel has been raised to a sufficient point to enable 1,000 cubic feet of water gas to be made by steam injection, no less than 4,000 cubic feet of the air-coke or producer gas have to be formed, and this quantity contains over 44 lbs. of carbon taken from the fuel. The 1,000 cubic feet of water gas are then made and contain a little over 15 lbs. of carbon, so that the production of the 1,000 cubic feet of water gas means an expenditure in round numbers of 60 lbs. of carbon.

These figures are calculated from the analyses of the water gas and producer gas, but they are amply verified by the fact that if the percentage of carbon in the coke be taken in pounds per ton and be then divided by 60, and multiplied by 1,000, figures will be obtained which will come within a few cubic feet either way of the actual yield of water gas obtained from the particular quality of coke. What that means is shown in the following table:—

Percentage of Carbon in Coke.	Pounds per Ton.	Water Gas from a Ton of the Coke.
		Cubic feet.
84	1859·2	30,986
85	1904	31,733
87	1948·8	32,480
90	2016	33,600
92	2060·8	34,346
95	2128	35,466
100	2240	37,333

In practice, results of several years' working with this type of generator at the Leeds Forge give an average of 34,000 cubic feet per ton of coke.

Some observers have given lower figures than these, but that has been due to coke from coal containing a considerable percentage of cannel forming a large proportion of the fuel used, as with a dirty and crumbly coke a longer blow has to be made in order to obtain the required temperature.

A thousand cubic feet of water gas contain as the combustible constituents—

Hydrogen	2·75 lbs.
Carbon monoxide	30 lbs.

and the thermal value will be represented by—

$$(2{\cdot}75 \times 34{,}500) + (30 \times 2{,}435) = 167{,}925 \text{ calories.}$$

The thermal value, however, of the 60 lbs. of carbon used in making the water gas would be—

$$8{,}137 \times 60 = 488{,}220 \text{ calories.}$$

In other words, the water gas formed has only just about 30 per cent. of the heating value of the carbon from which it has been formed, and this loss of 70 per cent. of the calorific value rendered the use of water gas as made by the old European process impossible, save for special purposes.

When, however, the air-coke or producer gas can be at once led away and burnt whilst hot for any purpose, another 223,328 thermal units will be produced, bringing the total calorific value of the two gases up to nearly 80 per cent. of the value of the carbon used in generating them.

If these conditions could have been satisfied, there is no doubt that water gas would have long ago been highly successful, but inasmuch as the producer gas is four times greater in volume than the water gas made, and as the gases are produced intermittently and not continuously, the problem of utilising both of them was an almost insurmountable difficulty, as if storage had been provided for the producer gas, the gas holder room required would have been enormous, whilst allowing it to cool down would have rendered it hardly worth burning. In some few installations a portion of the producer gas has been successfully used in firing boilers and other work of the same character,

but the difficulties before enumerated were so great that at the time they practically killed the general utilisation of water gas for fuel purposes.

When the manufacture of carburetted water gas was first successfully carried out by Lowe and Tessie du Motay, it became at once apparent that the producer gas, the loss of which had crippled all water gas processes, could be utilised for raising chambers filled with chequer brickwork to a high temperature in order to decompose the oils to yield the oil gas which, mixed with the water gas, rendered the latter luminous. It was in this way, by making the carburetted water gas plant a perfect heat machine, that its greatest success was achieved, as in raising the fuel to incandescence the producer gas, with all its heat in it, was at once burnt with a fresh supply of air in the superheating chambers, the practical loss of heat taking place throughout the whole apparatus being reduced to a minimum.

In all the attempts to make water gas which had seen the light up to 1896, the raising of the fuel to incandescence had practically always been obtained by using the air blast in so deep a bed of fuel that the carbon monoxide and residual nitrogen of the air formed the chief resultant products, and it must be remembered that when 1 lb. of carbon combines with oxygen to form carbon monoxide, as when forming producer gas, only 2,489 calories are developed, whilst if air be present in sufficient quantity to burn the carbon direct to carbon dioxide, the amount of heat which is evolved is 3·27 times as great, *i.e.*, 1 lb. of carbon gives 8,137 calories.

A process was devised by Mr. Carl Dellwik, in which this fact was utilised by the adjustment of the air supply, and by keeping the level of the incandescent fuel in the generator at a nearly constant height.

Under these conditions the producer gas ceases to exist as a by-product, and the gases from the blow consist merely

of the ordinary non-combustible products of complete combustion, carbon dioxide and nitrogen, the result being that double the quantity of water gas can be made per pound of fuel than was before possible, and the extra heat generated minimises the period of blowing, and enables runs or times of steaming to be continued far longer than before.

In the old "European" process it was necessary to blow for nearly ten minutes to bring the fuel bed up to the right temperature, whilst the period during which the incandescence was sufficiently great to decompose the whole of the volume of steam used, limited steaming to four or five minutes, whereas in the Dellwik process, the period of blowing rarely exceeds two minutes, and it is possible to steam for from seven to ten, according to the condition of the fuel.

When the author first examined this process, his previous experience in water gas making led him to believe that this procedure must inevitably form a considerable amount of carbon dioxide in the water gas, but analysis soon showed that this was a mistake, as the crude gas collected in the holder proved to be of excellent quality. The following analyses of samples taken at intervals during the process of making bear this out—

	I.	II.	III.
Hydrogen . . .	52·43	50·09	52·76
Carbon monoxide .	38·30	39·95	37·50
Carbon dioxide . .	4·73	5·38	4·08
Oxygen . . .	0·74	1·22	0·46
Nitrogen . . .	3·80	3·36	5·20

As 5 per cent. of carbon dioxide in the unpurified gas may be looked upon as a fair average when using the old "European" process, these results are distinctly good. In order to make quite sure that no mistake was being made, analyses were taken during a series of runs, when it was found that the average came out at 4·58, the highest being 4·9 and the lowest 4·2.

In the old process it is found that for the first two or three minutes, whilst the temperature of the fuel is very high, the reaction in the generator may be regarded as being—

$$C + H_2O = CO + H_2$$

but as the temperature of the fuel gets lower and lower, the action more and more nearly approaches to—

$$C + 2\,(H_2O) = CO_2 + 2\,H_2.$$

Experiments, however, show that whereas the first product of the decomposition of the steam by the carbon is carbon monoxide and hydrogen, if the fuel is so far cooled as only to admit of the decomposition of a portion of the steam, the excess of steam oxidises the carbon monoxide into carbon dioxide, and the secret of the low carbon dioxide in the gas made by the Dellwik process, in spite of the long period of steaming, is that instead of allowing the steam to blow into the fuel in large volumes, its flow is so regulated that even at the extreme end of the run there shall be no excess of steam to oxidise the carbon monoxide to dioxide.

An exhaustive series of tests was made with the apparatus at Warstein in Westphalia, and it was found that the completion of combustion during the period of blowing, claimed by the inventor, undoubtedly took place, as is shown by the following analyses made of the products of combustion given off during a blow. These analyses are confirmed by thirteen other analyses of the carbon dioxide in the blow gas, which yielded from 18·6 to 15·1 per cent. of carbon dioxide, instead of the 5 to 8 found in the "European" producer gas—

Carbon dioxide . . .	17·9	18·8
Carbon monoxide . . .	1·8	1·0
Nitrogen	78·6	79·5
Oxygen	1·7	0·7
	100·0	100·0

The generator consists of a sheet-iron shell, lined with fire-brick, which contains the fuel, coke; below the grate

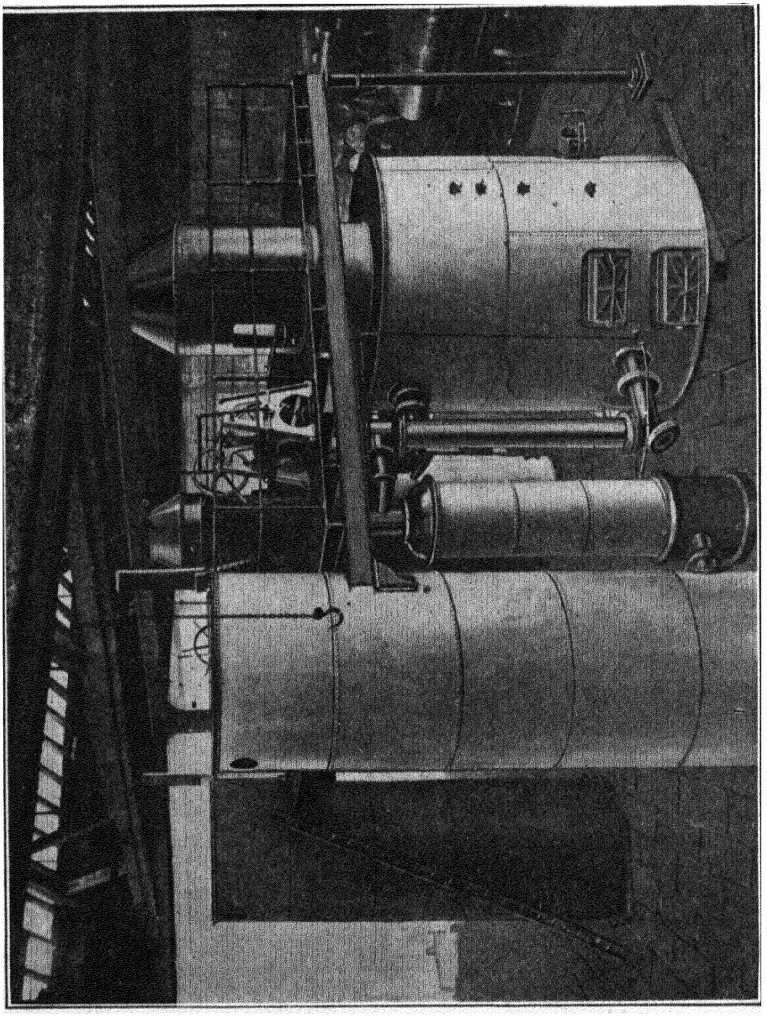


Fig. 38.—Dellwik water gas plant.

level is the valve for the air blast, whilst steam can be admitted either at the top or bottom of the generator. The

water gas is provided with two outlets, one at the top and the other at the bottom, connected by a three-way valve. A central stack valve, geared with the air blast valve, allows the products of the "blow" to pass away, and through it the fuel is fed into the generator. In practice, the generator is filled to the proper level with coke, which is blown up to vivid incandescence with the air blast, the products passing off through the central stack. When the right temperature is attained the air is cut off, the central valve being simultaneously closed, and steam is admitted at a carefully regulated rate which, passing either up or downwards through the coke, is decomposed into water gas. The gas escapes at either of its outlets into a scrubber, where it meets with a stream of water trickling over the coke; this cleanses and washes the gas, which is then stored in a holder. When the temperature of the fuel has fallen to a point at which carbon dioxide is formed in excess, the steam is shut off, and the fuel again raised to bright incandescence by the air blast.

The introduction of the Dellwik process for making water gas revolutionised its employment as a fuel. With the old European process, in spite of the production of water gas being only an average of 34,000 cubic feet of gas per ton of coke, it offered such enormous advantages in the welding of corrugated boiler flues as to lead to its adoption at the Leeds forge and at Essen for this purpose, whilst now, on the Continent especially, water gas is being largely employed in many manufacturing operations, more particularly in those processes where intense local heat is required, as in the welding of boiler plates and tubes for various purposes. In the welding of large tubes from plates, not only is the speed of working three to five times as great as with the previous system of coke firing, but there is no waste of time in waiting for the fire to attain the necessary temperature after renewing the fuel, there is no ash or fuel to handle,

and the supply can be cut off immediately the work is done: all these factors meaning increased comfort for the workmen and economy in labour.

Water gas has also been applied to the process of steel making, and the results attained have been very successful,

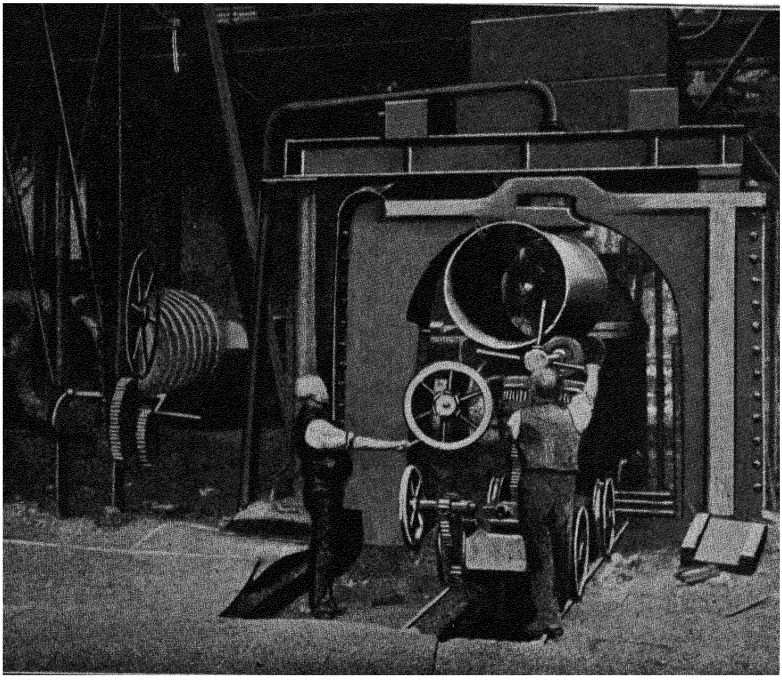


FIG. 39.—Welding boiler furnace with water gas.

showing a considerable economy in fuel consumption as well as a higher production rate, owing to the quicker working. The quality of the steel made in the open hearth furnace heated by water gas is excellent, and fully equals the best crucible steel. As an example of the economy and speed of the operation, it is stated that the consumption of gas required to melt a charge amounted to only 750 cubic

feet of water gas per hundredweight of steel. For the casting of large objects, the use of gaseous fuel permits of several furnaces being heated at once to the same temperature, and in a far more simple manner than with solid fuel.

Besides proving successful in connection with the manufacture of iron and steel, and the working of these metals, such as welding, annealing, chain making, etc., water gas is steadily gaining ground in other industrial processes, such as glass melting, glass blowing, enamelling, etc., and in fact for all the processes to which gaseous fuel can be put.

By generating the gas at a central station in a works and distributing it in pipes to the various departments where it is required, a considerable saving in the handling of fuel can be effected, as with solid fuel it would have to be carried round to the different places, which means labour and waste.

For the generation of power, water gas can be successfully used in internal combustion engines without any trouble from pre-ignition by simply regulating the degree of compression, a consumption of 30 to 35 cubic feet per horse-power per hour being the average amount used; and by employing small engines at the various points where power is required, all drawing gas from the central generating station, the distribution of power is much cheaper than in the case of steam, as all shafting and belting for transmission are done away with.

Water gas was used by Gillard as early as 1839 for lighting, by burning it under pressure for heating a small platinum mantle, but it was not a success, as the surface of the metal soon became eroded by the action of the carbon monoxide, and was also acted on by the iron carbonyl, a gaseous compound of iron and carbon monoxide, traces of which are always present in water

gas, and which breaks up in the water gas flame, depositing iron oxide on anything heated in it for any length of time.

Later on, when the "European" process was working at Essen, the town and works were lighted with water gas used in conjunction with the Fahnehjelm comb, which was introduced in 1883, and consists of a comb of fine rods of magnesia, set in a metal back. This was fixed at the requisite height above a flat flame burner consuming water gas, and gave a light of 4·3 candles per cubic foot of gas consumed.

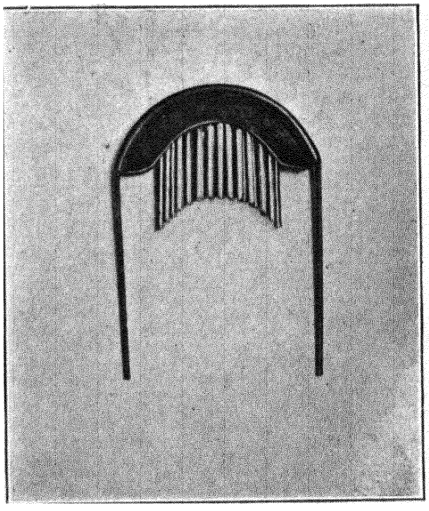


FIG. 40.—Fahnehjelm comb.

Its light-giving properties and endurance were afterwards improved by Dellwik, who dipped the comb in dilute chromic acid before use.

With an ordinary incandescent mantle, water gas gives a splendid light when burnt in an argand burner of proper construction, and the author has obtained a light of 19 candles per foot when using it in this way. Many observers contend that it has only a low illuminating power, because the gas has a calorific value of only 300 to 320 B.T.U. as against 620 in coal gas, but this mistake has arisen from using it in an ordinary incandescent burner, whereas water gas being non-luminous and easily oxidised requires no previous admixture with air. A water gas flame is hotter than a non-luminous coal gas flame, because a much larger volume has to be burnt in the same

space to give a flame of definite size, and it is the temperature of the flame that governs the light given by the mantle.

When the mantle is used with water gas alone the light given by the mantle soon falls, owing to the deposit of iron compounds on the fabric, but this can be avoided by washing the water gas in a scrubber with strong sulphuric acid.

Another water gas process used first at several works on the Continent, and an installation of which has been operated for many years at the Uxbridge Gas Works, is that known as the "Kramers and Aarts" process. The novelty in this apparatus consists of having two generators with a regenerating chamber filled with chequer brickwork behind them. When the coke in the generators is being raised to incandescence by the air blast, any carbon monoxide that it may contain will be burnt by the extra air supply in the regenerating chamber to heat the chequer work, and the products escaping up the chimney consist of the products of complete combustion only, while the heat which they contain is further utilised to raise the temperature of the extra air required for the combustion in the generator. When the right temperature of the fuel in the generators has been attained, steam is blown in at the bottom of the first generator, the steam being in excess: the resulting mixture of hydrogen, carbon monoxide, carbon dioxide, and steam is then passed through the regenerators, where it is highly heated, and traverses the second generator, entering at the top and passing downwards through the coke. By this arrangement the carbon dioxide produced by the excess of steam in the first generator becomes reduced to carbon monoxide, and any excess of steam is also decomposed into hydrogen and carbon monoxide. Inasmuch as in this generator the hottest portion of the fuel will be at the bottom, where the air blast has come more thoroughly in

contact with it, the gases finally leave the mass of fuel at the point of highest temperature.

It is well known that when steam is forced in a contrary direction to that in which the air blast has been driven through the generator, the proportion of carbon dioxide is always less than when the steam passes in the same direction as the air blast, and this principle has been used in many forms of generator. The K. & A. system is now known as the Perry system of water gas manufacture, and installations exist in this country at Liverpool, Sydenham, Oldbury, Wakefield, and many other places. The apparatus, however, is considerably more complicated than that of the Dellwik plant.

Many generators have been devised for the manufacture of carburetted water gas, and in these the gas is rendered luminous by admixture with the vapours of various grades of oil after and during manufacture. The processes can be divided into two classes: (*a*) continuous processes, in which the heat necessary to bring about the interaction of the carbon and steam is obtained by performing the operation in retorts externally heated in a furnace: and (*b*) intermittent processes, in which the carbon is first raised to incandescence by an air blast. When the air blast is cut off steam is admitted until the temperature falls too low for the action, when the air is again admitted. The process therefore consists of alternate "blows" and "runs."

The first class of processes has never been commercially successful. The best of the intermittent processes is the one originally devised by Lowe, which has undergone many improvements and modifications, and is now employed everywhere. In this apparatus the coke or anthracite is heated to incandescence by an air blast in a generator lined with fire brick, and the producer gas thus formed passes on to the superheaters, which are

chambers filled with chequer brickwork, and more air is admitted to ensure its combustion. By this means the superheater is raised to a high temperature. When the fuel and superheater are sufficiently hot, the air blast is cut off and steam blown through the generator, forming water gas, which meets the enriching oil at the top of the first superheater, called the carburettor, and then passes on to the fixing chambers, where the hydrocarbons are rendered permanent gases. The chief advantage of this apparatus is that a comparatively low temperature can be used for fixing, owing to the large amount of surface for superheating, which to a great extent does away with deposition of carbon.

This plant is the only one which has proved successful in this country; and practically all forms of water gas apparatus are now founded upon the same set of actions. Several other types of carburetted water gas producers have from time to time been introduced in England, but without result. In the Springer plant, the superheater and fixing chambers were placed above the water gas generator, an oil heater and vaporiser being also employed. As in the Lowe plant, an air blast raised the fuel to incandescence, the producer gas being used to heat the superheaters and fixing chambers. Steam was then admitted down through the fuel, and the resulting water gas was partly led back again to the fixing chamber and partly to the oil vaporiser, where it helped to distil the crude oil and returned with the vapour to the fixing chambers, where the oil vapours were converted into permanent gases. Making the steam pass down through the fuel after it has been raised to incandescence was also to be found in the Loomis plant, and, as we have seen, a great advantage is thus gained, for the fuel is hottest where the air blast enters, and by passing the water gas through the hottest portion of the fuel, the percentage of carbon dioxide is kept down. The Flannery

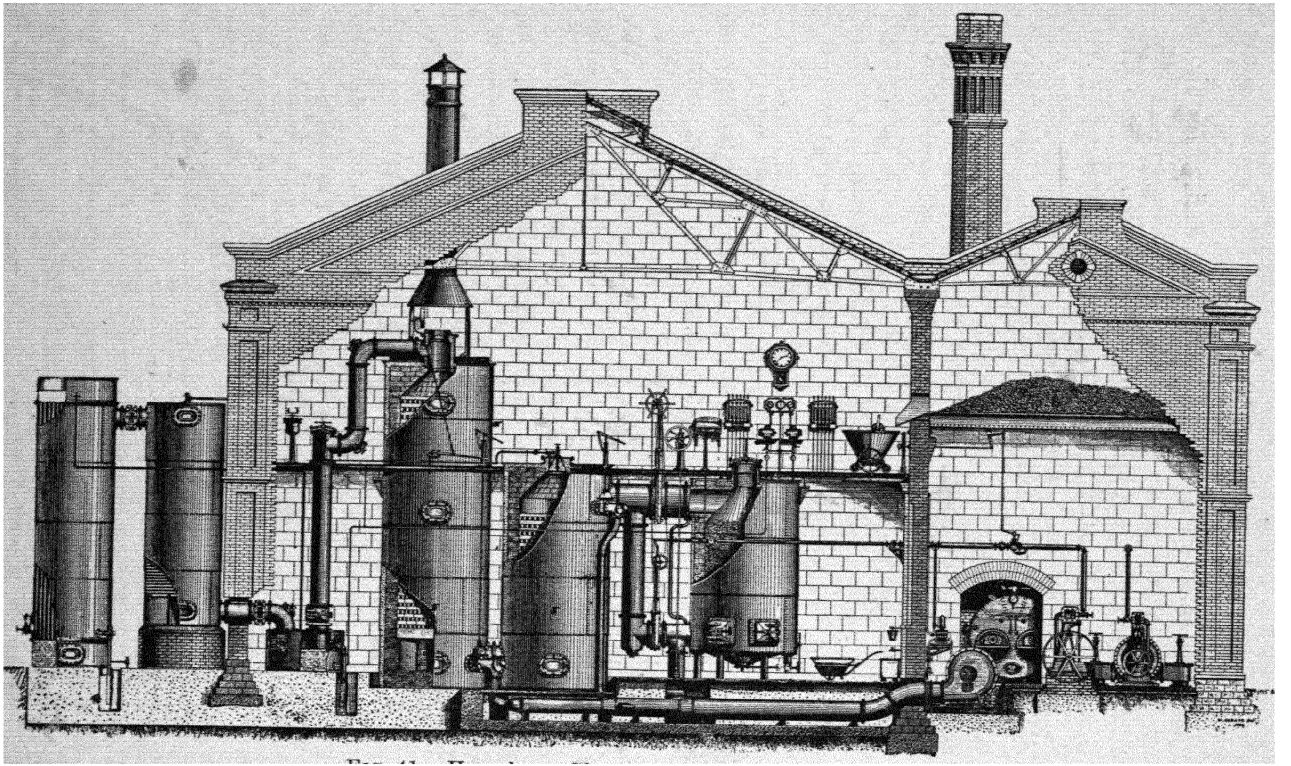


FIG. 41.—Humphreys-Glasgow carburetted water gas plant.

apparatus was only a slight modification of the Lowe. As the gas left the generator the oil was fed into it, and the mixed gases and vapours passed into a D-shaped retort placed in the top of the generator, where the oil was volatilised and fixed in the superheater, in presence of the water gas. The chief feature of the Van Steenburgh plant was that the top of the fuel formed the superheater, so that no fixing arrangement was required, but in all these forms of apparatus far too much oil tar was formed, owing to insufficient superheating of the oil vapour. The modification of the Lowe plant, which is most widely used at the present time, is that known as the "Humphreys and Glasgow" carburetted water gas plant. In this system the fuel is blown up to incandescence by an air blast in the generator, and the producer gas so formed is burnt in the carburettor and superheater, which are heated up by the combustion to the necessary temperature for decomposing the oil. When the fuel in the generator is sufficiently heated, the air blast is shut off, and steam is blown through it, the water gas passing to the top of the carburettor, where it meets the oil, and both are carried down through the carburetter, the oil being thoroughly "cracked" in its passage. In the superheater the oil vapours and water gas are subjected to another heating, which has the effect of finishing the conversion of the oil vapours into permanent gases. The mixed gases, after being subjected to washing, scrubbing and condensing, are ready for distribution as carburetted water gas.

The great objection to carburetted water gas in Europe has always been the high percentage of carbon monoxide, which constitutes from 26 to 30 per cent. of the carburetted gas. CO, as has been before pointed out, is one of the most virulent gaseous poisons known.

The composition of the mixture will of course vary with the proportion of oil gas mixed with the water gas, but the

quality most used for enriching coal gas is from 20 to 22 candle gas, and has the approximate composition :—

Hydrogen	37·20
Saturated hydrocarbons .	18·88
Unsaturated hydrocarbons . .	12·82
Carbon monoxide . . .	28·26
Carbon dioxide	0·14
Oxygen	0·06
Nitrogen	2·64
	100·00

So that the dilution of water gas by oil gas may be said to reduce the average percentage of carbon monoxide to 28, but with the exception of a short period in one of the divisions of Liverpool, carburetted water gas alone has never been distributed in this country, although in America about thirty of the largest companies send it out as a domestic supply.

In Great Britain it is almost entirely used to enrich and augment the supply of coal gas, and the amount added depends largely upon local circumstances, the table on top of p. 247 showing the maximum and average percentages put into the coal gas in some of the more important towns in 1913. Under ordinary conditions of working it is safe to say that 20 to 50 per cent. of carburetted water gas is added to the coal gas supply.

The whole question of what quantity shall be permitted hinges on the percentage of carbon monoxide present in the mixture, and this should be kept down to a point that will prevent such small leakages as are possible in a dwelling room from being actively injurious or endangering life.

It must be remembered that coal gas itself contains a certain proportion of carbon monoxide, the quantity being dependent upon the composition of the coal and upon the

PROPORTION OF WATER GAS MIXED WITH THE ORDINARY COAL GAS, IN VARIOUS CITIES AND TOWNS OF THE UNITED KINGDOM IN 1913.

Town.	Maximum Percentage.	Average Percentage.
Bath	50	19
Birkenhead	37	27
Birmingham	25	18
Blackburn	25	25
Bridlington	36	20
Brighton	40	29
Colchester	34	24
Hastings	39	28
Hornsey	43	21
Liverpool	50	33
London (Gas, Light and Coke Co.)	23	18
London (Commercial Gas Co.)	41	32
Norwich	31	21
Preston	35	20
Southend	36	22
Swansea	35	25
Tottenham	46	29
Winchester	31	24

conditions of temperature and exhaust in the retorts. It has been found that the presence of combined oxygen in coal gives rise during carbonisation to the formation of oxides of carbon, and M. Ste. Claire-Deville, from a long series of experiments on 59 different kinds of coal, established the following relations:—

In Coal.	In Gas.	
Percentage of Oxygen.	Carbon Dioxide, per cent.	Carbon Monoxide, per cent.
5 to 6·5	1·47	6·68
6·5 „ 7·5	1·58	7·19
7·5 „ 9	1·72	8·21
9 „ 11	2·79	9·86
11 „ 12	3·13	11·93

The presence of oxygen also in large percentage in the coal generally means a high yield of volatile hydrocarbons, hence a gas of high illuminating power; but such coals are rather avoided by the gas manager, as they are high in price and ruin the coke. High retort temperatures also seem to have an effect in increasing the percentage of carbon monoxide. In an analysis of gas by Mr. Lewis T. Wright, it is shown that whereas a Derbyshire caking coal yielded 8·72 per cent. of carbon monoxide when distilled at a dull red heat, the same coal yielded 13·96 per cent. of this gas at a bright orange heat.

A heavy exhaust would also tend in the same direction, as any trace of air leaking into the retort would form the monoxide. With the coals mostly used, however, from the Newcastle and Durham districts, the average percentage of carbon monoxide rarely exceeds 4 to 5; and it is now possible to gain an idea of the quantity that might be allowed in the mixture sent out as illuminating gas.

There is no danger of poisoning by such mixtures during the daytime, as the smell of the gas attracts attention to the danger long before the gas reaches a serious proportion; nor is it any good considering the cases of large leaks, as from broken mains or torn down fittings, for there would always be the risk of fatal results whether the gas was coal gas only or a mixture of coal and water gas.

The real risk is during sleep from such leakages as might be produced by leaky joints or partly re-turning a loose tap when putting out the gas. Such a leak would practically never be a serious one, as if it were, it would be detected before the occupant of the room could get to sleep.

The author's own view is that practical safety is assured as long as the percentage of carbon monoxide in the gas supply does not exceed 16 to 17. In the Departmental

Committee's Report on this subject in 1899, they recommend "that the proportion of carbon monoxide in the public gas supply at night should be regulated to 12 per cent., or such greater amount as the Department may consider advisable"; and in the body of their report they say: "In some cases 12 per cent. of carbon monoxide in the gas supplied might be proper, in others 16, or perhaps 20. . . . With the present condition of gas supply, 20 per cent. is the highest proportion of carbon monoxide that should be allowed, and this percentage should be used only under special circumstances."[1]

The views of the authorities in London are that the amount of carbon monoxide in the gas distributed should not exceed 16 per cent., and the Legislature is always so chary of doing anything to hamper unnecessarily a great industry, that the limit is not likely to be fixed below this point; indeed, as coal gas *per se* may contain up to 12 per cent., fixing anything lower than 16 would be practically prohibiting the use of a valuable adjunct to gas manufacture. Taking, for the sake of calculation, the allowable limit as 16 per cent., this would mean that an ordinary coal gas containing 5 per cent. of carbon monoxide might have its bulk increased by carburetted water gas until the mixture contained 52 of coal gas and 48 of carburetted water gas, whilst if blue water gas were used the limit would be reached when the mixture contained 66 of coal gas to 34 of blue water gas; in other words, to 100 volumes of coal gas one might add 92 of carburetted water gas, or 51·5 of blue water gas, before reaching the limit of 16 per cent. of carbon monoxide in the mixture.

Where the desire is to provide a high candle-power gas such processes as the Humphreys and Glasgow system of making carburetted water gas are by far the best method of enrichment that can be employed, but the introduction of the incandescent mantle has wrought such a change in the

[1] See note (15) on p. 257.

conditions of gas consumption that the parliamentary standard governing the illuminating power of gas has been relaxed, and the attention of the gas manager is now largely devoted to giving a gas supply of fair heating value at as cheap a rate as possible, so as to fit it not only for illuminating but fuel purposes.

Looked at from a common-sense point of view the incandescent mantle will be seen to be merely a method of enrichment. Instead of increasing the illuminating power of a flame by crowding into the gas more and more hydrocarbons, which, during combustion, are capable of separating carbon particles, the incandescence of which would increase the amount of light emitted by the flame, and *pro rata* the amount of heating with the mantle, the flame is charged with incombustible particles of far greater light emissivity than the carbon possesses, and they do their work without that increase in the temperature of the atmosphere inseparable from the other processes. It is therefore the introduction of the incandescent mantle and the improvements which are possible in its construction which really give the possibilities to the gas of the future.

Taking now the enriched, or, as some now prefer to call it, the adulterated 16-candle gas as supplied during the nineties, the light which can be obtained from it is entirely dependent upon the burner in which it is consumed. This may be stated as in table on opposite page.

In considering the value given to the gas by these burners, it is seen that, according to the method by which it is burnt, the consumer may obtain anything from 35 candles down to less than one candle per cubic foot of gas. It must also be borne in mind that the burners employed in these tests were all good, well-made burners, giving the best duty that could be obtained from them, whilst an examination of the burners used in consumers' houses shows that in most cases any antiquated and corroded burner is considered

LIGHT EMITTED PER CUBIC FOOT OF 16-CANDLE GAS CONSUMED PER HOUR.

Burner.	Candle Units.
Incandescent (high pressure) . . .	30 to 35
,, (Kern)	20 ,, 25
,, (ordinary)	14 ,, 19
Regenerative	7 ,, 10
Standard Argand	3·20
Ordinary Argand	2·90
Union jet flat flame, No. 7 . . .	2·44
,, ,, 6 . . .	2·15
,, ,, 5 . . .	1·87
,, ,, 4 . . .	1·74
,, ,, 3 . . .	1·63
,, ,, 2 . . .	1·22
,, ,, 1 . . .	0·85
,, ,, 0 . . .	0·59

good enough at which to burn the gas, and the very people who are loudest in their complaints as to the quality of the gas are those who most disregard the method of its consumption.

It is quite clear that under such conditions as these the supply of gas of a high candle power is simple waste of money, and it is manifestly unfair that the consumer of average intelligence, who is willing to utilise the benefits given by the incandescent mantle, should have to pay for a quality of gas only rendered necessary by the inertia of those who decline to march with the times.

Water gas is the only gaseous product cheap enough and sufficiently rich in calories to use in admixture with coal gas as a combined heating and illuminating gas, and a number of experiments have been made to ascertain the effect of merely mixing together coal gas and water gas in bulk.

In practice, if a 16 per cent. limit was fixed by Parliament for the carbon monoxide in the gas, it would be

manifestly unwise to approach the limit too closely, as during a press of work owing to fog or other causes that threw a strain on the resources of the works, a slight want of uniformity in mixing might bring the percentage above the limit. In these experiments 40 volumes of blue water gas were added to 100 of coal gas, which would give 28·5 per cent. of water gas in the mixture, and bring the carbon monoxide up to about 14 per cent. The gases were measured through a meter before mixing, and the resulting mixture was tested for calorific value in a Junker's calorimeter. The blue water gas used was purified from carbon dioxide, and had a calorific value of—

Calories per cubic foot	80·0 gross	73·4 net
B.T.U.	320·0 ,,	293·6 ,,

The results obtained are shown in the following table:—

Illuminating value of coal gas—				
Coal gas	17·6	16·0	15·3	15·1
Thermal value of coal gas—				
Calories gross	172·0	159·9	158·8	149·9
,, net	155·3	143·8	142·0	134·6
B.T.U. gross	688·0	639·6	632·0	579·6
,, net	621·2	575·2	568·0	538·4
Mixture—				
Calories gross	146·0	135·6	136·8	129·1
,, net	131·7	122·8	123·2	116·7
B.T.U. gross	584·0	542·4	547·2	516·4
,, net	526·8	491·2	492·8	466·8
Percentage reduction in thermal value—				
Gross	15·1	15·2	13·4	13·9
Net	15·1	14·6	13·4	13·3

This table shows that, given an ordinary gas coal such as we should in practice use, yielding 10,000 cubic feet per ton of a 15 to 16-candle power gas, it may have added

to the 10,000 cubic feet 4,000 cubic feet of blue water gas, with a reduction of only 13 to 15 per cent. in thermal value.

The experiments made by Mr. Patterson and others show that the reduction in candle power is practically proportional to the volume of water gas added, as one would expect, so that the candle feet per ton of coal carbonised would be practically the same whether they were present in 10,000 cubic feet of coal gas, or 14,000 cubic feet of the mixture.

Instead, however, of mixing the blue water gas with the coal gas, a distinct advantage is to be gained by passing the gas into the foul main. This is done at several places in Germany, notably at Erfurt, and it is found that a distinct gain in candle power is obtained owing to the water gas becoming, to a slight extent, carburetted with benzol vapour present in the hot gas, which, if allowed to cool, would be taken up by the tar.

The saving is found by less benzol being required to bring the gas up to a given candle power when the mixture is made in this way, than when, as is done in some other places, the water gas is enriched by benzol, and is then afterwards mixed in with the coal gas.

In utilising water gas for the dilution of coal gas it is possible, however, to make it perform a far more important function than that of merely increasing the volume. As has been pointed out, one of the weakest points in the manufacture of coal gas is to be found in the process of carbonisation, which has undergone little or no change since the earliest days of the gas industry. When the coal is placed in the hot retort, evolution of gas at once commences with great rapidity, and, working with a five hours' charge, the largest proportion and the richest portion of the coal gas is evolved during the first three hours. The general course of the reactions is well shown in the

following table of results, found by Mr. Lewis T. Wright in his studies on carbonisation :—

Time of Observation (Seconds).	Percentage of Total Gas.	Average Retort Temperature.	Candle Power per 5 c. ft.
		°F.	
30	12·3	1,108	21·8
60	26·1	1,212	20 2
90	38·9	1,200	17·7
120	52·6	1,292	14·8
150	65·8	1,315	13·5
180	78·6	1,360	11·7
210	86·5	1,435	10·7
240	92·6	1,531	7·1
270	96·4	1,613	5·1
300	100·0	1,671	3·8

In a lecture given before the Incorporated Institution of Gas Engineers, in 1900, the author suggested that, instead of using water gas merely as a diluent, it should be made a factor in the distillation itself. He proposed that a stream of water gas should be passed through the crown of the retort during the process of carbonisation, so as not only to hurry the newly-born hydrocarbon gases out of contact with the hot walls of the retort, but also by diluting them to prevent the secondary reactions—which were so important a factor in the production of tar—from taking place, and by so doing to save many of the important lighting and heating constituents from destruction.

This process, which has for some reason been dubbed "Auto-carburetting," is now in use in a few English works and a large number of Continental ones, and is giving excellent results, and should prove of considerable value in the attempts of the gas manager to provide a cheap gas fit for both heating and illuminating purposes.

The financial position of a gas works largely depends upon the market which can be obtained for the coke and other

by-products, and where the demand for this is limited it is a very great advantage to the gas manager to be able to keep up the price of his coke by utilising it for the manufacture of either blue or carburetted water gas, and it would manifestly be a still greater advantage if the excess of tar could also be dealt with on the works.

In order to meet this object Mr. C. B. Tully has devised a

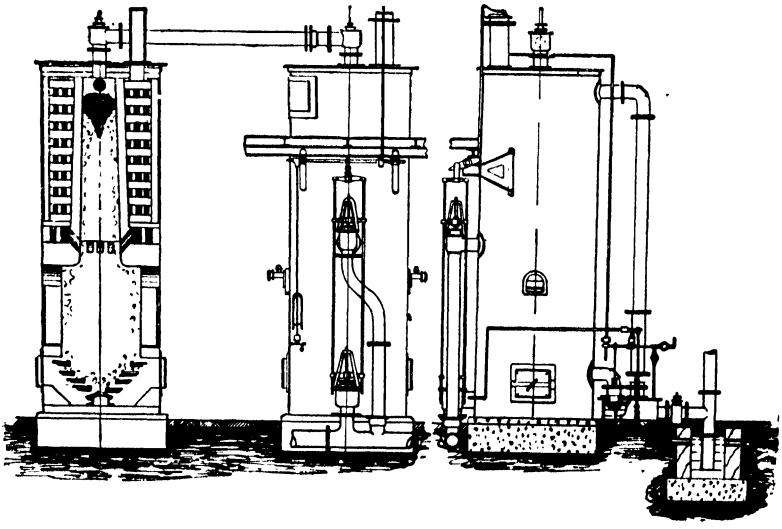


FIG. 42.—Tully's C.H. gasification plant.

plant for use in small gas works, in which. instead of carburetted water gas being made with oil, tar and ordinary bituminous coal or slack is utilised for this purpose.

Ever since the manufacture of coal gas attained to a position of importance, attempts have been made to utilise the tar produced from it for reconversion into gas, but all efforts in this direction have been more or less failures, owing to the difficulty of again breaking up into gaseous products the complex hydrocarbons and naphthalene present in it, whilst the

large amount of free carbon and pitch has been an insurmountable difficulty, as when a temperature sufficiently high to effect the decomposition into permanent gases has been attained, the yield of free carbon and heavy pitch has been so great as to choke everything up.

Mr. Tully, in conjunction with the late Professor Vivian B. Lewes, surmounted this difficulty by designing a generator in which the fuel column is nearly double that found in a carburetted water gas generator, and three times more than that in a blue water gas generator. It is the lower portion only of this which is raised to incandescence by an air blast introduced through openings in the lower part of the generator. About midway up the firebrick lining nostrils connect with a flue passing entirely round the generator and opening into a stack pipe which is closed at the top by a snift valve. In this way the incandescent portion of the fuel is maintained at a definite height, as the products of the "blow" pass away through this flue, whilst the upper portion of the fuel is only raised to a moderate temperature. When the necessary incandescence of the fuel has been attained, the air blast is shut off and the snift valve closed, and the exhauster is started. At the same time tar is injected into the fuel from the clear space below a projecting ring in the firebrick lining between the flue and the air injectors, and steam also is turned on at the bottom of the generator; this is directed upon the clinker and serves to break it up, and then passing upwards is converted into water gas. The tar gets broken up into carbon and gaseous products containing a large proportion of methane, and these mingling with the water gas formed from the steam, pass upwards through the generator. The carbon is filtered out by the cool charge above, and is used up as the fuel gradually sinks into the zone of combustion. The gas which finally leaves the generator is a mixture of hydrogen, carbon monoxide. and methane, with a very small

percentage of carbon dioxide. From the generator the gas passes through the scrubber into the condenser to the exhauster, which forces it into the holder.

Methane-hydrogen, as the gas is called, differs from water gas in many respects; it burns with a yellow instead of a blue flame, due to the large volume of methane present, and the percentage of carbon monoxide is very much less. An analysis of methane-hydrogen made from coal gas tar gives the following result:—

Carbon dioxide	2·8
Carbon monoxide	28·8
Unsaturated hydrocarbons	0·8
Saturated hydrocarbons	19·2
Hydrogen	42·4
Oxygen	0·2
Nitrogen	5·8

while the gas, owing to the quantity of the hydrogen and methane present, has a satisfactory thermal value.

The Tully C.H. complete gasification plant is now in use in a very large number of gas works in the United Kingdom, and it is claimed for it that it is the most useful and flexible water gas producer that has been brought out, since it will gasify any carbonaceous material and generate gas of 300 to 500 B.T.U. value.

(14) Stewart, in his recent paper upon "Heat Conservation and Water Gas," read before the London and Southern District Junior Gas Association on March 26th, 1920, has shown that in the most modern plants a working efficiency of 50 per cent. has been attained.

(15) At the present time (1920), the Board of Trade sanction for loans, raised by gas undertakings for extension of their water-gas plant, is granted only on the understanding that the percentage of CO in the mixed gas supplied to consumers is not to exceed 15 per cent.

CHAPTER IX.

POOR FUEL GAS.

Incomplete combustion — The principle of the gas generator — Thermal considerations—Bischof generator—Siemens and his work—Air-producer gas—Blast furnace gas—Dowson or semi-water gas—The Dowson type of generator—Anthracite as a fuel, and the considerations governing the size used—The composition of Dowson gas—Mond gas, and its production—The Buire-Leucauchez generator—The growth of the internal combustion motor — Suction gas plant — The Berrier suction generator—Pintsch suction plant—Dowson suction plant—The adoption of the suction plant and gas engine for marine purposes—The Emil Capitaine plant—The use of bituminous coal for suction plant, and the troubles to be overcome—The Duff-Whitfield generator —The Boutillier plant.

THE poorest in heat value, but for many purposes the most valuable as fuel, is the so-called generator or producer gas, formed by the incomplete combustion of carbon in a limited supply of air, and consisting of a mixture of combustible carbon monoxide and the residual nitrogen of the air. The small yellowish and blue flames which play over the top of a coal or coke fire that has burnt clear, show the principle of its formation; the coke freed from all volatile matter merely emits the glow of incandescence in its combustion, but the small flame flickering above it marks the combustion of a secondary product. The draught in the chimney caused by the air and gases above the fire becoming heated and expanded and rushing upwards, draws in more air from the room, some passing above the fire, some through it. As the latter portion comes in contact with the

incandescent fuel at the bars or grate of the stove, air is in excess, and complete combustion takes place, carbon dioxide being produced; this, together with the residuum of the air, is drawn forward by the draught of the chimney through the red-hot fuel, and the carbon dioxide, parting with one half its oxygen to a further portion of carbon, yields a double volume of carbon monoxide, so that for every cubic foot of carbon dioxide that passes through the red-hot mass of carbonaceous matter, two cubic feet of the monoxide are produced, and reaching the surface of the fuel, there meet air streaming direct to the chimney, and being at a temperature above its ignition point, burn with the oxygen, giving the flickering flame, and re-forming carbon dioxide, which together with the residual air and nitrogen passes up the chimney.

Now close in the space above the fire grate so that all air drawn in by the chimney draught must pass through the red-hot fuel, when a gas producer is obtained, and the mixture of carbon monoxide and nitrogen may be lighted, if desired, at the mouth of the chimney pot.

It is quite clear that the flame burning on the chimney stack cannot give as much heat as the solid fuel and flame burning in the open grate, and one can gain an idea of the sort of loss taking place by calculation from the data already given (page 230).

In order to simplify the problem, let us suppose we are dealing with pure carbon and oxygen, instead of coke and air. By the calorific data already given—

A unit weight of carbon burning to carbon dioxide gives 8,137 calories.

A unit weight of carbon burning to carbon monoxide gives 2,489 calories.

A unit weight of carbon monoxide burning to the dioxide gives 2,435 calories.

Taking a pound for our unit, we see then that if we burn it

completely in our grate, 8,137 calories or 14,652 B.T.U. will be evolved.

If, however, only half the required oxygen be used, and carbon monoxide is formed, supposing this to be possible, only 2,489 calories or 4,212 B.T.U. would be generated on the grate, but combustible carbon monoxide would be obtained.

Taking the equation as

Carbon.		Oxygen.		Carbon monoxide.
$2C$	+	O_2	=	$2CO$
24		32		56

if 24 lbs. of carbon give 56 lbs. of carbon monoxide, then 1 lb. of carbon gives 2·33 lbs. When 1 lb. of carbon monoxide burns to carbon dioxide, 2,435 calories are obtained, so that the $2{\cdot}33 \times 2{,}435 = 5{,}673{\cdot}5$ calories available when the carbon monoxide burns. We have therefore in the combustion of 1 lb. of carbon generated

2,489 calories on the grate
5,673 ,, in the gas

or a total of 8,162

(The discrepancy between 8,162 and 8,137 calories is due to small errors in the thermal values as determined experimentally.)

So that the difference between completely burning the solid carbon in the grate or producing gas from it is that in the first case we get the whole of the heat developed locally, whilst in the second case we get a little under 30 per cent. of the heat developed on the grate of the producer, and over 70 per cent. available in the gaseous fuel; a large amount of this loss, however, can be saved if the gas can be burnt close to the generator, and before it has time to cool.

Where the heating work to be done demands great local intensity, then the solid fuel completely burnt in a furnace would be the best to employ; but for very many operations the use of the solid would be so wasteful as to make it worth while to sacrifice the 30 per cent. of the heat in converting the remainder into gas, the ease and economy of the application of which will generally make up for the initial loss, and in many cases lead to a very large saving.

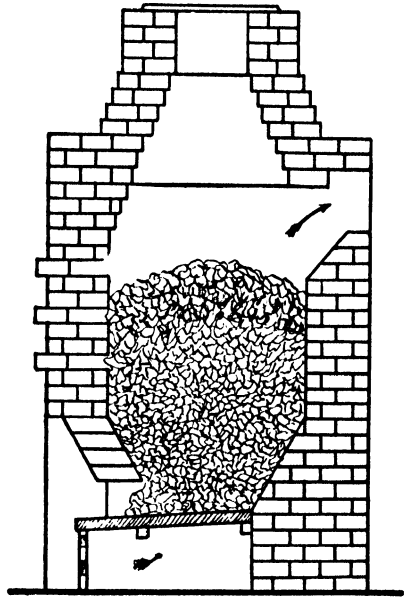


FIG. 43.—Bischof generator.

The introduction of the gas producer probably dates back to 1839, when Bischof devised a simple form of generator, in which a chimney draught drew air in through the firegrate of a furnace, and the gases escaping at the outlet were utilised for gas firing.

The most important epoch in the history of the rise of producer gas was when in 1857 Siemens invented his system of regeneration, in which chambers of chequer work were heated to a high temperature by the products of combustion escaping from the furnace, the heat being afterwards utilised to raise the temperature of the air and fuel gas, which by their combustion gave the heat in the furnace. Used in connection with this recuperating device a gas producer showed such economy and developed such high temperatures that it revolutionised many manufacturing processes.

In the first generators made on this system Siemens, like Bischof, used the draught of a chimney to draw the air through the incandescent fuel, and adopted the ingenious device of making the flue that gave the draught also a syphon, which, as the gas cooled and increased in weight, flowed down to the furnace. The slow flow of air that could be obtained in this way, however, was a drawback, and the idea soon arose of increasing the rapidity of combustion in the generator by means of an air blast produced by a blower or a centrifugal fan.

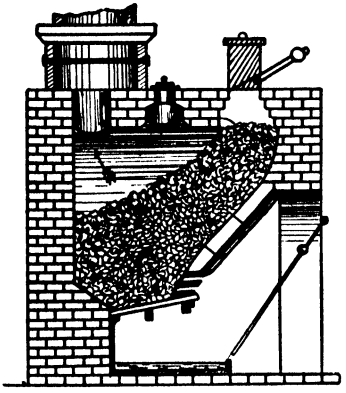


FIG. 44.—Siemens producer.

When made by any such processes as those originated by Bischof and Siemens, in which air and incandescent fuel alone are employed, the only variations in the composition of the gas will be those arising from differences in the fuel used and the rate of flow of air.

Where coke is the fuel used the composition of the gas will approximate to—

	Per cent.
Carbon monoxide	29·0
Carbon dioxide	4·0
Hydrogen	2·5
Nitrogen	64·5
	100·0

the trace of hydrogen being formed from moisture in the fuel. Such a gas is of very low calorific value, a cubic foot only giving about 19 calories, or 72 B.T.U.

When, however, slack is employed, as is the case with

nearly all producers on a large scale, the hydrocarbons in the coal improve the composition and thermal value, a typical analysis of a Siemens gas made with slack approximating to—

	Per cent.
Carbon monoxide	22·6
Carbon dioxide	4·4
Hydrogen	7·8
Methane	1·5
Nitrogen	63·7
	100·0

with a thermal value of 32 calories, or 125 B.T.U. per cubic foot.

Blast furnace gas, until lately allowed to burn to waste at the mouth of the furnaces in which the reduction of iron from its ores is carried out, is a gas of much the same character as the air-producer gas, and is now collected and used for steam raising and other fuel purposes, such as heating the blast.

In order to collect the gases, the mouth of the blast furnace is generally closed by means of a bell cone, which, whilst allowing the feeding of fuel and ore into the furnace, closes it against escape of gas, whilst ducts open into the upper throat of the furnace and conduct away the gases, in many cases liquid by-products being condensed from the gas before it is burnt.

The composition of such gas will vary considerably, but its average analysis will not differ much from the following:—

	Per cent.
Carbon monoxide	27·71
Carbon dioxide	8·62
Hydrogen	1·34
Nitrogen	62·33
	100·00

Its thermal value is, if anything, less than coke-producer gas, averaging 18 calories, or 70 B.T.U.

The introduction of a blast to the gas producer at once caused an undue rise of temperature above the firebars, and led to serious trouble from clinkering and destruction to the iron grate, and attempts were then made to introduce air by means of a steam injector, as it was even then recognised that steam had a powerful influence in reducing temperature, and thus preventing, or at any rate diminishing, clinkering, whilst the production of an increased volume of hydrogen in the resulting gas increased to a valuable extent the thermal efficiency of the gas produced.

Such gas is a varying mixture of generator or producer gas with water gas, and is generally known as "Dowson gas," owing to the fact that at the commencement of the eighties it was J. E. Dowson who first perfected the method of making the mixed gas, and devised a practical apparatus for its production, although it had been used on the continent some years before, and Joshua Kidd had taken out a patent for increasing the value of the producer gas by passing steam as well as air through the fuel.

The thermal advantages of such a process are manifest. It has been seen that the formation of producer gas by the passage of air through a bed of incandescent carbonaceous fuel is an exothermic action, heat being developed, whilst the production of water gas by passing steam through the heated fuel is endothermic, *i.e.*, absorbs heat, and it is clear that if the passage of air and steam could be so regulated that the one action generated as much heat as the other absorbed, the fuel in the generator would be kept at a constant temperature, and a gas of fairly uniform composition would be obtained.

Assuming, for the sake of simplicity, that we are dealing with pure carbon and oxygen, the conversion of 1 lb. of carbon into carbon monoxide would evolve 2,489 calories

(p. 59), whilst the conversion of 1 lb. of carbon into water gas by the decomposition of steam would use up 2,361 calories (p. 230). One might imagine that if in a producer one half the carbon was burnt to producer gas by air, and the remaining half made into water gas by steam, a fair balance of temperature would be established. Any such theoretical considerations are, however, entirely futile, as they presuppose that the whole of the heat generated by the combustion of the carbon by air can be utilised for supplying that required for the formation of the water gas, whilst in practice the heat escaping in the products, lost in radiation, and from many other causes, necessitates a considerably larger proportion of air to steam.

Gas made in this way shows a considerable increase in thermal efficiency, owing to the increase in the percentage of hydrogen present, whilst these forms of apparatus give an advantage over air producers owing to the thermal actions in the generator using up a certain proportion of the heat as it is generated; but it must be clearly borne in mind that for a given weight of fuel used in the generator, the heat units available in the gas formed must always be less than the amount which could have been generated by the direct combustion of the fuel, the advantage of gasifying the fuel being in ease of application, cleanliness, and ability to concentrate the heat at the desired spot.

Very many forms of generator for the production of this semi-water gas have been devised, and in this country those most used are the Dowson, Wilson, Dawson, Mason, and Duff, whilst for making the mixed gas on a very large scale the Mond plant is the most economical, owing to the recovery of ammonia formed from the nitrogen in the fuel used.

Plant of the Dowson type is mostly installed for power purposes, and for use in the gas engine it is essential that the gas should be scrubbed free from tar vapour and dust,

and should be delivered to the engine at atmospheric temperature: to ensure efficiency, the fuel to be employed in the producer is generally selected according to the purpose for which the gas is to be used. With the Dowson type of generator anthracite is the usual fuel, as the amount of tar produced by its combustion is small, and the quality of the gas good. The anthracite is generally screened at the colliery, the standard sizes being regulated according to the size of mesh through which it will pass.

Size of Coal.	Will not pass	Will pass
Large . .	5 in. mesh. .	
Cobbles . .	3 ,, .	5 in. mesh.
Nuts (French) .	$1\frac{3}{4}$,, .	$2\frac{1}{8}$,,
,, (German)	$\frac{3}{4}$,, .	$1\frac{3}{4}$,,
Peas . .	$\frac{3}{8}$,, .	$\frac{3}{4}$,,
Duff or slack .	. . .	$\frac{3}{8}$,,

All sizes down to peas can be used, but for the best working the size should be governed by the diameter of the generator, and this becomes still more important when the anthracite is used for water gas making, as is often the case in America.

When the anthracite is fed into the generator it packs most closely in the centre throughout the whole depth of fuel, and is loosest around the sides, with the result that in making gas both the air and steam show a tendency to work up near the walls of the generator, and there is a want of uniformity in the action, the central portion of the fuel in the generator being rendered partially inactive. With a large generator "nuts" might render as much as 30 per cent. of the fuel inoperative, whilst "cobbles" would reduce the inactive zone to 10 per cent. of the total.

It must be remembered, however, that the surface of fuel exposed, and the resistance to air blast and steam are also important factors, and the smaller the coal the greater will

be the surface and the less the space left for the passage of the gases, and this also requires proper adjustment.

An idea of the difference made to these factors by the size of the anthracite may be gathered from the following table.

Size of Coal.	Clearance in percentage of generator space.	Surface of fuel exposed per cubic foot of generator space.
Large	47 per cent.	7 sq. feet.
Cobbles	46 ,,	10 ,,
Nuts (French)	44 ,,	22 ,,

The smaller sizes can only be used in small generators, and slack or duff is a fatal drawback, as it chokes the air spaces between the pieces of coal, and forces the blast and steam to form channels, which, exposing too small a surface of incandescent fuel to the rapidly flowing gases, leads to the production of a gas of unsatisfactory composition.

The Dowson generator consists of an iron shell lined with fire brick, in which the fuel rests upon fire bars below which the air is injected by a steam gas jet. The fuel is introduced at the top by means of a closed feed, and the gas is drawn off from the top of the generator, and after passing a hydraulic seal, goes through two scrubbers to free it from ash, dust, and tar vapour, and is then ready for use.

The average of a number of analyses gives as the composition of the gas the following results:—

	Per cent.
Hydrogen	18·19
Methane	1·40
Carbon monoxide	25·17
Carbon dioxide	5·98
Nitrogen	49·26
	100·00

The calorific power is 42 calories, or 163 B.T.U. In practical working it is not easy to maintain the gas of quite such high thermal value, as the clinker formed in

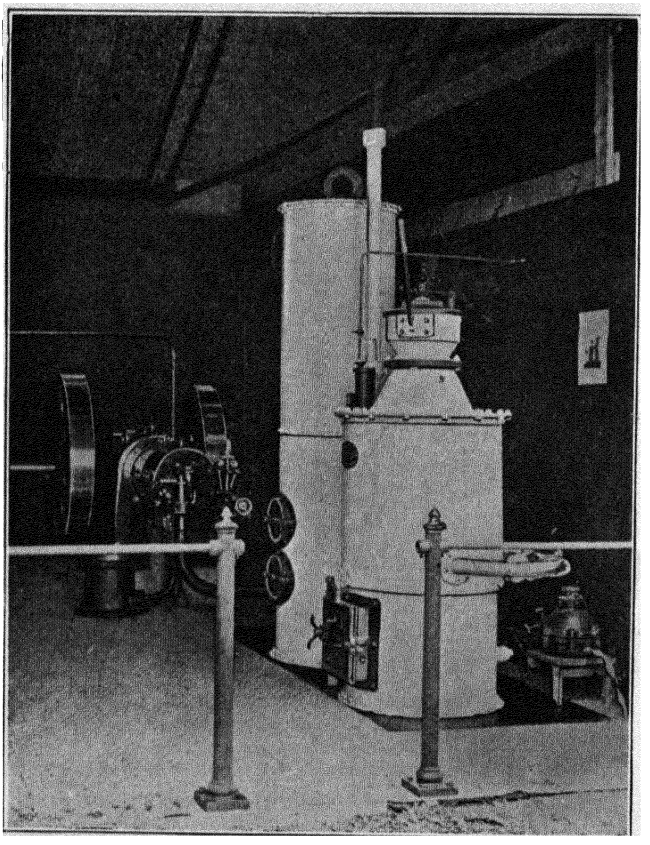


FIG. 45.—Dowson generator.

the generator disturbs the results, and the calories per cubic foot gradually fall, until just before clinkering the value of the gas may be as low as 38 calories, or 150 B.T.U. The make, with a generator of this description, approximates to 80 cubic feet per pound of anthracite

consumed in the generator. The form of Dowson generator now used as a suction plant is shown in Fig. 45.

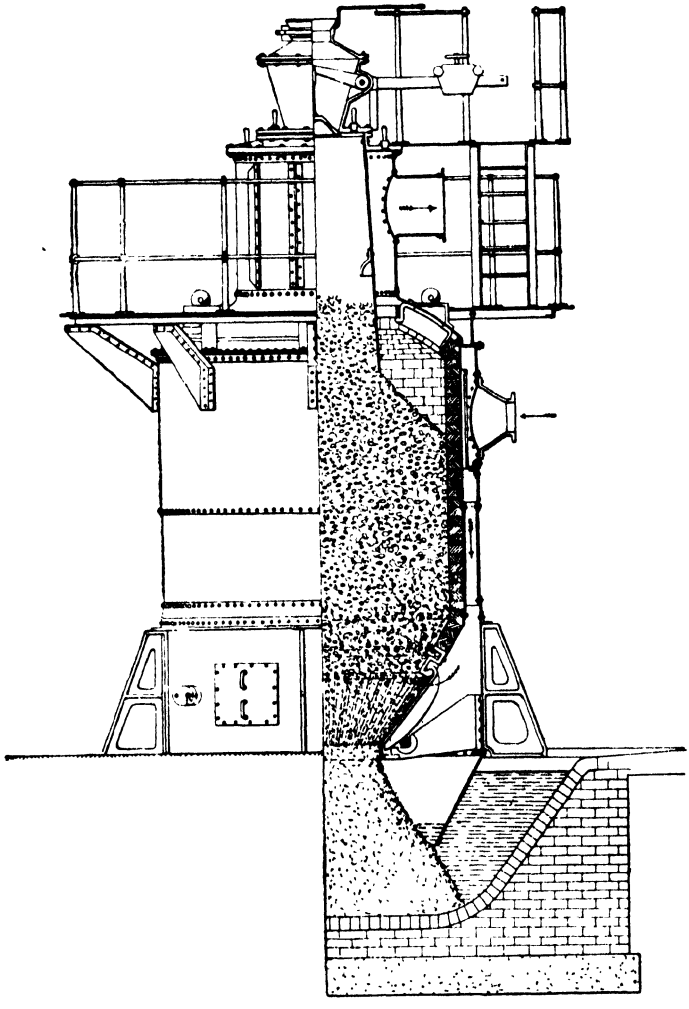


FIG. 46.—Mond generator.

In the Dowson and other producers of this type the steam, generally superheated, is the motive power that

draws in the air necessary to keep up the thermal conditions in the generator, but in several other systems the steam and air are fed independently to the generator, and the most important of these is the Mond process, designed in the first place to recover the nitrogen present in slack, which is done by using such an excess of steam in the generator that the temperature is kept down, and the nitrogen converted into ammonia by the hydrogen liberated from the steam. The excess of steam present oxidises a large proportion of the carbon monoxide produced into carbon dioxide, which is present in the gas in considerable quantities, and this reduces its calorific value, but it contains a larger proportion of hydrogen, the high thermal value of which makes it a valuable power gas, whilst the process necessary for the recovery of the ammonia ensures its being well cleansed.

Cheap bituminous slack is automatically fed in charges of 8 to 10 cwts. into a bell-shaped casting that forms a continuation to the feeding hopper, and enters the generator for some little distance. Here the freshly introduced slack remains a short time, and undergoes a process of distillation, the hydrocarbon gases and tar vapours having to pass downwards through the body of hot fuel in the generator before they can escape, the vapours being in this way converted into fixed gases.

The body of the generator is lined with fire brick, and at the bottom is a basket fire grate of inclined fire bars sloping down into a water seal for the removal of ashes and clinker.

The generator has a double lining, and the mixture of air and steam passes in and down between the two casings, in this way keeping down the temperature of the inner lining, and at the same time heating the feed. The proportion of steam used is very large, being about 2½ lbs. for every pound of fuel gasified, and this excess

serves the dual purpose of keeping the temperature below the point at which the ammonia formed by the combination of the nitrogen and hydrogen would again be decomposed, and also, by preventing caking and clinkering in the fuel, facilitates the automatic working of the plant.

Leaving the generator, the producer gas, containing still an excess of steam, passes at a temperature of about 450° C. to the regenerator, consisting of a series of double tubes, where the hot gases, flowing through the inner tube, heat up the air and steam mixture flowing through the outer tube on their way to the generator. The gas then passes through the washer, a chamber in which rotating paddle-wheels throw up a fine spray, which cools the gas to 90° C. (194° F.), and so cooled it passes up a tower in which the gas is washed by 4 per cent. sulphuric acid, the ammonia being converted into ammonium sulphate, which remains in solution, and is continuously withdrawn and replaced by fresh acid. The gases, now cooled to 82° C., pass on to a cooling tower, where cold water condenses some of the remaining water vapour from it, and reduces the temperature to 61° C., at which it leaves the plant. The water, heated by cooling the gas, then flows down a third tower, up which the air feed for the generator, driven in by a blower, is passing, and saturates it with water vapour, and the moistened air, being further heated in the regenerator, passes on to the generator.

The quantities and temperatures are so arranged that for every ton of slack fed into the generator about 2½ tons of steam and 3 tons of air are blown in, and about 160,000 cubic feet of gas are obtained per ton of fuel, with about one ton of ammonium sulphate for every 28 tons of fuel consumed, about 23 tons being gasified and 5 used for producing the extra steam required.

The composition of the Mond gas approximates to—

	Per cent.
Hydrogen	24·8
Methane	2·3
Carbon monoxide	13·2
Carbon dioxide	12·9
Nitrogen	46·8
	100·0

The thermal value of the gas is usually about 38 calories or 150 B.T.U., so that, in spite of the cooling effect of the 13 to 16 per cent. of carbon dioxide found in it, the increase in the quantity of hydrogen and methane suffices to bring the calorific value up to as high a value as is found in a semi-water gas. The specific gravity of the gas is about 0·8.

The complication in the plant needed for the ammonia recovery, which is the profit-earning part of the plant, renders it unfitted for installations of less than 4,000 h.p., and to give the best results it should work continuously. As this production is far beyond the needs of any but a few of the largest works, Parliamentary powers have been obtained for distributing the gas as a fuel supply in South Staffordshire over an area of some 120 square miles, the gas being sent out from the works through a 3 ft. main under a pressure of 10 lbs. per square inch. By using a battery of generators the gas can be kept constant in production, and gas holders for storage dispensed with, the trunk mains really forming a storage chamber for the gas under pressure. It is supplied to the consumer through a reducing valve, which cuts down the pressure to that most suitable for the work in which it is to be employed.

Another type of semi-water gas generator is the "Buire-Leucauchez." In this system no external source of steam

L.C.C.

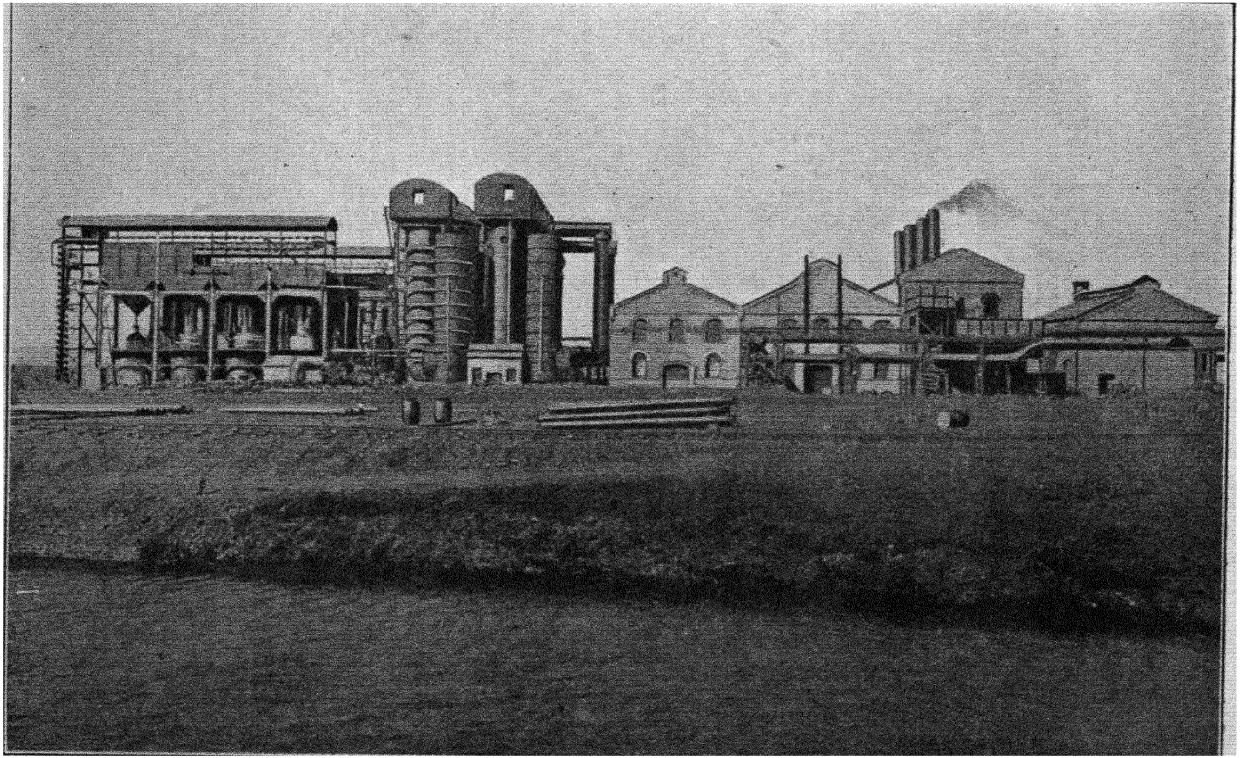


FIG. 47.—Mond plant, South Staffordshire.

is employed, but a thin stream of water is allowed to trickle on to highly-heated iron plates below the generator grate, and being evaporated by the radiant heat, is caught up as steam by the air blast and carried into the bed of incandescent fuel.

When poor fuel gas first forced its way into notice it was entirely as a heating agent chiefly for steam raising; then came the adaptation of it to metallurgical and manufacturing processes, brought about by the introduction of the regenerative system by Siemens; and finally it has achieved its great success in the direct production of power by the internal combustion engine.

The last forty years have seen the rise of the gas engine from the early forms of the Otto and Langen type, which was limited in size to about 3 h.p., and certainly showed no sign of being a bantling which in less than forty years would compete with the steam engine in all sizes up to 1,000 h.p. as a source of motive power. The gas engine has even grown out of its name, and has now assumed the more ambitious title of "internal combustion motor" in order to enable it to cover the use of not only those gases rich in calories, such as coal, oil, and water gas, but also the poor producer and semi-water gases, and even petroleum vapour, alcohol, benzene, and atomised oil.

Up to 1879 no fuel but coal gas was used in the gas engine, but in that year Dowson showed that it was possible to use the gas now commonly known by his name, and as the engine was gradually improved in construction, and the problems to be solved in its use became clearer, so modifications were made that led to the present compression type of engine and its further improvement, until now an indicated efficiency is claimed for it of over 30 per cent., whilst the size of the engine has grown from the original 3 b.h.p. Otto engine of 1876 up to 2,000 b.h.p.'s, and for

many phases of power work the steam engine has practically passed away.[1]

When it was realised that the large percentage of incombustible nitrogen in the Dowson gas was not an insuperable objection to its use in the gas engine, small generators of that type were largely employed for the production of the cheap semi-water gas for engines of moderate horse power. In attempting to further simplify the form of such generators the idea was revived of drawing the air or air and steam into the bed of incandescent fuel, instead of driving it in, but in place of using the suction of a flue to do this, as Bischof and Siemens had done in the earliest forms of generator, the attempt was made to use the suction in the engine cylinder, caused by the thrust of the piston, not only to draw gas from the generator to the combustion chamber of the engine, but also to draw air and steam into the fuel in the generator, so that the engine in its working should bring about the make of gas needed to continue its action. So arose the suction generator, which has so largely increased the use of the gas engine.

The first of this type of generator was made, the author believes, by M. Leon Berrier in 1894, who fitted a suction pump to the side of the engine cylinder; the pump being driven by the fly-wheel, sucked gas from the generator and compressed it into the engine cylinder, whilst the lowering of pressure in the generator sucked air and water vapour into the fuel, and made a fresh charge of gas.

The first plant of this type that the author saw was near Berlin, in 1895, at Messrs. Pintsch's works, in which steam was generated by the heat of the gas passing to the engine in an external vaporiser, and was drawn under the grate of the generator and carried into the fuel by the air sucked in, whilst after passing through a scrubber, a purifier and a regulating valve, the gas travelled on to the combustion chamber of the engine. Since then many forms of

[1] See note (16) on p. 286.

suction generators have been devised, differing mainly in small details only, but tending to the simplification of the plant.

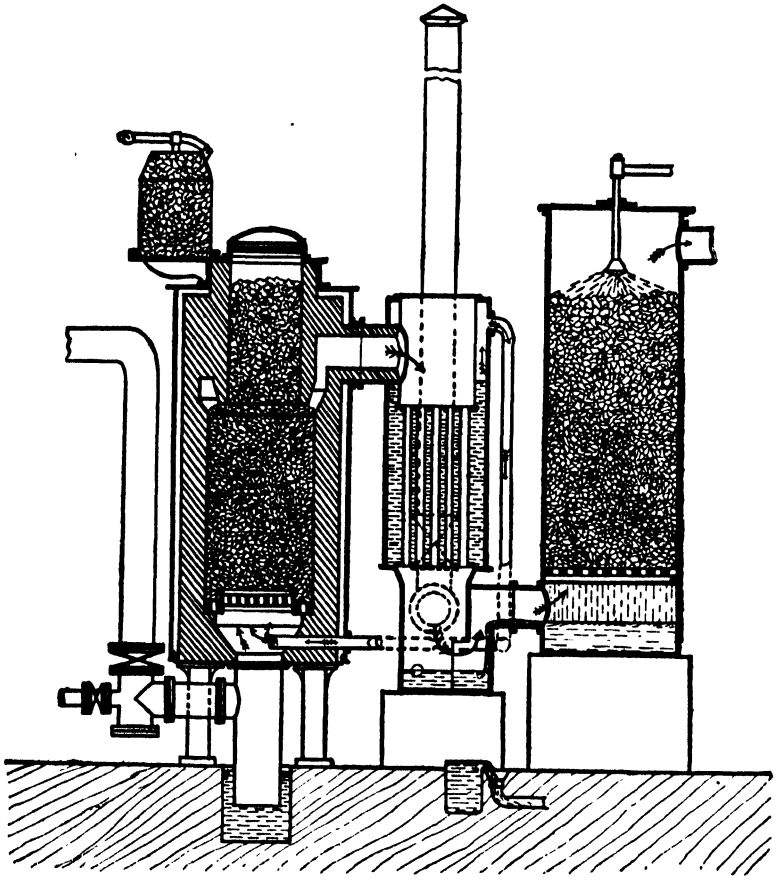


FIG. 48.—Pintsch suction plant.

As an example of the latest type the Dowson suction plant, shown in section in Fig. 49, may be taken. In this plant the anthracite peas forming the fuel are placed in the container, which holds sufficient to last for several hours,

and pass by gravity into the body of the generator as the fuel in it burns low. Water supplied at the right rate from

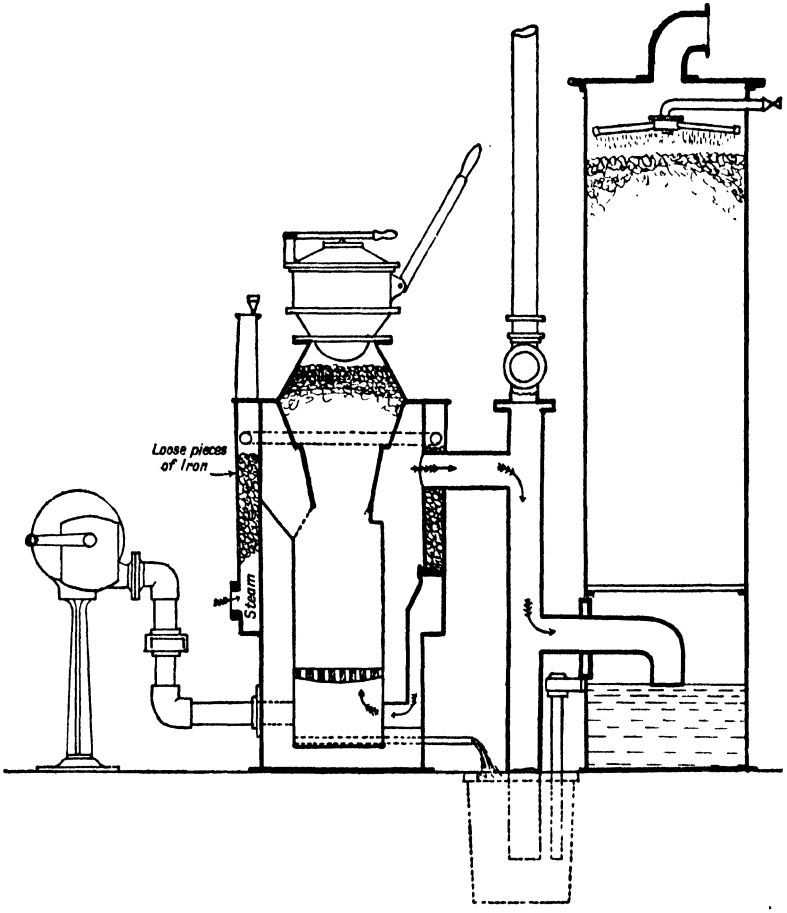


FIG. 49.—Dowson suction plant.

a circular drip pipe, fed by a bird fountain, trickles on to a column of broken brick or iron in a chamber in the top lining of the generator, whilst air entering the vaporising chamber mingles with the steam, and the two then are

sucked down below the bars at the bottom of the generator and pass upwards through the fuel: being there converted into gas, it passes through a water seal and coke scrubber to the engine.

This form of plant has many advantages, not the least being the small stand-by loss when not at work, and low cost of repairs. The average fuel consumption is one pound of anthracite per brake h.p. hour, so that with anthracite at 20*s.* per ton, the b.h.p. only cost about 0·1 of a penny.

Tests of the gas made in a Dowson suction plant by Mr. Ballantyne give the composition as being—

	Per cent.
Hydrogen	15·2
Methane	1·2
Carbon monoxide	21·0
Carbon dioxide	8·2
Oxygen	0·2
Nitrogen	54.2

The fuel used was anthracite "peas," and its thermal value was 35·3 calories or 137·7 B.T.U per cubic foot, and as a rule the thermal value of the suction gas is about ten per cent. below that of gas made in the pressure plant.

The latest development in the use of the gas engine and suction plant is in the direction of adapting it for marine purposes, and this is due to Herr Emil Capitaine, who not only played a leading part in developing the marine motor, but has devoted many years to adapting the gas engine for the propulsion of vessels.

On a small scale this has been successfully accomplished, and a 16 ton gas motor launch, named after the inventor of the system, *Emil Capitaine*, took part in the reliability trials for motor boats held in the Solent

in 1905, and attained an average speed of ten miles per hour for ten hours on a consumption of 412 lbs. of anthracite, this weight including the stand-by losses of the generator.

Several tugs, barges, and other vessels fitted on the same principle have been used on the Continent, and a gas motor

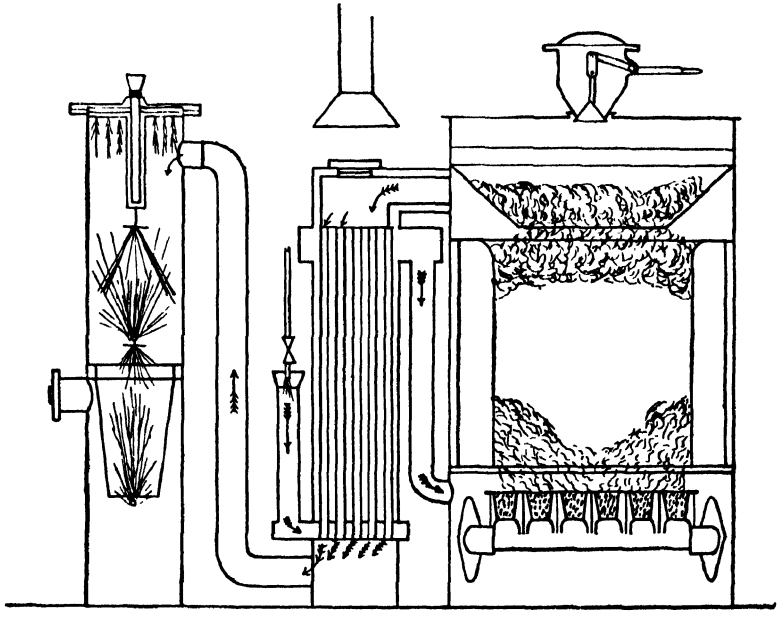


FIG. 50.—Capitaine suction plant.

barge, fitted by Messrs. Thornycroft, in the spring of 1906, made an extended tour of the English canals, the engine being under weigh for forty days. To demonstrate the possibility of making marine gas engines of considerably higher horse power, Messrs. William Beardmore have constructed sets of engines of 500 and 1,000 h.p., to work with gas producers on a 7,000 ton cargo steamer.[1]

It has been pointed out that one of the greatest essentials in

[1] See note (16) on p. 286.

using gaseous fuel for power is that it should be clean and free from tar or dust, which might give rise to choking in the valves and glands of the engine, and in the suction plants used with land engines coke scrubbers are employed, which would occupy far too much space for marine work.

In the suction plant devised by Capitaine for his small power engines, the bulky coke scrubber is done away with, and the gas leaving the generator is first made to give up as much of its heat as possible to the ingoing air and steam in a double tube regenerator, and then passes on to a small tower, in which it is washed and further cooled by very fine sprays of water, which form, with the tar and dust, a fog in the gas, which is got rid of by passing the gas through a centrifugal machine running at a high speed; this throws out the moisture and impurities, and leaves a clean gas to be sucked out by the engine.

In order to start the generator a fire is lighted, and the anthracite having been fed in, air is blown in by a hand-driven fan until the gas produced will burn properly at a test cock; this will take nearly half an hour with a generator of the size needed to supply 50 to 100 h.p. As soon as the gas is sufficiently good to burn, the engine is started by compressed air, and after a few strokes begins to run automatically. With large engines and producers a small oil motor is used for blowing up the fuel in the generator to the right temperature and starting the engine.

The size of the generator is of course governed by the horse power required, the area of the fire grate necessary being 0·05 square feet per h.p., as against 0·2 square feet in an ordinary steam boiler consuming 15 lbs. of coal per square foot of grate area.

The composition of the gas is much the same as with an ordinary suction plant, an analysis of the gas

from the Capitaine generator using anthracite as a fuel being—

	Per cent.
Hydrogen	14
Methane	1
Carbon monoxide	25
Carbon dioxide	6
Nitrogen	54
	100

The constant and rapid changes in speed of a marine engine when entering a crowded waterway is a serious trouble, as after working for some time at a slow speed, the fire in the generator gets dull, and if the full load is then put on, and a large charge of air and steam is drawn into the fuel, a poor gas results until the temperature has recovered itself.

The floor space occupied by the suction generator and engine for the larger powers may be taken as half a square foot per h.p., which compares favourably with the space taken up in vessels of the mercantile marine using steam power, although of course considerably above that possible in the service or in fast liners. The superficial area of engine and boiler space in various vessels is shown in the table on p. 282.

As regards weight, the suction plant and gas engine compare favourably with steam, giving the same power at three-quarters the total weight of the steam plant.

It is clear that if the marine gas engine is to be used for big powers, and is to take a place on ocean-going steamers, the fuel used in the generator cannot be restricted to anthracite or coke: it must be a fuel like bituminous coal, which can be obtained at any port, and although such cleansing processes as those adopted by Capitaine answer perfectly with a clean anthracite, directly a bituminous

coal comes to be used, coke scrubbers and elaborate condensing apparatus become a necessity for getting rid of the tar vapours and other products of the decomposition of the hydrocarbons from the coal. As we have seen in the Mond and some other processes, bituminous slack is the fuel used, but at once a complicated plant for the recovery of the by-products becomes a necessity. Such plants could never be employed afloat, and until a really successful

	SS. Deutschland.	SS. Koning Wilhelm der Grosse.	H.M.S. King Alfred.	SS. Celtic.	SS. Duke of Cornwall.	H.M.S. Juno.	SS. Indian.
Total i.h.p. . .	38,900	30,000	30,000	13,000	5,520	9,830	2,120
Highest mean speed in knots .	23·51	22·79	23	16	19·75	20	10·75
Superficial area of engine and boiler space per i.h.p., sq. feet . .	0·425	0·42	0·346	0·96	0·405	0·44	0·949
Total weight of machinery in tons . . .	5,670	4,460	2,575	2,975	612	904	455
I.h.p. per ton of machinery. .	6·35	6·71	11·65	4·37	9·02	10·88	4·66

bituminous coal generator has been devised, which will give a gas so clean as to require but very little treatment between the generator and engine, the problem of high power marine gas engines for big ships will remain unsolved. There have been many attempts to construct generators that will do this, but there are several factors which have prevented any of them being completely successful when employing the wide range of qualities in coal which have to be faced, and many of the generators for which success has been claimed have had their weak points made manifest when it has been attempted to use them for

a highly bituminous caking coal of the kind met with in many foreign ports.

A generator can be made to deal with any non-caking coal, but directly the caking varieties are employed, the fuel swells and arches of coke are formed in the generator,

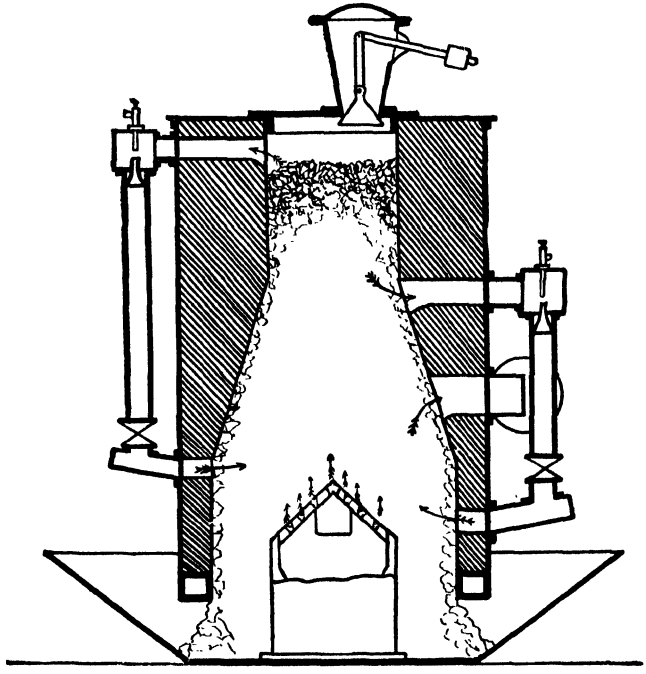


FIG. 51.—Duff-Whitfield plant.

which produce cavities in the fuel, clinker, and other troubles that at once interfere with anything like uniformity in the composition of the gas or working in the generator, whilst if this trouble is overcome, the question of the destruction or elimination of the tar remains, and an idea of what that means is shown by the hundreds of failures in the gas industry to convert tar into permanent gas.

A description of two of the most successful generators

using bituminous coal will give an idea of the general lines upon which inventors are working in their attempts to solve these difficulties.

In the Duff-Whitfield generator, the hydrocarbon gases and tar vapour formed by the distillation of the coal freshly

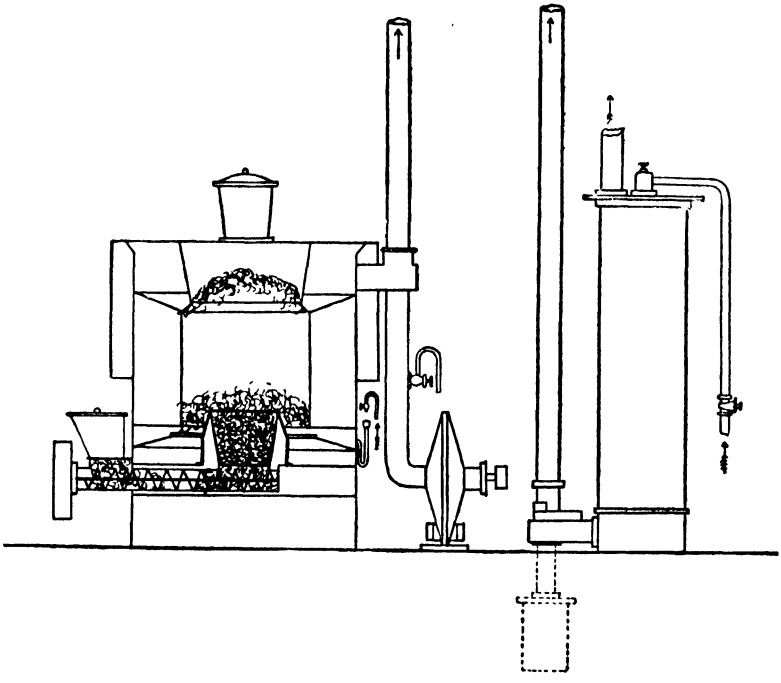


FIG. 52.—Boutillier suction plant.

fed into the generator are led by a pipe from the space at the top of the fuel, and are discharged into the incandescent mass just above the entering air, which, being the hottest point in the fuel bed, tends to decompose them, and before reaching the exit port these vapours have to traverse a considerable depth of heated fuel, which as far as possible completes the action.

In the Boutillier plant, the generator is under-fed by a

spiral stoker, which supplies the coal to the bottom of the generator. The gas and tar distilling out pass up through the whole bed of incandescent fuel, which, as in the case of the Duff-Whitfield arrangement, effects its complete decomposition. The Kerpeley & Tees are other producers of this type.

In these days of rapid engineering advancement it is never safe to dogmatise with regard to future developments, but the author's own feeling with regard to the marine gas engine is that it will be a success up to a few thousand horse power, but that it is doubtful if we shall ever see our monster liners and battleships developing the enormous power used by means of gaseous fuel burnt in any of the present forms of gas engine, the difficulties being to sufficiently cleanse the gas from tar without using up too much space for scrubbers and washers, and with the present forms of engines to sufficiently vary the speeds without the risk of stopping the engine.

If these troubles were once thoroughly got over the economy of the suction gas plant would soon ensure its introduction on a very large scale. In a paper read early in 1907 before the Manchester Association of Engineers, Mr. A. V. Coster quoted figures showing the economy of gas engines over steam, each plant giving 1,400 i.h.p. on 200 days' steaming.

In the case of gas the cost of fuel was £1,350, whilst with steam it amounted to £3,375—a saving in favour of gas of £2,025, whilst the weight of the gas plant was only 267 tons as against 373 tons with steam as the motive power.

The necessity of a perfectly clean gas from the suction plant arises from the fact that regularity in running is dependent on keeping the valve seats free from tar, and scrubbing the gas with spray seems the most effective method of doing this, a 20 b.h.p. plant using from 2,000 to 3,000 gallons of water per week for ten hours a day working.

The consumption of fuel in a gas suction plant during the time gas is not being made, known as "the stand-by loss," is far lower than with any form of steam engine, generally only amounting to about one-seventh.

In some recent trials of small plants the following results as to full consumption were obtained, the plants being from 15 to 20 b.h.p. :—

Using anthracite as a fuel—

Full load : 1·1 lbs. per b.h.p. hour.

Half load : 1·6 „ „ „ „

Water : 1 gallon per b.h.p. hour at full load and $\frac{3}{4}$ at half load.

Using coke as fuel—

Full load : 1·3 lbs. per b.h.p. hour and $1\frac{1}{2}$ gallons of water.

In all cases fuel needed for starting is included.

(16) The gas engine, in its larger sizes, has not proved entirely satisfactory ; and since the turbine type of engine has greatly improved the efficiency of steam for power generation purposes, the use of gas power is confined now chiefly to engines of comparatively small size. Where large volumes of poor or waste gases are available, the modern plan is to employ these for steam generation in specially-designed boilers, as described in a recent work on "Waste Fuels," by John B. C. Kershaw (Constable & Co., 1920).

CHAPTER X.

THE FUEL OF THE FUTURE.

Comparison of the thermal values of our fuels: Solid, liquid, and gaseous — The internal combustion engine as a measure of efficiency with gaseous fuel—The future of the fuel question—The life of our liquid fuel supply—The era of gaseous fuel—The utilisation of the peat deposits of the world—Modern methods of making peat a valuable fuel—The calorific value of peat briquettes as compared with other fuels—The problem of the future—The fixation of solar energy and its regeneration by combustion—Fermentation and the production of alcohol from vegetation—Alcohol as a fuel—Denaturated or methylated spirit: Its calorific value — Practical trials of substitutes for petrol—Future of alcohol as a motor fuel.

HAVING reviewed the various fuels and the way in which they are employed, it will be well to now collect and contrast the data available with regard to their calorific value, so as to obtain a clearer idea of their relative value in thermal units as apart from their intrinsic value in practice.

AVERAGE THERMAL VALUE OF FUELS.

	Calories.	British Thermal Units.
Coal—		
Newcastle	8,446	15,203
Welsh	8,402	15,123
Lancashire	8,113	14,602
Derbyshire	8,120	14,616
Anthracite	8,677	15,619

AVERAGE THERMAL VALUE OF FUELS—*continued.*

	Calories.	British Thermal Units.
Coke—		
Oven coke	8,020	14,436
Gas Coke	7,900	14,226
Peat—		
30 per cent. water	3,000	5,400
20 ,, ,,	4,000	7,200
10 ,, ,,	5,000	9,000
5 ,, ,,	5,500	9,900
Wood—		
Ash	4,711	8,480
Beech	4,774	8,591
Birch	4,771	8,586
Elm	4,728	8,510
Fir	5,035	9,063
Oak	4,620	8,316
Pine	5,085	9,153
Charcoal	8,137	14,646

LIQUID FUEL.

Petroleum (fuel)—		
American	10,904	19,627
Russian	10,800	19,440
Texas	10,700	19,242
Caucasus	10,340	18,611
Borneo	10,461	18,831
Burmah	10,480	18,864
Petroleum spirit (·684)	11,624	20,923
Shale oil	10,120	18,217
Blast furnace oil	8,933	16,080
Heavy tar oil	8,916	16,050
Alcohol absolute	7,184	12,931
10 per cent. water	6,400	11,520
20 ,, ,,	5,700	10,260
methylated	6,200	11,160

GASEOUS FUELS.

Natural gas	12,008	21,615
Coal gas (London, 16 c.p.)	10,666	19,220
Water gas	4,430	7,980
Mond gas	1,402	2.525
Dowson gas	1,310	2,353
Suction-plant gas	1,200	2,160
Air-coke gas	540	972
Blast-furnace gas	528	951

In this table the calories represent the number of kilos of water raised 1° C. by the combustion of 1 kilo of the fuel, whilst the British thermal units represent the number of pounds of water raised 1° F. by the combustion of 1 lb. of the fuel.

In the case of the gaseous fuels the calorific value is determined per cubic foot burnt, and is then calculated from the specific gravity of the gas to heating value per pound.

	Cubic feet per pound at 60° F.	British Thermal Units.	
		Per cubic foot, gross.	Per pound.
Coal gas (16 c.p. London)	31	620	19,220
Water gas	26·6	300	7,980
Mond gas	16·4	154	2,525
Dowson gas	15·9	148	2,353
Suction-plant gas	16	135	2,160

The calorific value of a fuel tells us exactly how many heat units can be developed from a given weight by combustion, but it affords us no clue as to how much of that heat we can translate into mechanical work, the latter operation being dependent upon the degree of perfection in the heat engine we employ for the conversion, and often

proves a more important factor than the heating value of the fuel.

The classic researches of Joule showed us that 778 foot-pounds were equal to 1 British Thermal Unit, and we know that 33,000 foot-pounds per minute are equal to one horse power, and it follows that, on the assumption that we are using a theoretically perfect motor, $\frac{33{,}000}{778}$ or 42·42 British Thermal Units per minute will give one horse power.

The perfect motor has not yet however been attained, and the percentage ratio of the attained to the theoretical is generally spoken of as the efficiency of the engine, and is best expressed in efficiency per brake horse power. This factor is determined by experimentally finding the thermal units per minute developed by the fuel and the brake horse power, when $\frac{42{\cdot}42 \times 100}{\text{B.T.U. per minute per b.h.p.}}$ gives the percentage efficiency per brake horse power. The ratio of the true value of fuels as a source of power can be arrived at by taking their maximum efficiency as obtained in practice, and seeing how that percentage of their utilised heating value compares one with the other.

Fuel.	British Thermal Units, per lb.	Efficiency, per b.h.p.	B.T.U. utilised, per lb. $\frac{\text{B.T.U.} \times \text{Efficiency}}{100}$
Coal (steam engine)	14,800	8·6	1273
Coal (turbine)	14,800	12·0	1776
Oil (in Diesel engine)	19,440	32·0	6220
Petrol	20,923	22·0	4603
Alcohol	11,160	38·0	4241
Coal gas	19,220	25·0	4805
Mond gas	2,525	26·0	656
Dowson gas	2,353	26·0	612
Suction gas	2,160	26·0	562
Blast-furnace gas	951	25·6	243

The factors in the internal combustion motor which make for high efficiency are to be found not only in the engine itself, but also in being able to employ high compression of the explosive mixture, a cool cycle, and proper proportioning of the combustible and air.

The conversion of the heat units of a solid fuel like coal into mechanical work means having first to convert them into steam, and then utilise the steam in the steam engine, a process so wasteful that with a good type of boiler and condensing engine only about 8½ per cent. of the theoretical value of the heat units in the coal is converted into power, which the turbine increases to 12 per cent., whilst with a liquid or gas the internal combustion motor offers a conversion so far more economical that it is small wonder that steam as a source of power is looked upon as doomed.

The great advantages in weight of fuel employed however are somewhat tempered by cost, as for instance in the case of coal and oil, because although a pound of oil in the best type of engine gives five times as much power, oil of the necessary quality could not be obtained in bulk under 4*d.* per gallon, and it is the cost sheet which to the user is the true test of efficiency.

In the following table[1] the approximate cost per b.h.p. is given—

	Consumption per b.h.p.	Cost of Fuel.	Pence per b.h.p.
Coal . . .	2 lbs.	18*s.* 6*d.* per ton	0·2
Oil (sp. gr. ·8) .	0·4 ,,	4*d.* per gallon	0·2
Petrol (sp. gr. ·7) .	0·55 ,,	1*s.* ,,	0·94
Methylated spirit (sp. gr. ·82) .	0·6 ,,	2*s.* ,,	1·75
Coal gas . . .	16 cub. ft.	2*s.* per 1,000 cub. ft.	0·4
Power gas . .	1 lb. (anthracite)	20*s.* per ton	0·1

[1] These are all pre-war costs and are only of value for comparative purposes.

The future of the fuel question is one that always must be fraught with the deepest interest. There is not the slightest doubt that with regard to fuel, the world is in the position of a man who is living on his capital, and although the end may be long delayed it is bound to come sooner or later.

The question of the life of our coal supplies is one that has occupied an enormous amount of attention, and is being very fully dealt with by a Royal Commission, which has already issued a warning note:—"Vast as are the available resources, it must be borne in mind that a large percentage of them are of inferior quality, or are contained in deeper and thinner seams, which cannot be worked at the present cost."

We may take 236 million tons of coal as representing the quantity annually raised in this country, and it is interesting and instructive to note the uses to which it is applied, the figures quoted being those compiled by the Royal Commission on Coal Supplies:—

Factories	22·97	per cent.
Domestic	13·87	,,
Iron and steel manufacture	12·17	,,
Mines	7·80	,,
Gas works	6·50	,,
Railways	5·63	,,
Potteries, brickworks, glass-works and chemical works	2·16	,,
Metal and minerals	·43	,,
Coasting steamers	·87	,,
Steamers over seas	7·25	,,
Exported	20·35	,,

Of the total coal supply of the country about 52 million tons are annually used for the production of power, and

although in the best forms of triple expansion engines worked by the most economical forms of boiler it is possible to get the consumption of coal down to 2 lbs. per horse-power hour, the average consumption is a little over 5 lbs. An examination of the engines in the factories throughout the country reveals all kinds, from the most modern to beam engines erected in the first half of the last century, and if all these ancient steam wolves were relegated to the scrap heap and replaced by steam turbines, and where possible by internal combustion engines fed either by coal gas or suction gas, the average consumption could easily be reduced to $1\frac{1}{2}$ lbs. per horse-power hour.

The question of the probable future supply of liquid fuel is still less encouraging.

As long ago as 1886 Professor J. P. Lesley, addressing a meeting of the Institute of Mining Engineers in Pittsburg, said :—" I am no geologist if it be true that the manufacture of oil in the laboratory of Nature is still going on at the hundredth or the thousandth part of the rate of its exhaustion. And the science of geology may as well be abandoned as a guide if events prove that such a production of oil in Western Pennsylvania as our statistics exhibit can continue for successive generations. It cannot be. There is a limited amount. Our children will merely and with difficulty drain the dregs. I hold the same opinion respecting natural gas, and for the same reasons, with the difference merely that the end will certainly come sooner and be all the more hastened by the multiplication of the gas wells, and of the fireboxes and furnaces to which it is led."

This has proved to be true with regard to the natural gas, whilst, although statistics show that the output of oil is increasing, an analysis of the returns indicates that this is due to increase in the number of wells, and not to any increase in natural supply, the oil-bearing wells being

extremely short-lived, and the rapid multiplication of new wells using up at an alarming rate the available area over which the oil is found.

Under these conditions it is impossible to resist a glance forward to the period when, our capital being exhausted, we are driven to search out fresh means of developing the heat energy upon which commercial supremacy is so absolutely dependent.

As our present supply of solid and liquid fuel becomes less and less, there will be an intermediate period in which fuel substances hitherto neglected will be pressed into service, whilst feverish economy will take the place of the prodigal waste which at present characterises our use of existing fuels.

The use of steam as a motive power will grow less and less before the conquering strides of the internal combustion motor, and where it is used it will be in the turbine and not in the reciprocating engine. This period also will see great advances in the centralisation of power production, and in no case will this be more marked than in the manufacture of gas, which, made in coke ovens at the colliery, will be distributed under pressure over great distances, the gas being not a high power illuminating gas but a mixture of the coal gas from the coal and water gas from all the coke that is not required for metallurgical purposes, the mixture having 8 to 10 candle power, and between 400 and 500 B.T.U.'s per cubic foot, with a selling price of under 1*s*. per thousand, and will be used for illumination with the incandescent mantle, heating in the gas stove, and power in the gas engine.

This period will also see the utilisation of the vast deposits of peat, and the rapid commercial development of those countries in which it is to be obtained.

An idea of the general distribution and quantity of peat likely to be available may be gathered from the following

table, showing the areas of peat bogs in various European countries, whilst in Canada and America the supplies are even more vast.

Sweden. . . .	5,198,500 hectares.
Norway . . .	1,600,000 „
Denmark . . .	81,000 „
Finland . . .	7,400,000 „
Russia (in Europe) .	38,000,000 „
Ireland	475,000 „
Germany . . .	2,837,000 „

In a drained "settled" bog the content of dry peat fibre is about 12½ per cent.

One hectare is 2·47 acres, thus containing 1,250 tons of peat per metre of depth of bog. A bog with an average depth of 2½ metres will consequently give 3,125 tons of peat (calculated as dry fibre) per hectare.

In all processes for the preparation of a useful fuel from the enormous peat deposits of the world the trouble has been to find a method by which the large quantity of water held by the raw peat could be economically reduced to a percentage that would make the peat a fuel of sufficiently high calorific value to compete with the other solid fuels.

The raw peat as won from the bog contains anything up to 88 per cent. of water so firmly held by the fibre that pressure, centrifugal wringing, and other mechanical means are unable to eliminate any considerable percentage, whilst to evaporate by artificial heat the 80 to 88 per cent. of water would use more fuel than would be left, the result being that air-drying has been the only possible method to employ to get rid of at least part of the moisture in the peat.

Air-drying, however, necessitates time, space, and, above all, dry atmospheric conditions, the latter being rarely met with in the humid districts in which the peat bogs are

found, and the result has been that the practical output of peat fuel has been very small, whilst the thermal value has been so low that it has had no market where other forms of fuel were obtainable.

It has now been found that when peat, as obtained from the bog, is pulped into a homogeneous mass and heated under pressure to a temperature between 150° and 180° C. it ceases to hold the water in the same way as before, with the result that it can be mechanically wrung or pressed out of the peat, whilst the residue on slightly warming can be moulded into briquettes having a considerably higher calorific value than any previously made, whilst chemical actions just started in the tissues of the peat cause the exudation of small quantities of hydrocarbons of the nature of paraffins, which, on pressing the warm peat residue in a briquetting machine, cause the fibres to bind together into a dense ebonite-like mass having a specific gravity of 1·28 with a good non-absorbent surface.

The author has tested both laboratory-made medallions and briquettes made in this manner on a commercial scale for calorific value in the Mahler Bomb, with the following results:—

Medallion = 5,744 calories = 10,337 B.T.U.
Briquettes = 5,136 „ = 9,245 „

Peat briquettes have been made for some time in both Sweden and Canada, the process generally being to take the raw peat with its contained water, amounting to between 80 and 90 per cent. of the mass, air-dry the moisture down to 50 per cent., disintegrate and dry by artificial heat down to 15 to 20 per cent. of moisture, pulverise and mould hot into briquettes.

The ordinary peat briquettes made by such a process have a calorific value below 4,000 calories, the most often quoted figure being 3,802 calories, given by a determination

made by the Royal Chemical Institution of Berlin, and the great superiority of this type of briquette in thermal value is entirely due to the more thorough elimination of water during the process of manufacture.

The importance of eliminating the water may be seen from the following analyses of moisture in peat, and the calorific value of the samples as determined by the Bomb :—

Percentage of Moisture in the Peat.	Calorific Value.
26·0	3,246
22·0	3,802
21·0	4,115
16·0	4,331
15·0	4,490
12·0	4,832
7·37	5,136
6·12	5,489
5·9	5,744

If these figures be plotted diagrammatically it will be seen that it is practically correct to say that each 10 per cent. of moisture present in the peat reduces the thermal value by 1,000 calories.

A black peat medallion, which gave a calorific value of 5,744 calories, was made in the laboratory by the wet carbonising process at a temperature of 180° C., which means a pressure of nearly 10 atmospheres, or 150 lbs., on the square inch, and contained 5·9 per cent. of moisture; whilst a peat briquette made by the same process and which had a thermal value of 5,136 calories, and had been made on a commercial scale at a temperature of 155° C., contained 7·37 per cent. of moisture.

In order to gain a clear conception of the fuel value of the peat briquettes, it will be well to contrast their thermal value with other forms of fuel.

Eight thousand four hundred calories may be accepted as fairly representing the run of English coals, whilst the average of the German coals would be nearly 1,000 calories less, *i.e.*, 7,400.

It is not, however, the best samples of coal which are

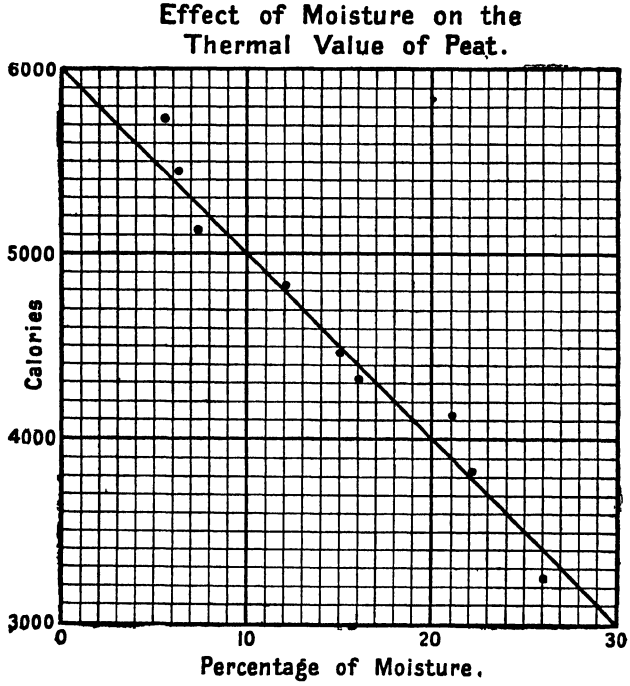


FIG. 53.

always exported, so that it would be probably fair to take 8,000 calories as a heat standard.

Taking now the peat briquettes at 5,136 calories, the ratio to ordinary coal will be $\frac{5136}{8000} = 0{\cdot}64$, or approximately two-thirds the value, weight for weight, of coal.

The briquettes, however, would have a considerable advantage in stowing over coal, owing to their packing

close; a ton of briquettes will occupy 30 cubic feet, whilst the average stowage value of the Newcastle coal would be 43 to 45 cubic feet, or one-third greater, so that bulk for bulk the briquettes would represent just about the same heating value.

It is not, however, with high grade English coal that the peat briquette comes into competition at present as a fuel, but with brown coal and lignite, which, on account of the high moisture and ash contained in them, rarely have a heating value much exceeding 4,000 calories and often below 3,000. Such coal, however, is often made into briquettes, in which a good deal of the moisture is driven off, which increases their calorific value, and it is with these brown coal briquettes that the peat briquettes will come most largely in competition.

These brown coal briquettes are mostly made in Germany, and taking seven well-known brands, the calorific values range from 4,323 calories to 5,098, the average of them all being—

4,959 calories, or 8,926 British Thermal Units.

So that the peat briquettes made by this process are fully equal to the best brown coal briquettes in thermal value, and far superior to them in ash and sulphur.

The peat briquettes burn with a clean, bright combustion, which can easily be regulated so as to be practically smokeless, and as they are not brittle the loss from breakage is very small. These properties make the briquettes an ideal fuel for the house and for many manufacturing operations, and their adoption on a large scale would do much towards cleansing the air of our big towns from the smoke nuisance due to the use of bituminous coal.

There is another point in drawing comparisons between different kinds of fuel based on their calorific value that must not be overlooked, and that is the amount of air

needed for complete combustion. This, in the case of peat, is less than with coal, the result being that, in practice, so sharp a draught not being required, the heat of the peat is better utilised, and in working results the peat will often in steam raising more than hold its own with coal of a considerably higher thermal value.

The peat, however, will not last for ever, and a time must be reached when a world, bankrupt in fuel, has to face one of the greatest problems that can be formulated, and then the work of ages long past will be utilised, and the memory of the work of men like Priestley, Sausaure, Helmholtz, and many others will help to a solution of this all-important question.

We have seen that, no matter what the source of our oil supplies may be, all other forms of fuel at any rate are of vegetable origin, and we have also seen (p. 24) the wonderful cycle in Nature by which the balance of animal and vegetable life is kept constant, the energy derived from the sun being the determining factor which enables plant life to feed on the products of animal life, so revivifying the atmosphere as to make the living world a possibility. The more one studies this marvellous action, the more clearly does one see that the whole energy of the world is sunlight, that the vibrations of life are just as dependent upon the sun's rays as the growth of the plant, the only difference being that the plant has the power of absorbing and fixing a certain proportion of the energy flooded down upon it, whilst the living animal has to derive its energy second-hand from the vegetation and, in the higher grades of life, from the flesh that fed on it.

In the same way, in combustion we see that the heat we derive from our coal, our peat, or wood, is simply energy which, during the life of the plant, has been rendered latent in doing the chemical work of breaking up carbon dioxide and water vapour, and storing the carbon in combination

in the cellulose in such a form that, on burning back to carbon dioxide once more, the energy is again liberated as the heat and light which had its origin in the sun's rays, although thousands of years may have elapsed since those rays fell on the growing vegetation that afterwards formed our coal fields. Life without light is impossible, and both vegetation and animal at once deteriorate as soon as it is to any extent withdrawn. It is no false impulse that makes us yearn for sunny climes; sun is life, and the sun's energy during countless ages has been stored up in the fuel beds of the world, and having squandered these, when we find ourselves bankrupt in our powers of heat production, it is to the sun again that we must turn.

When we take stock of our sources of energy we find that we can employ gravity, muscular force, or the heat of combustion to generate power, but if we go still further back we find the energy of the sun behind them all. Without the sun the circulation of water in Nature would cease, and gravity would not help us much without water power; cut off vegetation, and muscular power, deprived of vegetable and animal food, ceases; cut off light, and the world returns to a lifeless mineral mass.

As far as our knowledge goes, it is vegetation, and vegetation only, that has the power of storing sun energy in such a form that it can be reproduced and converted into power when we require it, and the extent to which this action takes place is but limited, Helmholtz having calculated that of the energy exerted by the sun's rays on any area of growing vegetation about one fifteen-hundredth is fixed in doing chemical work, but small as this fraction is, it is an important asset in the future of the world, and although gravity employed as water power generated by cataracts and tides will be an important source of power, it is to the growing plant that we must turn for the main supply of energy generated in the fuelless world of the future.

It is quite clear that existing conditions would render impossible the conversion of vegetation into any of the forms of fuel to which we are accustomed, as, apart from the fact that the vegetation that formed our coal measures grew under entirely abnormal conditions, the conversion of the cellulose into peat, lignite, and coal is an operation which requires a combination of time, temperature, and pressure impossible now to attain, whilst, save to a very limited extent, timber even takes too long in its growth to be more than an insignificant adjunct. After careful consideration of every possible method by which growing vegetation could be rapidly converted into available fuel for the generation of heat, we are forced to the conclusion that fermentation will be the only practical solution of the problem.

Of the many forms of cellulose produced by the growing plant, starch is one of the most important, as it possesses an organised structure and is essential to the germination of the seeds. It is found in abundance in potatoes, wheat, and rice, an idea of the composition of which can be obtained from the following analyses:—

	Potatoes.	Wheat.	Rice.
Starch	20·2	60·8	83·0
Water	75·9	12·1	5·0
Gluten	—	10·5	6·0
Albumen	2·3	2·0	—
Dextrin and sugar	—	10·5	1·0
Woody fibre	0·4	1·5	4·8
Oily matter	0·2	1·1	0·1
Mineral matter	1·0	1·5	0·1
	100·0	100·0	100·0

During germination a remarkable substance called "diastase" is formed, which has the power of inducing

the conversion of starch into dextrin and maltose, which, when fermentation is started by the addition of a small quantity of yeast, is converted into alcohol.

During this action 95 per cent. of the grape sugar is split up into alcohol and carbon dioxide, 4 per cent. forms succinic acid, whilst about 1 per cent. is used up by the yeast in its growth.

Although grain contains such a larger proportion of starch than potatoes, the latter will always be the more economical source of fuel alcohol, as the crop per given area is much larger. For instance, an acre of land will yield about $12\frac{1}{2}$ cwts. of grain, equal to $8\frac{1}{5}$ cwts. of starch, but from the same ground you could get 125 cwts. of potatoes, yielding 22 cwts. of starch.

A ton of potatoes yields from 25 to 28 gallons of absolute alcohol, or up to 30 gallons of 90 per cent. spirit, and this would mean that potatoes would have to be grown in such quantities as to sell at 20*s*. a ton[1] if the methylated spirit was reduced to 1*s*. a gallon. It must, however, be remembered that excise restrictions very much increase the cost of production, whilst the Government charges for supervision and denaturation amount to about 5*d*. per gallon, and that when the day comes that sees the world dependent on alcohol fuel, such restriction will be swept aside or reserved for potable alcohol.

The beetroot sugar industry has made great strides forward in France, and beetroot molasses is a cheaper source of alcohol than even potatoes, whilst still later experiments show that wood sawdust can be made so generous a source of alcohol that over 50 gallons of 90 per cent. alcohol per ton can be obtained from it, and, when the great demand for alcohol as a fuel arises, it will be found that vegetation in all its forms will by proper treatment yield to

[1] In Ireland, in a good season, potatoes cost 35*s*. to 40*s*. per ton wholesale.

fermentation and give us the means of regenerating the solar energy that caused its growth.

For years past in both Germany and France the importance of keeping labour on the land and preventing overcrowding in the cities has led to the Governments of those countries doing all in their power to encourage the production of industrial alcohol, and in Germany especially State aid has not been spared to develop agriculture in this particular direction, and when we desire to know the value of alcohol as a fuel, we find that our own meagre experiments are entirely overshadowed by the work which has been done on the Continent.

If we are to judge a fuel entirely by its calorific value, alcohol would prove itself but a poor substitute for the hydrocarbons derived from shale or petroleum, but, as has been pointed out on several occasions, there is a factor quite as important as calorific value, and that is the ease with which calories can be converted into work, and the use of alcohol and petrol respectively in the internal combustion motor is as good an example of this as could be cited.

If we take the calorific value of alcohol as given by various observers, we are struck by the wide differences in the figures determined by them, and when one determines the value by experiment, one finds that the determination presents several difficulties. In the Bomb the difficulty of exact weighing with a volatile liquid and the formation of a trace of aldehyde during burning introduce errors, whilst if we vaporise and determine the calorific value in the Junker calorimeter, it is difficult to obtain a sufficiently high rate of combustion with accurate weighing to give true results. Another source of error, of course, is that the so-called "absolute alcohol," unless most carefully prepared, may contain a considerable percentage of water.

The molecular heat of combustion of ethylic alcohol, as determined by Faure and Silbermann, was 330,450,

which would give 7,183·7 calories per unit, whilst determinations in the Mahler Bomb give 6,950 calories, so that we shall not be far from the truth in taking 7,000 calories, or 12,600 B.T.U., as the thermal value of absolute alcohol, whilst methylated alcohol in the calorimeter gives a heating value of 6,200 calories, or 11,160 B.T.U., which is further

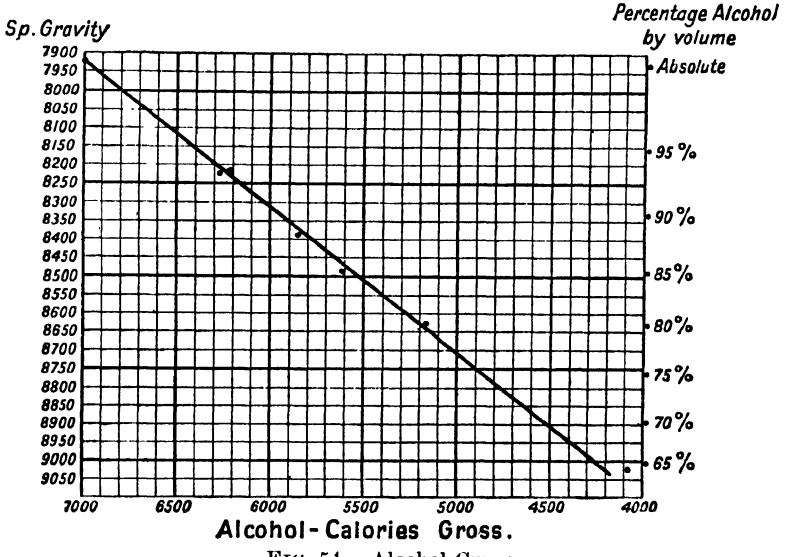


FIG. 54.—Alcohol Curve.

reduced when 20 per cent. of water is present to 5,450 calories, or 9,810 B.T.U.

Taking the values determined for alcohol with known percentages of water and plotting them diagrammatically, a line is obtained which will give the calorific value for any percentage of alcohol, and this may be approximately obtained by taking the specific gravity of the sample by means of the hydrometer and by reference to a specific gravity table.

It is, however, the denaturated or methylated spirit that we must take into consideration, as it is the only form of

alcohol which at present, and probably for a long time to come, will be available for industrial purposes.

This form of alcohol is, as a rule, 90 per cent. spirit, to which has been added something sufficiently foul in smell and taste to prevent even the most hardened drinker from attempting to use it as a beverage.

In England this is done by mixing with the spirit 10 per cent. of methylic alcohol, or wood naphtha (CH_4O), which has a lower thermal value than the ordinary, or ethylic alcohol (C_2H_6O), the calorific value of pure wood naphtha being 5,307 calories, or 9,552 B.T.U.

Taking now the methylated spirit with its thermal value of 6,200 calories, let us see how it compares as a source of energy with those at present in use.

As before pointed out, it is the internal combustion motor that at present must be taken as the index of success in the generation of energy, and in this field of utility alcohol at once comes into competition with petrol, which from the advent of automobilism has occupied the pride of place.

Taking the thermal value of the two liquid fuels, alcohol seems to have but little chance as a competitor:—

	Calories.	British Thermal Units.
Petrol (sp. gr. ·684) .	11,624	20,923
Methylated spirit . .	6,200	11,160

the calorific value of the spirit being not much more than one-half that of the petrol.

When, however, they come to be tested directly one against the other in practice, the difference practically nearly disappears, and in experiments made with a pair of eight horse-power engines, one designed for alcohol and the other for petrol, the consumption was:—

Petrol . . .	340	grams	per horse-power hour.
Methylated spirit .	373·5	„	„ „

the efficiency calculated for the petrol being only 16·5 per cent., whilst for the alcohol it rose to 28 per cent.

Moreover, it must be borne in mind that an enormous amount more work and experience has been brought to bear upon the petrol motor than has been devoted to alcohol motors, and there is very little doubt that when attention becomes more concentrated on the use of alcohol it will be found far more fitted than petrol for a motor fuel. The fact that it is possible to attain so much higher an efficiency from alcohol is due to two sets of factors—first, the greater ease with which complete combustion can be obtained, and the smaller proportion of air needed as compared with petrol; and secondly, the fact that with alcohol far higher compression and a comparatively cool cycle is possible, conditions which are amongst the most important in fuel economy.

Taking first the question of combustion, we have seen that a good petrol may for all practical purposes be looked upon as hexane, C_6H_{14}, as it is a mixture of this with the lower and next higher members of the group in proportions which give about this composition.

The complete combustion of this compound will be represented by :—

$$\underset{2 \text{ vols.}}{C_6H_{14}} + \underset{19 \text{ vols.}}{19\,O} = 6\,CO_2 + 7\,H_2O$$

so that two volumes require 19 volumes of oxygen, and as oxygen constitutes 20·9 per cent. of the atmosphere, we can take the amount of air required as

$$\frac{100 \times 19}{20{\cdot}9} = 90{\cdot}9,$$

or one volume will require 45·45 volumes of air. In a petrol motor this would mean that for complete combustion there should be not more than 2½ per cent. of petrol vapour in

the mixture entering the combustion chamber. Since practice has led to generally $1\frac{1}{2}$ times the theoretical proportion of air being admitted, the petrol vapour is diluted with about 68 times its volume of air, four-fifths of which is inert nitrogen, taking no part in the action, but tending to hinder and retard the combustion; indeed, under ordinary pressure, such a mixture would not burn, much less explode.

The compression of this mixture before explosion can only be taken to something like 80 lbs. per square inch, owing to the risk of premature ignition, and the explosion then takes place with such rapidity that the diluting action of the nitrogen present prevents anything like complete combustion taking place, and the low efficiency and stench of the petrol motor is the result. With completed combustion the products would be simply carbon dioxide and water vapour, whilst the atmosphere of the London streets since the advent of the motor 'bus needs no analysis to show what is taking place.

Compounds like the members of the paraffin group that go to form petrol, are highly susceptible to change from rise of temperature, and the heat generated by the compression already brings about a certain amount of change, otherwise there would be no risk of pre-ignition. We know that a temperature of 1,200° C. is needed to ignite the mixture at atmospheric pressure, and at the moment of explosion such portions of the hydrocarbon as do not happen to be in contact with the necessary oxygen for their combustion, owing to the hindering action of the inert nitrogen, undergo changes, some simple, some complex, which result in the products of combustion containing not only the products of complete combustion and the product of incomplete combustion, carbon monoxide, but considerable quantities of hydrocarbons, such as ethane, propane, and acetylene. These are formed by the heat at the moment of explosion from the

hydrocarbon vapours, and it is these products added to those from the lubricants that give the noisome stink which is the chief drawback to the autocar, or at any rate the chief cause of its unpopularity amongst the general public.

It has been shown by M. Sorel that in many cases in the petrol engine 82 per cent. of the hydrogen and 42 per cent. of the carbon present in the petrol is wasted owing to such secondary reactions.

If we take the petrol as being C_6H_{14}, then its percentage composition will be—

Carbon	83·7
Hydrogen	16·3
	100·0

so that as $\frac{16{\cdot}3 \times 82}{100} = 13{\cdot}04$, and $\frac{83{\cdot}7 \times 42}{100} = 35{\cdot}15$, the total amount used in the actual explosion would be—

Carbon	83·7 − 35·2 =	48·5	per cent. available
Hydrogen	16·3 − 13·0 =	3·3	,, ,,

and the thermal value of the proportion used would be 5,085 calories instead of 11,624.

With alcohol, however, we do not find the same difficulty in getting approximately complete combustion, when once the mixture of vapour and air is made.

Taking in the first place absolute alcohol, we find that its completed combustion may be represented by the equation:—

$$C_2H_6O + 3\,O_2 = 2\,CO_2 + 3\,H_2O$$
$$2 \text{ vols.} \quad 6 \text{ vols.}$$

so that the air required will be $\frac{100 \times 3}{20{\cdot}9} = 14{\cdot}3$ vols. per vol. of alcohol vapour, or roughly one-third the amount needed by the petrol, and it is fairly easy with this more

moderate proportion to attain an approximation to complete combustion, more especially as double the compression possible with petrol can be used. Where combustion with alcohol is incomplete, the products are aldehyde, acetic acid, and carbon monoxide, and it seems probable from the work of Dr. Trillat that there are three distinct stages of combustion in the engine cylinder, which are largely dependent upon the existing temperature—

	Temperature.		
I.	200 to 400° C.	$C_2H_6O + O = C_2H_4O + H_2O$	(Ethaldehyde)
II.	400 to 500° C.	$C_2H_6O + O_2 = C_2H_4O_2 + H_2O$	(Acetic acid)
III.	above 500° C.	$C_2H_6O + 3\,O_2 = 2\,CO_2 + 3\,H_2O$	

When it was first proposed to use alcohol instead of petrol in the internal combustion engine, it was prognosticated that the formation of acetone and acetic acid would cause such rapid corrosion and destruction of the valves and metal work as to render its use impossible, but the experience gleaned by experiment in both France and Germany shows that with a little thoughtful care all trouble due to this cause can be so minimised as to be practically of no importance.

There is no doubt but that the use of methylated alcohol or wood naphtha for denaturating the alcohol tends to the production of acetone and other acetic compounds of a more or less corrosive tendency, and on the Continent, when industrial alcohol has been required for power purposes, denaturation by benzene and pyridine bases and colouring by aniline dyes has been largely employed.

One's first idea is that if alcohol could be enriched in thermal value by admixture with some hydrocarbon of high calorific value with a vaporising point so close to that of alcohol that we could rely upon their vaporisation taking

place *pro rata* during carburetting, then it seems probable that the ease of burning of the alcohol might help the combustion of the hydrocarbon, and lead to a higher efficiency being developed.

It would not do to use a mixture of petrol and alcohol, as they do not dissolve in each other, and the petrol is far more volatile than methylated spirit, but benzene answers admirably for the purpose, and has been tried in conjunction with alcohol in all proportions up to a mixture of equal parts.

Benzene, as we have seen (page 98), is one of the first products of the distillation of coal tar, and is now obtained in enormous quantities on the Continent, and to a limited extent also in this country, from the recovery plants fitted to coke ovens in which the metallurgical coke is produced.[1] This hydrocarbon has the formula C_6H_6, and is only a little less volatile than petrol, one pound giving 4·5 cubic feet of vapour measured at normal temperature and pressure.

Like all the volatile hydrocarbons, there is a certain amount of variation in the determinations of its calorific value, which according to Thomsen is—

10,102 calories, or 18,188 British thermal units, but the value as determined in the Bomb is generally approximately—

9,880 calories, or 17,780 British thermal units. The commercial benzene is sold as 90 per cent. or 50 per cent. benzol according to the percentage distilling at the boiling point of water.

Like petrol, it evolves inflammable vapour, even at the freezing point, and as regards danger in storage and use, is for all practical purposes the same as petrol, and can be perfectly well used in its place for motors.

The experiments made with alcohol carburetted with benzene have been highly satisfactory, and indeed the mixing of the hydrocarbon with the alcohol seemed to get over certain troubles as to temperature of carburation, which in many of

[1] See note (17) on p. 318.

the experiments with alcohol, when the ordinary form of carburettor was used, had shown themselves, and also showed a certain economy. M. Cheveau has found, however, that even when mixed with the alcohol the tendency to undergo changes other than combustion, owing to decomposition and other causes, although it gives increased power, leads to a less efficiency than can be obtained with alcohol alone, and that a mixture of equal volumes of benzene and alcohol in experiments made by him on a 16 b.h.p. motor working at 180 revolutions gave an efficiency of 32 per cent., whilst with 90 per cent. alcohol alone he obtained an efficiency of 38 per cent.

Benzene can, however, never form a permanent carburettor for use with alcohol, since its present low price is entirely dependent on the demand for it for the production of aniline colours being more than satisfied by the amount condensed from the coke ovens. Before this source for it was utilised the benzene from coal tar fetched as high as 15*s.* per gallon, whereas now it can be obtained at 2*s.* 6*d.*, and if any large demand for it arises for use in the internal combustion engine, the price must again quickly rise to a prohibitive limit.

In any case benzene can only be used as a carburettor for alcohol so long as raw fuel, such as coal, remains plentiful, and it will disappear as soon as the natural fuel supply fails. It is to alcohol, and alcohol alone, to which posterity will have to turn for a fuel, and the sooner this fact is recognised, and the full force of experiment is turned on to the problems of the alcohol motor, the better.

The advantages of alcohol alone as a fuel are so great that it seems a pity that Government restrictions should render it practically impossible as an economical fuel. The motor boat and the submarine will undoubtedly play an important part in the coast warfare of the future, yet alcohol will be the only fuel available if our foreign oil supplies are cut off.

Moreover, the safety of alcohol as compared with petrol in not forming an explosive atmosphere at ordinary temperatures, the power of extinguishing it when on fire by water, and the fact that it only consumes one-third the amount of air for a given power make it a far better liquid fuel than petrol for use in a submarine.

A point which is greatly in favour of the use of alcohol in the motor, as compared with all other liquids yielding inflammable vapours, is that when mixed with air in the cylinder there is a greater range of composition over which the mixture is explosive than is found with any of the others.

The effect of compression upon the range of mixtures of vapour and air which are explosive has never been determined, but the effect is probably fairly constant with all such mixtures, so that the explosive range of various hydrocarbons and air will probably vary to much the same extent under compression in the cylinder as they do under atmospheric pressure.

Alcohol vapour mixed with air is explosive at atmospheric pressure when the percentage of vapour is 4 per cent., and continues explosive until there is more than 13·6 per cent. present, so that the mixture may contain any percentage between these limits and still explode, whilst with other inflammable vapours the quantity is as follows:—

	Explosive Percentage.	Range.
Alcohol . . .	4·0 to 13·6	9·6
Ether . . .	2·9 „ 7·5	4·6
Benzene . . .	2·7 „ 6·3	3·6
Petrol . . .	2 „ 5	3·0

The value of this extra range must be manifest when one considers the difficulty of getting an exact mixture of vapour and air in the cylinder.

Fifteen years ago petrol was selling in bulk for 9*d.* per gallon, which was rather below its cost of production at that time. To-day it is selling for 4*s.* 7*d.* per gallon, and even at this price the demand far exceeds the supply, owing to the great expansion of motor transport.

The possibilities of alcohol and alcohol-mixtures as substitutes for petrol are therefore greatly improved, as compared with those open in 1907, and numerous trials of these mixtures are now being made under actual conditions of transport or flight.

As an example, the tests with a new motor fuel called "Alcogas" by the U.S. Post Office (Aviation Department) may be referred to. "Alcogas" is a mixture of alcohol, 38 parts; petrol, 30 parts; benzol, 19 parts; ether, 7½ parts; and toluol, 4 parts.

The tests were made with a Curtiss Model R4 machine equipped with a high-compression Liberty 12 motor, running under service conditions on the air mail service between New York and Washington. Thirty-one trips were made on this 218-mile non-stop flight between August 4th and September 19th, 1919, and the fuel consumption was compared with that of a similar Curtiss model using high test aviation petrol, on the same journey, but doing the reverse trip between these dates.

The tests indicated a saving of 3·3 gallons of fuel an hour in favour of the alcohol fuel. Noting the revolutions per minute, the saving was even greater, as the alcohol fuel showed 1,514·3 r.p.m. as against 1,507·8 with petrol. This means not only that there was a saving of 3·3 gallons of fuel per hour, but that 6·5 r.p.m. were gained by the use of the alcohol mixture.

Another mixed fuel containing alcohol which has been placed on the market in America is obtained by mixing alcohol and ether with what is known in the oil-refining industry as "engine distillate." This hydrocarbon, when used alone for internal combustion motors, leads to the

deposition of carbon on the valves and internal walls of the cylinder, and also causes ignition troubles due to its comparatively high b.p.

The early experiments proved the value of the new fuel, and from these it was concluded that the addition of alcohol to the ordinary petroleum fuels prevented them from forming any carbon deposit in the engine, and ensured a thoroughly clean combustion. The addition of the ether produced a better solution of the alcohol in the hydrocarbon. It was also a carbon preventive, and secured the low b.p. necessary for easy starting. As regards the cost of the new mixture, the following figures have been given :—

8 gallons " distillate," at 13 cents .	\$1·04
⅓ gallon alcohol, at 45 cents . .	0·15
⅔ gallon ether, at 60 cents . .	0·40
	\$1·59

Yield, 9 *gallons mixture at a cost of* 17 *cents per gallon.*

Alcohol can be made in the United States, it is stated, for much less than 45 cents per gallon, and a well-built plant of large capacity can produce it usually for 25 cents, thus bringing the maximum cost of ether down to 30 or 35 cents per gallon.

A substitute for petrol, which was brought out in South Africa during the war and has been registered under the trade name of " Natalite," contains 54 per cent. of alcohol, 45 per cent. ether, and 1 per cent. trimethylamine. The object of the latter is to render the spirit so nauseous that it cannot be drunk as a beverage, and it is also claimed that it serves to neutralise the acetic acid formed on combustion and thus to prevent corrosion of the cylinder and valves.

A factory for the manufacture of " Natalite " was started at Durban in 1918, with a capacity of 3,000 gallons per day, using the molasses and refuse from the Natal sugar industry as raw material, and a second factory has been erected at

Nairobi in British East Africa, working on the sugar-cane plantations.

The selling price of the new mixture is stated to be 2*s.* 6*d.* per gallon in drums, and its use as a substitute for petrol is extending.

The actual calorific value of "Natalite" is only about 70 per cent. that of petrol; but owing to the oxygen that is present in the combined state in the manufactured spirit, the thermal efficiency obtained in the use of "Natalite" is higher than with petrol, and this to some extent balances the lower B.Th.U. per gallon. The vapour tension of the alcohol and ether mixture is greater than that of petrol at all temperatures.

As regards the possible sources of alcohol on a large scale, all vegetable matters containing starch or sugar can be employed for the manufacture, by use of fermentation processes. The following table, compiled by Heriot, and taken from the *Journal of the Society of Chemical Industry* of 1915, shows the amount of alcohol which can be obtained in practice from one ton of the raw materials named :—

Material.	Gallons of absolute alcohol produced per ton.
Cane molasses	69
Beet molasses	63
Potatoes	30
Beetroots	20
Maize	84
Rice	80 to 90
Wood sawdust	28 to 45

Concerning the actual production of alcohol from vegetable matter by fermentation processes, the following figures are drawn from a recent book by C. Simmonds on the subject, and they prove that before the war Russia, Austria, France and Germany were all producing large amounts of alcohol from maize, beet and potatoes. A very large proportion of the alcohol obtained from these sources was employed in Germany

for technical purposes, and four-fifths of the output in this case was said to be derived from potatoes, which yielded on the average only 26 gallons of alcohol per ton.

AVERAGE FOR FIVE YEARS, 1909—1913.

Country.	Million Gallons of 100 per cent. Alcohol.			Chief Materials Employed.
	Total Production.	Used in Beverages, etc.	Used for Technical Purposes.	
Austria-Hungary	60·6	42·7	10·4	Maize, beet, molasses.
France . .	59·3	42·3	14·7	Beet, molasses, fruit, potatoes.
Germany . .	82·9	46·7	34·9	Potatoes, grain, molasses, fruit.
Italy . .	9·4	6·1	2·3	
Russia . .	125·9	97·3	8·8	Potatoes, grain.
United Kingdom	26·0	18·2	3·9	Grain, molasses.
United States .	72·2	56·4	5·8*	Grain, molasses.

* Three years average.

The question of growing crops for the production of alcohol has been under discussion recently at a Conference of Agriculturists in Australia, and it is interesting to note that the Australian Institute of Science and Industry is carrying out experiments in that vast continent upon the production of alcohol from the "prickly-pear," a vegetable pest which covers 23 million acres, and is said to be spreading at the rate of one million acres a year. Any plan that would make it possible to utilise this rapidly-growing weed for some useful purpose would be of inestimable benefit to the agriculture of the country, for this vegetable pest now threatens to invade even the cultivated districts of the southern continent.

As regards the non-vegetable sources of alcohol, in Switzerland it has been produced from calcium carbide and acetylene gas; in Sweden from the waste liquors of the sulphite wood-pulp industry; and in U.S.A. from the refuse of saw-mills.

The raw materials of the industry are therefore very abundant and widely distributed, and there is no reason why the manufacture of power-alcohol should not develop in the outlying portions of the British Empire.

The chief hindrances to the development of the manufacture are, however, the out-of-date laws regulating the manufacture and sale of ethyl-alcohol in the United Kingdom, and until these laws are altered little progress can be made. In June, 1919, the Board of Trade Departmental Committee which had been appointed in the previous year to consider the whole question of power-alcohol presented a report in favour of admitting alcohol intended for power purposes into this country free of duty, and specifying the regulations which might be adopted to prevent this alcohol from being used as a beverage.

The ground is now cleared for further legislation, and before another revision of this book is taken in hand it is probable that the old regulations concerning the sale and use of alcohol for industrial and power purposes will have disappeared, and that the profuse vegetation of the tropical portions of the Empire will be turned to good use as raw material for the manufacture of this most valuable substitute for petrol.

(17) During the war, benzene (or benzol) has been recovered in very large amounts from the coal gas of the ordinary gas works by washing the gas, after cooling, with suitable oils. This process is known as "stripping" in the gas industry, and it is likely to be continued if the price offered for the benzene continues to be remunerative.

According to Montgomery, 26,000,000 gallons of benzol were added to our production during the war period by the extension of "oil scrubbing" in the gas works of the United Kingdom; and our total output in this country of oil fuel in 1919 was estimated by the same authority to be at the rate of 44,000,000 gallons per annum.

APPENDIX.

1. Tables and Scientific Data . . . . *pp.* 321—330

2. General Characteristics of the different Types of Fuel-oil Burner, with Illustrations . . . *pp.* 330—332

3. Extracts from the late Professor Vivian Lewes' Society of Arts Lectures (1911—1915):

   (*a*) Vertical continuous Retorts for Gas Manufacture. *pp.* 332—335

   (*b*) The Atomisation of Liquid Fuel for Marine Purposes. *pp.* 336—338

   (*c*) Benzol and Alcohol as Substitutes for Petrol. *pp.* 338—339

4. Miscellaneous Extracts:

   (*a*) A new American Type of Burner . . *pp.* 339—340

   (*b*) Experiments in U.S.A. Navy with Fuel Oil. *pp.* 340—341

   (*c*) Statistics of Oil-fired Plants in New England. *p.* 341

   (*d*) Furnace Construction and Regulation of Fuel-Oil Burners. *p.* 342

   (*e*) Records of actual Steam-raising Results with Fuel Oil. *pp.* 342—343

APPENDIX.

TABLE OF ELEMENTS.

Elements.	Symbol.	Atomic Weight.		Specific Heat.
		O = 16	H = 1	
Aluminium	Al	27·1	26·9	0·219
Antimony	Sb	120·2	119·3	0·049
Argon	A	39·9	39·6	—
Arsenic	As	75·0	74·4	0·083
Barium	Ba	137·4	136·4	—
Bismuth	Bi	208·5	206·9	0·030
Boron	B	11	10·9	0·254
Bromine	Br	79·96	79·36	—
Cadmium	Cd	112·4	111·6	0·054
Cæsium	Cs	132·9	131·9	0·048
Calcium	Ca	40·1	39·8	0·180
Carbon	C	12·00	11·91	variable
Cerium	Ce	140·25	139·2	0·044
Chlorine	Cl	35·45	35·18	—
Chromium	Cr	52·1	51·7	0·104
Cobalt	Co	59·0	58·56	0·103
Columbium	Cb	94	93·3	—
Copper	Cu	63·6	63·1	0·093
Erbium	Er	166	164·8	—
Fluorine	F	19	18·9	—
Gadolinium	Gd	156	155	—
Gallium	Ga	70	69·5	0·079
Germanium	Ge	72·5	71·9	0·074
Glucinum	Gl	9·1	9·03	—
Gold	Au	197·2	195·7	0·032
Helium	He	4	4	—
Hydrogen	H	1·008	1·000	—
Indium	In	115	113·1	—
Iodine	I	126·9	125·90	0·054
Iridium	Ir	193·0	191·5	0·032
Iron	Fe	55·9	55·5	0·112
Krypton	Kr	81·8	81·2	—
Lanthanum	La	138·9	137·9	0·045

TABLE OF ELEMENTS—*continued.*

Elements.	Symbol.	Atomic Weight.		Specific Heat.
		O = 16	H = 1	
Lead	Pb	206·9	205·35	0·031
Lithium	Li	7·03	6·98	0·940
Magnesium	Mg	24·36	24·18	0·245
Manganese	Mn	55·0	54·6	0·122
Mercury	Hg	200·0	198·5	0·033
Molybdenum	Mo	96·0	95·3	0·066
Neodymium	Nd	143·6	142·5	—
Neon	Ne	20	19·9	—
Nickel	Ni	58·7	58·3	0·109
Nitrogen	N	14·04	13·93	
Osmium	Os	191	189·6	0·031
Oxygen	O	16·00	15·88	—
Palladium	Pd	106·5	105·7	0·059
Phosphorus	P	31·0	30·77	0·202
Platinum	Pt	194·8	193·3	0·032
Potassium	K	39·15	38·86	0·166
Praseodymium	Pr	140·5	139·4	—
Radium	Rd	225	223·3	
Rhodium	Rh	103·0	102·2	0·058
Rubidium	Rb	85·5	84·8	
Ruthenium	Ru	101·7	100·9	0·061
Samarium	Sm	150·3	148·9	
Scandium	Sc	44·1	43·8	—
Selenium	Se	79·2	78·6	0·084
Silicon	Si	28·4	28·2	0·165
Silver	Ag	107·93	107·12	0·056
Sodium	Na	23·05	22·88	0·293
Strontium	Sr	87·6	86·94	—
Sulphur	S	32·06	31·83	—
Tantalum	Ta	183	181·6	—
Tellurium	Te	127·6	126·6	0·048
Terbium	Tb	160	158·8	—
Thallium	Tl	204·1	202·6	0·032
Thorium	Th	232·5	230·8	0·027
Thulium	Tm	171	169·7	—
Tin	Sn	119·0	118·1	0·052
Titanium	Ti	48·1	47·7	0·112
Tungsten	W	184	182·6	0·034
Uranium	U	238·5	236·7	—
Vanadium	V	51·2	50·8	0·115
Xenon	Xe	128	127	—
Ytterbium	Yb	173·0	171·7	—
Yttrium	Yt	89·0	88·3	—
Zinc	Zn	65·4	64·9	0·093
Zirconium	Zr	90·6	89·9	0·066

WEIGHTS AND MEASURES.

Avoirdupois Weight.

Drachms.	Oz.	Lbs.	Qrs.	Cwts.	Ton.	French Grammes.
1 =	·0625 =	·0039 =	·000139 =	·000035 =	·00000174 =	1·771846
16 =	1 =	·0625 =	·00223 =	·000558 =	·000028 =	28·34954
256 =	16 =	1 =	·0357 =	·00893 =	·000447 =	453·59
7,168 =	448 =	28 =	1 =	·25 =	·0125 =	12,700
28,672 =	1.792 =	112 =	4 =	1 =	·05 =	50,802
573,440 =	35,840 =	2,240 =	80 =	20 =	1 =	1,016,048

Long Measure.

Ins.	Feet.	Yards.	Fath.	Poles.	Furl.	Mile	French Metres.
1 =	·083 =	·02778 =	·0139 =	·005 =	·000126 =	·0000158 =	·0254
12 =	1 =	·333 =	·1667 =	·0606 =	·00151 =	·0001894 =	·3048
36 =	3 =	1 =	·5 =	·182 =	·00454 =	·000568 =	·9144
72 =	6 =	2 =	1 =	·364 =	·0091 =	·001136 =	1·8287
198 =	16½ =	5½ =	2¾ =	1 =	·025 =	·003125 =	5·0291
7,920 =	660 =	220 =	110 =	40 =	1 =	·125 =	201·16
63,360 =	5,280 =	1,760 =	880 =	320 =	8 =	1 =	1,609·315

Measure of Capacity.

Pints.	Galls.	Cubic ft.	Litres.
1 =	·125 =	·02 =	·5676
8 =	1 =	·1604 =	4·541
16 =	2 =	·3208 =	9·082
64 =	8 =	1·283 =	36·32816
512 =	64 =	10·264 =	290·625
2,560 =	320 =	51·319 =	1,453·126
5,120 =	640 =	102·64 =	2,906·25

1 gallon = 277¼ cubic in. = ·16 cubic ft. = 10 lbs. dist. water = 4·543458 litres.
1 cubic ft. = 6·2321 gallons.
1 grain = ·064799 gramme. 1 lb. avoir. = ·453593 kilogram.

Useful Data.

1 lb. avoir. = 16 oz. = 7,000 grains = 453·59 grammes = 1·21527 lb. troy.
1 lb. troy = 12 „ = 5,760 „ = 373·242 „ = 0·82285704 lb. avoir.
1 oz. avoir. = 437·5 grains = 28·35 grammes = 0·9114583 oz. troy.
1 cubic cent. = ·0610270734 cubic in. = ·282 fl. drms. = ·00176 pint = ·0352 fl. oz.
1 cubic ft. = 28315·3 c. c. = 6·2321 gallons = 28·3153 litres = 997·1364 fl. oz. = 49·8568 pints.
1 gallon = ·16046 cubic ft. = 277·274 cubic in. = 4·54346 litres.
1 cubic in. = 16·386 c. c. = 4·616 fl. oz. = ·0164 litre = ·02885 pint.
1 litre = ·035316 cubic ft. = ·220096 gallon = 61·0270 cubic in. = 1·761 pint.
1 fl. oz. = 28·396 c. c. = 1·7329 cubic in.
1 pint = 567·919 c. c. = ·020057 cubic ft. = 34·659 cubic in. = ·567920 litre.
1 gramme = ·002204 lb. = ·03527 oz. = 15·432348 grains.

Table for Converting Degrees of the Centigrade Thermometer into Degrees of Fahrenheit's Scale.

Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.	Centigrade.	Fahrenheit.
—90°	—130°	40°	104°	170°	338°
85	121	45	113	175	347
80	112	50	122	180	356
75	103	55	131	185	365
70	94	60	140	190	374
65	85	65	149	195	383
60	76	70	158	200	392
55	67	75	167	205	401
50	58	80	176	210	410
45	49	85	185	215	419
40	40	90	194	220	428
35	31	95	203	225	437
30	22	100	212	230	446
25	13	105	221	235	455
20	—4	110	230	240	464
15	+5	115	239	245	473
10	14	120	248	250	482
—5	23	125	257	255	491
0	32	130	266	260	500
+5	41	135	275	265	509
10	50	140	284	270	518
15	59	145	293	275	527
20	68	150	302	280	536
25	77	155	311	285	545
30	86	160	320	290	554
35	95	165	329	295	563

To convert °F. to °C. $\frac{(°F. - 32) \times 5}{9} = °C.$

To convert °C. to °F. $\frac{°C. \times 9}{5} + 32 = °F.$

Table of the Corresponding Heights of the Barometer in Millimetres and English Inches.

Millimetres	=	English inches.	Millimetres	=	English inches.	Millimetres	=	English inches
720	=	28·347	724	=	28·504	728	=	28·662
721	=	28·386	725	=	28·543	729	=	28·701
722	=	28·425	726	=	28·583	730	=	28·740
723	=	28·465	727	=	28·622	731	=	28·780

TABLE OF THE CORRESPONDING HEIGHTS OF THE BAROMETER ETC.—*continued.*

Millimetres	=	English inches.	Millimetres	=	English inches.	Millimetres	=	English inches.
732	=	28·819	747	=	29·410	762	=	30·000
733	=	28·858	748	=	29·449	763	=	30·039
734	=	28·898	749	=	29·488	764	=	30·079
735	=	28·937	750	=	29·528	765	=	30·118
736	=	28·976	751	=	29·567	766	=	30·158
737	=	29·016	752	=	29·606	767	=	30·197
738	=	29·055	753	=	29·645	768	=	30·236
739	=	29·095	754	=	29·685	769	=	30·276
740	=	29·134	755	=	29·724	770	=	30·315
741	=	29·174	756	=	29·764	771	=	30·355
742	=	29·213	757	=	29·803	772	=	30·394
743	=	29·252	758	=	29·843	773	=	30·433
744	=	29·292	759	=	29·882	774	=	30·473
745	=	29·331	760	=	29·922	775	=	30·512
746	=	29·370	761	=	29·961			

TABLE OF THE TENSION OF AQUEOUS VAPOUR EXPRESSED IN INCHES OF MERCURY, AT 32° F., FOR EACH DEGREE F. BETWEEN 0° AND 100°.

Temp. °F.	Inches of Mercury.	Temp. °F.	Inches of Mercury.	Temp. °F.	Inches of Mercury.	Temp. °F.	Inches of Mercury.
0	0·0439	19	0·1027	38	0·2291	57	0·4653
1	0·0459	20	0·1073	39	0·2381	58	0·4822
2	0·0481	21	0·1121	40	0·2475	59	0·4997
3	0·0503	22	0·1171	41	0·2571	60	0·5178
4	0·0526	23	0·1223	42	0·2672	61	0·5364
5	0·0551	24	0·1278	43	0·2775	62	0·5556
6	0·0576	25	0·1335	44	0·2882	63	0·5755
7	0·0603	26	0·1395	45	0·2993	64	0·5959
8	0·0630	27	0·1457	46	0·3108	65	0·6170
9	0·0659	28	0·1522	47	0·3226	66	0·6388
10	0·0689	29	0·1589	48	0·3349	67	0·6612
11	0·0721	30	0·1660	49	0·3476	68	0·6843
12	0·0753	31	0·1733	50	0·3607	69	0·7081
13	0·0788	32	0·1810	51	0·3742	70	0·7327
14	0·0823	33	0·1883	52	0·3882	71	0·7580
15	0·0861	34	0·1959	53	0·4026	72	0·7841
16	0·0899	35	0·2038	54	0·4175	73	0·8109
17	0·0940	36	0·2119	55	0·4329	74	0·8386
18	0·0982	37	0·2204	56	0·4488	75	0·8671

TABLE OF THE TENSION OF AQUEOUS VAPOUR—*continued.*

Temp. °F.	Inches of Mercury.	Temp. °F.	Inches of Mercury.	Temp °F.	Inches of Mercury.	Temp. °F.	Inches of Mercury.
76	0·8964	83	1·1274	89	1·3652	95	1·5457
77	0·9266	84	1·1643	90	1·4088	96	1·5971
78	0·9577	85	1·2023	91	1·4537	97	1·7498
79	0·9898	86	1·2413	92	1·4998	98	1·8039
80	1·0227	87	1·2815	93	1·5471	99	1·8595
81	1·0566	88	1·3228	94	1·5958	100	1·9170
82	1·0915						

BOILING POINT AND LATENT HEAT OF WATER UNDER VARYING PRESSURES.

Pressure.	Boiling Point.	Latent Heat.
1 atmosphere	212° Fahr.	966 thermal units.
2 ,,	249° ,,	940 ,,
3 ,,	273° ,,	923 ,,
4 ,,	291° ,,	910 ,,
5 ,,	306° ,,	900 ,,
6 ,,	319° ,,	891 ,,

WEIGHT AND VOLUME OF GASES.

	Weight.		Volume.	
	Per Cubic Metre in Kilos.	Per Cubic Foot in Pounds.	Per Kilo. in Cubic Metres.	Per Pound in Cubic Feet.
Air	1·29318	0·08073	0·773	12·385
Nitrogen	1·25616	0·07845	0·796	12·763
Oxygen	1·4298	0·08926	0·699	11·203
Hydrogen	0·08961	0·00559	11·160	178·83
Carbon dioxide	1·9666	0·12344	0·508	8·147
Carbon monoxide	1·2515	0·07817	0·800	12·800
Carbon vapour	1·0727	0·06696	0·932	14·930
Aqueous vapour	0·8047	0·05022	1·242	19·912
Sulphurous acid	2·8605	0·1787	0·349	5·596
Ethylene	1·2519	0·07814	0·799	12·797
Methane	0·7155	0·04466	1·397	22·391
Acetylene	1·1900	0·07428	0·840	13·456
Benzol	3·3333	0·208	0·303	4·808
Ethane	1·3415	0·08565	0·746	11·950

TABLE FOR CORRECTION OF VOLUMES OF GASES FOR TEMPERATURE, GIVING THE DIVISOR FOR THE FORMULA

$$V^1 = \frac{V + B}{760 \times (1 + \delta t)}$$

$\delta = 0{\cdot}003665$ = co-efficient of expansion for gases.

t	$760 \times (1 + \delta t)$.	Log. $[760 \times (1 + \delta t)]$.	t	$760 \times (1 + \delta t)$.	Log. $[760 \times (1 + \delta t)]$.	t	$760 \times (1 + \delta t)$.	Log. $[760 \times (1 + \delta t)]$
°C.			°C.			°C.		
14·0	798·99	2·9025	18·0	810·13	2·9085	22·0	821·27	2·9144
2	799·55	8	2	810·69	8	2	821·88	7
4	800·10	2·9031	4	811·25	2·9091	4	822·39	2·9150
6	800·66	4	6	811·80	4	6	822·95	3
8	801·22	7	8	812·36	7	8	823·50	6
15·0	801·78	2·9040	19·0	812·92	2·9100	23·0	824·06	9
2	802·33	3	2	813·47	3	2	824·62	2·9162
4	802·89	6	4	814·03	6	4	825·17	5
6	803·45	9	6	814·59	9	6	825·73	8
8	804·00	2·9052	8	815·15	2·9112	8	826·29	2·9171
16·0	804·56	5	20·0	815·70	5	24·0	826·84	4
2	805·12	8	2	816·26	8	2	827·40	7
4	805·68	2·9061	4	816·82	29·121	4	827·96	2·9180
6	806·23	4	6	817·37	4	6	828·52	3
8	806·79	7	8	817·93	7	8	829·07	6
17·0	807·35	2·9070	21·0	818·49	2·9130	25·0	829·63	9
2	807·90	3	2	819·05	3	2	830·19	2·9191
4	808·46	6	4	819·60	6	4	830·74	4
6	809·02	9	6	820·16	9	6	831·30	7
8	809·58	2·9082	8	820·72	2·9141	8	831·86	2·2900

The British Thermal Unit is the amount of heat required to raise 1 lb. of pure water 1° F., or from 39·1° F. to 40·1° F.

The Large Calorie (French Unit) is the amount required to raise 1 kilogram of water through 1° C.

The Small Calorie (Scientific Unit) is the amount of heat required to raise 1 gramme of water from 0° C. to 1° C.

The Pound Centigrade Unit is the amount of heat required to raise 1 lb. of water from 0° C. to 1° C.

British Thermal Unit.	Large Calorie.	Small Calorie.	Pound Centigrade Unit.	Foot-pounds.
B.T.U.	Ca.	Ca.	lb. C.U.	
1	0·252	252	0·555	778
3·9682	1	1,000	2·2046	3,080
0·003968	0·001	1	0·002046	3·08
1·8	0·4536	453·6	1	1,397

QUANTITY OF AIR REQUIRED FOR THE COMBUSTION OF FUELS.

	Composition.				Air per Kilogram.	Air per Pound.
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	cu. m.	cu. ft.
Coke	98·0	0·5	—	—	10·09	162·06
Coal, anthracite	95·4	2·2	1·8	0·5	9·01	144·60
„ bituminous	87·0	5·0	4·0	—	8·93	143·40
„ coking	85·0	5·0	6·0	—	8·68	139·41
„ cannel	84·0	6·0	8·0	—	8·79	141·07
„ smithy	77 0	5·0	15·0	—	7·67	123·15
Charcoal	90·0	2·0			8·53	133·90
Lignite	71·0	5·0	19·0	—	7·02	112·43
Peat, dry	58·0	6·0	30·0	—	5·75	92·36
Wood, dry	50·0	6·0	42·0	1·0	4·57	73·36
Petroleum	85·0	14·0	1·0	—	10·76	172·86
Natural gas	68·7	22·5	1·0	6·2	14·20	227·93
Coal gas	58·0	23·7	1·4	3·8	14·51	233·06
Water gas	34·0	5·9	43·0	3·4	3·16	50·70
Producer gas	1·0	5·0	21·0	69·0	·72	11·56

COMPOSITION OF VARIOUS FORMS OF GASEOUS FUEL.

Table A.
Coal Gas.

	P.Ct.
Hydrogen	54
Methane	33
Illuminants	4
Carbon monoxide	6
Nitrogen	3

Calorific value, 669 B.Th.U. gross.
Air to burn 1 cubic foot, 5·5 cubic feet.

Table B.
Blue Water Gas.

	P.Ct.
Hydrogen	51·9
Carbon monoxide	40·1
Methane	0·1
Carbon dioxide	4·8
Nitrogen	3·1

Calorific value, 295 B.Th.U. gross.
Air to burn 1 cubic foot, 2·31 cubic feet.

Table C.
Producer Gas.

	P.Ct.
Carbon monoxide	28·0
Hydrogen	2·5
Methane	1·0
Carbon dioxide	4·0
Nitrogen	64·5

Calorific value, 107 B.Th.U. gross.
Air to burn 1 cubic foot, 0·86 cubic foot.

Table D.
Rich Producer Gas.

	P.Ct.
Carbon monoxide	28·8
Hydrogen	18·1
Methane, etc.	3·5
Carbon dioxide	4·5
Nitrogen	45·1

Calorific value, 212 B.Th.U. gross.
Air to burn 1 cubic foot, 1·66 cubic feet.

From William Young Memorial Lecture before North British Gas Engineers' Association, 1919.

COST OF 100,000 BRITISH THERMAL UNITS IN VARIOUS FORMS.

(Sir George Beilby.)

In good coal, at 27*s.* per ton	100,000 B.Th.U. cost 1*d.*
,, ,, 54*s.* ,, ,,	,, ,, 2*d.*
In gas of 500 B.Th.U. per cubic foot, at 4*s.* 2*d.* per 1,000 cubic feet	,, ,, 10*d.*
In kerosene, at 2*s.* 6*d.* per gallon	,, ,, 19*d.*
In petrol, at 3*s.* per gallon	,, ,, 25*d.*
In electricity delivered for heating purposes at 2*d.* per B.T.U.	,, ,, 58*d.*

PRICES AND PRODUCTION OF GAS IN THE LONDON AREA.

Prices charged for gas in the London area in 1919, 3*s.* 8*d.* to 6*s.* 4*d.*
Total expenditure, 3*s.* 6*d.* to 4*s.* 5*d.*
Profits varied between 4·22*d.* and 6·69*d.* per 1,000 cubic feet.
The water gas percentage on total make varied from 21 per cent. up to 43 per cent.

DETAILED FIGURES FROM "THE GAS JOURNAL" ISSUE, OF FEBRUARY 24TH, 1920.

	Gas Light and Coke Co.	South Metropolitan Gas Co.	Commercial Gas Co.	Brentford Gas Co.
Gas sold (thousands) .	30,508,889	13,414,601	3,792,028	4,278,007
Gas made per ton of coal carbonised (cubic feet) . .	12,201	12,275	13,442	11,444
Coke made for sale per ton of coal (cwt.) .	10·26	9·99	11·59	10·32
Percentage of coke used as fuel . .	17·23	18·59	14·19	17·45
Price charged per 1,000 cubic feet .	4/4, 4/2 & 4/8	4/4 & 4/8	3/8	4/- & 4/10
Total expenditure (less residuals) . .	49·42*d.*	51·33*d.*	42·01*d.*	51·83*d.*
Total receipts . .	56·11*d.*	57·73*d.*	47·98*d.*	56·05*d.*
Balance, being profit .	6·69*d.*	6·40*d.*	5·97*d.*	4·22*d.*
Cost of coal per ton .	38*s.* 8·97*d.*	38*s.* 7·80*d.*	36*s.* 10·91*d.*	—
Water gas percentage on total make of gas	23·61	—	26·26	43·65

Compiled by F. G. Bradfield, Sec., The Commercial Gas Co., Ltd.

GENERAL CHARACTERISTICS OF THE DIFFERENT TYPES OF FUEL-OIL BURNER.

STEAM-JET BURNERS.

Steam atomising burners are divided into two distinct classes according to the method employed for bringing the steam into contact with the oil. These two types are known as the "outside-" and "inside-mixing" burners.

In the former the steam and oil pass from the burner by separate nozzles,

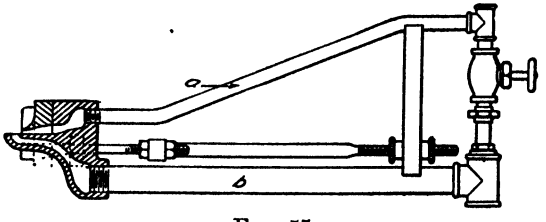


FIG. 55.

and are mixed directly in the combustion chamber of the boiler furnace. This "outside-mixing" type is much used for stationary land boilers and for locomotives; the jet of steam being driven across the oil jet, and by

its action here creating a suction effect which carries air into the furnace with the atomised oil spray.

The second class of steam atomising burner is designed on the usual injector principle, the suction created by an interior steam jet being employed to draw both the oil and air to the burner nozzle, where they are caught by the steam from a circular ring of jets and are blown into the furnace at the angle required to give a spreading effect to the flame.

Figs. 55 and 56 represent typical steam atomising burners of these two classes. The chief advantages of the steam atomising burner are the simplicity of the design and equipment, and the longer and less intense

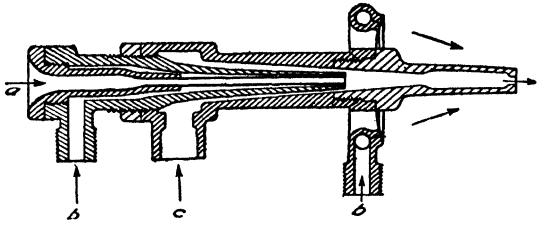


FIG. 56.

flame which they produce in the furnace. By suitable devices a short spreading cone of flame can also be produced.

Their disadvantages are many and include (1) the increased loss of heat due to the escape of uncondensed steam with waste gases up the chimney; (2) the large amount of steam required from the boiler to work the steam jets; and (3) the extinction of the flame at the burner if priming of the boiler should occur after the oil jet is lighted.

For these reasons, steam atomising burners have fallen to some extent into disfavour, and burners in which air or mechanical power is employed to atomise the oil are now more generally employed in spite of the extra cost of installation.

AIR-JET BURNERS.

Fig. 57 illustrates a typical American air-jet burner. The oil enters this burner under pressure at (*a*) and is regulated by the spindle valve (*d*). The

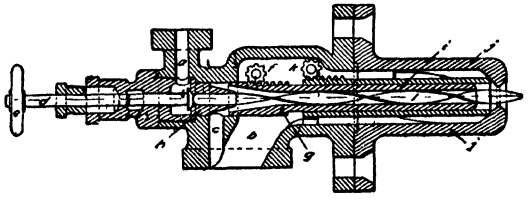


FIG. 57

supply of compressed air, previously heated, enters at (*b*) and (*c*), that entering at (*c*) mixing with the oil spray controlled by (*e*). The air can be

regulated at two points; first by the pinion (*f*), which moves the internal tube over the oil nozzle, and second by the pinion (*k*), which adjusts the opening of the outer tube, or sleeve, against the casing (*j*). The size and intensity of the flame from burners of this type are difficult to regulate, and as already stated, they yield a shorter and hotter flame than burners in which steam is the atomising force, since the combustion of the oil is completed in a much shorter period of time. In some cases however, a short and intensely hot flame is advantageous for the work required, and air jet burners are being used both for marine boilers and for metallurgical purposes.

Mechanical Burners.

This type of burner effects the atomising of the oil by purely mechanical means, the oil being forced under high pressure through small slots arranged at a tangent in the burner nozzle, and in this way a whirling spray of very fine oil particles is produced in the combustion chamber of the furnace.

The Kermode burner, which has been widely used in the Navy and mercantile marine of this country, is based on this principle, and Fig. 58 shows

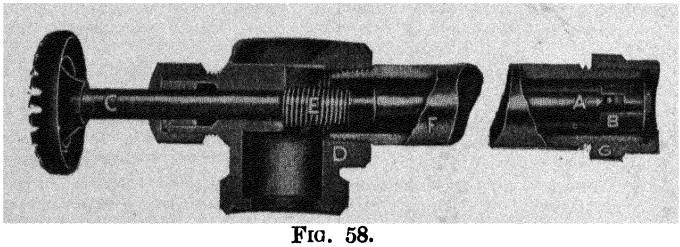


Fig. 58.

an American burner of this same type. By use of the adjusting rod C the position of the burner tip B can be altered to give very close regulation of the size and length of flame. This type of oil burner not only requires less steam for operating the oil compressor than is required by the steam-jet type of burner, but all the condensed water from the pump and heater can be returned to the boiler feed tank. It is this feature especially which has caused its very general adoption for marine work, and for many land installations of liquid fuel firing for boilers, since the replacement of the water equivalent of the steam used by steam jets, is a very serious problem at sea and also for many power generating plants on land.

From "Efficiency in the Use of Oil Fuel," by G. M. Wadsworth, 1918. (U.S.A. Bureau of Mines publication).

VERTICAL CONTINUOUS RETORTS FOR GAS MANUFACTURE.

The modern forerunner of the vertical continuous process was, as I have already pointed out, the Settle-Padfield retort, which I tested at Exeter seven or eight years ago, with the principle of which I was immensely taken, and which gave splendid results. Its passage, however, from the experimental to the practical scale, as in so many cases, proved its undoing;

but on looking up a notebook of that date, I find that I obtained the following results :—

Coal used—Poor slack, No. 4 Cammerton.

Make per ton . .	Gas	13,250 cubic feet.
	Illuminating power .	14·72 candles (London Argand).
	Heating value . .	533·7 B.Th.U.
	Tar	None.
Same coal in horizontal retort . . .	Gas	9,862 cubic feet.
	Illuminating power .	15 candles.

The Settle-Padfield process consisted of a semi-vertical or, if I may call it so, boot-shaped retort, much of the same design as now used in shale distillation. The vertical portion was about 6 feet in length, and the inclined part at the bottom 3 feet. The junction of the two portions was the weak part of the apparatus, as it was liable to crack, thus leading to infiltration of furnace gases, which was discovered when the gas given in the above test was analysed. The leak was then made good, and further tests gave 13,000 to 13,200 cubic feet per ton of 15-candle gas. The outstanding feature of the process was that the upper 3 or 4 feet of the vertical portion of the retort were left empty, and that the coal was fed in at the top by a plunger in charges of 2 to 7 lbs. per stroke as desired, and fell through the empty heated zone on to the red hot coke, where it was carbonised on the heated surface. The first run of rich gas, therefore, rose straight up through a zone of radiant heat to the mouthpiece at the top of the retort. The weakness in this process was that the coke was allowed to accumulate, and was then at intervals removed through an ordinary oven door at the bottom of the incline, so that the "baking area" varied according to the amount of coke at the bottom of the retort. Had the retort been a plain vertical one, with an automatic coke remover working *pro rata* with the coal feed, it would have been the perfect embodiment of the true conditions for carbonisation, as the temperature needed only a little lowering in the superheating portion of the retort. The idea was to carbonise all the tar formed, so that if any condensed it was returned to the retort, and this phase of the subject is well worth discussion.

In the Settle-Padfield experimental retort, I should say, speaking from memory, that the temperature in no part of the retort was 1,000° C., if so much, and yet at this temperature 13,000 cubic feet of gas per ton were made from Cammerton slack. The gas tested in the London Argand burner gave 15 candles, which would have been 17·5 on the No. 2 Argand.

The same coal in a horizontal retort gave 9,862 cubic feet of the same candle-power gas, and ten gallons of tar per ton, so that the alteration in the method of carbonising and the tar (which if formed was returned to the retort) gave a gain of some 3,000 cubic feet. The temperature of the lower portion, however, was insufficient to drive out all the more resistant volatile matter, and a very good coke was the result.

Now, what was it that caused that rattlejack old retort to give results better, if anything, than the beautiful models of constructive skill that we see in the two present continuous systems ?

In the first place, we all know the importance of a large ratio of heating surface to the mass of coal, and if you consider how the ground-up slack must have piled itself up on the top of the mass of red-hot material, heated from below, washed by the ascending hot gases from the last charge, and radiated upon by the sides of the red-hot retort above, you will see that

the heating surface was far greater than in any other system. Instead of heat slowly penetrating to it, the fuel was plunged, the moment it left the feed, into a red-hot area, which drove off a good deal of gas before even it reached the carbonising mass below, and was deposited, sweating tar, on the hot surface. The gases as they were disengaged, rushed straight upwards to the exit without coming in contact with any surface to decompose them, the radiant heat being just sufficient to fix and get the best out of the tar vapour.

To many the idea of a heated space above the carbonising coal, seems like going back to the lightly-charged horizontal with the space that led to disaster, but they do not realise that radiant heat does little harm and much good if there is not too much of it, and that it is contact with hot surfaces that is fatal. In the horizontal the gases rushed up to the top of the arch and were decomposed by the contact. In a vertical space they rush to the cool top and exit pipe, hardly touching the sides, whilst the radiant heat performs such beneficent functions as breaking up the hexahydrides in the tar vapour into aromatic hydrocarbons and hydrogen.

Mr. W. G. Africa, in a paper read in October last at St. Louis, in relating his experience with vertical retorts, says that they got unusually high results as to candle power by leaving a space of 4 feet of heated retort above the coal, thus fixing the vapours which in full retorts do not reach the proper temperature for gasification.

Now, my idea of a perfect continuous system would be a vertical retort like the one that Glover first made, which had the space at the top. This retort would be provided with a semi-intermittent feed and coke removal device, with the addition of the cooling chamber, and also with secondary air regeneration, the heat in the flues being concentrated on the outside of the retort at the spot where the coal falls on to the surface of the coke, as it is here that heat is withdrawn most rapidly. The temperature might then fade away above and below this area to, say, 800° C., and if properly regulated, 6 to 8 per cent. of the volatile matter of the poor gas-forming residues would be left in the coke in order to make a perfect domestic fuel, any shortage of gas being made up by blue water gas.

The volume of gas actually made from the coal might only be 9,500 to 10,000 cubic feet, but it would be rich in saturated hydrocarbons, and would probably stand dilution with 5,000 cubic feet of water gas to bring it down to statutory requirements.

In this way it should be possible to make more gas than at present and in addition thereto a valuable fuel, whilst we should have attained practically the ideal of carbonisation—uniformity.

It has always been felt by the gas-engineer that tar meant a great waste of vaporised carbon, which, if it could be kept in the gaseous form, would give an enormous addition to the gaseous products and would represent a large proportion of heat and light. Experiment, however, has shown that the gasification of tar and of tar oils is a most thankless task, and most gas engineers look upon it from the point of view taken by Lewis T. Wright, namely, that tar is a child of high temperature, born in the heat of the retort, and so thoroughly acclimatised as to resist all further attempts to gasify it successfully.

From Cantor Lecture IV., upon "The Carbonisation of Coal," delivered at the Society of Arts, December, 1911, by Professor Vivian B. Lewes, Professor of Chemistry, Royal Naval College, Greenwich.

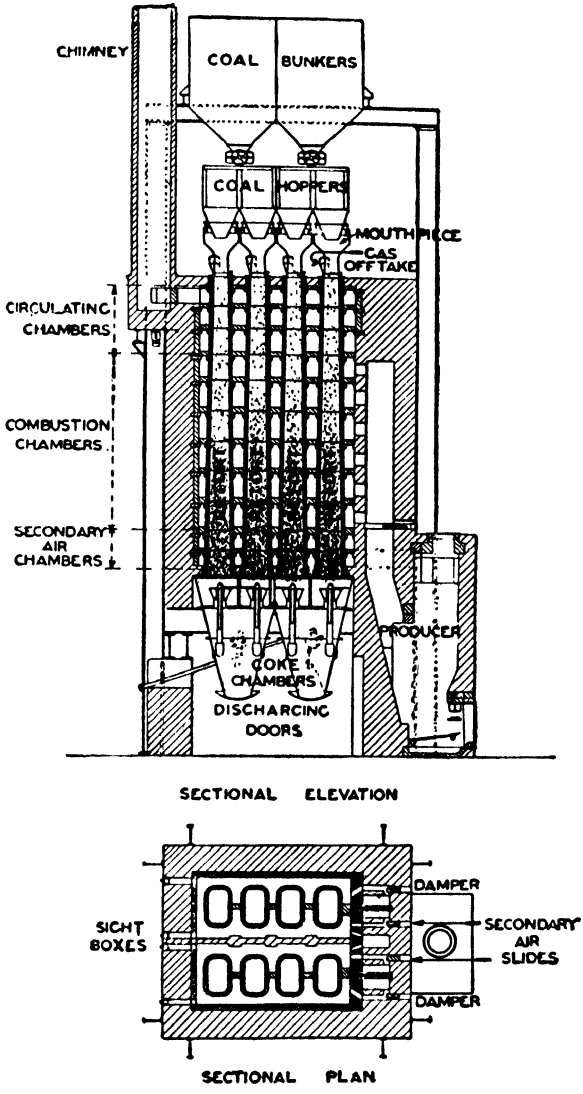


FIG. 59.—Section of Glover-West vertical continuous retort for coal-gasification.

THE ATOMISATION OF LIQUID FUEL FOR MARINE PURPOSES.

The gasifying of the oil being attended by many troubles, naturally the next idea that arose was to disintegrate the oil into the finest possible spray so as to aid combustion by getting the oil as near the gaseous condition as possible. The pioneers in this work were Mr. Holden, of the Great Eastern Railway; Urquhart, the great Russian railway engineer; Aydon, Wise and Field, Rushden, Orde and others.

The methods of atomising oil may be of three kinds :—

(1) To spray the oil in as fine a state of division as possible by means of steam from a properly arranged injector.

(2) To use air under pressure instead of steam for this purpose, the air also serving to help the combustion.

(3) To supply the oil itself under pressure and drive it out through a specially arranged jet in such a way that it should be disintegrated.

Steam injection facilitates the burning of the oil, inasmuch as when the minute oil particles become heated to a high temperature they interact with the steam and form simpler bodies, which are more easily consumed without the formation of smoke than by the other processes; but it was soon found that although with the boilers used in the ships of the mercantile marine and stationary boilers very fair results could be obtained, yet that, when, owing to shortage of room, the combustion space in the boiler had to be reduced as low as possible, it became extremely difficult to get smokeless combustion.

From a very early date in the history of liquid fuel it became evident that its great future would be for marine purposes, owing to (1) the ease with which it could be filled into the bunkers, (2) the fact that the ballast holds could be used to store the liquid fuel, which could then be displaced, as used, with water, so storing the oil below the level of the boilers instead of above, as was a necessity with coal bunkers, and (3) the saving in labour; whilst, for the Navy especially, the fact that the weight of energy in the form of fuel which could be carried by the vessel was far greater for oil than coal, so increasing the radius over which the vessel was able to act without taking in fresh supplies, was, of course, an advantage that could be placed against its high cost.

When, however, attempts came to be made to introduce it, it was found that although various injector burners answered admirably in tramp steamers of the kind most largely used in the mercantile marine, with service vessels the furnace space was too small to allow the proper combustion of the amount of oil needed to give the required power, and that as a result dense black smoke was formed, which would at once have revealed the whereabouts of the vessel to an enemy in case of war, and which also lowered the efficiency of the oil. Another trouble which cropped up about this time was that, in order to provide the steam necessary for the atomisation of the oil, extra boilers would have had to be provided, and at one time the idea of using liquid fuel was very nearly killed. Injection by means of compressed air also had the drawback that the jet of oil-mist driven forward into the furnace space passed through it too rapidly for complete combustion, whilst the power used to give the pressure again necessitated the use of steam, and under these conditions direct pressure burners began to be experimented with.

Already a burner had proved successful in Russia, in which the oil under pressure was atomised or broken up by being injected on to the edge of a

cutter, this causing its disintegration, whilst in the Hamburg-American line another pressure burner, devised by Körting, in which compressed oil was injected through a fine spiral opening, had also proved successful, and a burner of the oil-pressure type was eventually adopted in the British Navy.

The great advantage of ejecting the oil into the furnace space as a swirling cloud of mist instead of a direct driven spray is that its passage through the furnace and combustion space is so retarded as to give sufficient time to complete its combustion, and one of the best burners made on this principle is the "Kermode," which is now being used largely throughout the world. In this burner the swirling motion given to the oil spray in the Körting injector is accentuated by causing the oil to escape under a high pressure through three small channels arranged in the face of the jet and impinging upon a central cone is such a way that it is driven forward into the furnace space as a rotating cone of mist having its apex at the burner mouth and increasing in diameter as it passes up the furnace.

This burner used with forced or induced draught gives splendid results, and during the last few years has entirely done away with the trouble that was before found of excessive smoke.

The usual method employed in fitting an oil fuel installation for marine work is to pump the oil from the tank or bilge in which it has been stored into a settling tank to separate any water, and thence through a filter of fine wire gauze, from which it passes through a steam-heater, generally consisting of a nest of tubes, through which the oil flows whilst exhaust steam is passed through the casing, raising the oil to a temperature a little below the boiling point of water, which causes it to flow easily and yet gives no danger of an evolution of gas forming a break in the column of oil, which might cause extinction of the flame at the burner.

The oil is then generally passed through a second filter, and is injected by means of the burner into the boiler space, which is supplied with the necessary air through valves fitted round each burner, the oil being used either alone or as an auxiliary to coal.

When in marine work the fuel to be used is oil only, it is usual to do away with the fire-bars and to line the furnace with fire brick, but when used as an auxiliary to coal the fires are levelled, the draught below the grate cut off, and air admitted above the fire only, the oil being injected above the fire, and constituting about 25 per cent. of the fuel burnt.

In actual working afloat over long periods in tramp cargo-boats the relative values of oil and Welsh steam coal may be taken as Welsh steam coal 100 tons, fuel oil 66 tons, *i.e.*, 34 tons less consumption to give the same result when employed for steam raising, whilst when solar oil is used in the Diesel engine 18·18 tons of oil are equal to 100 tons of coal, a saving of 81·8 per cent.

It must always be remembered, however, that such figures give a false idea as to the economy to be found in the use of liquid fuel, which consists largely in the saving in labour, stowage space, and the more even speed attained owing to the necessity of cleaning and clinkering the fires being done away with, a factor of great importance in tropical seas.

The following results (see table on p. 338) give the actual evaporation in practice from the same boiler, and show that tar oil as a fuel is considerably inferior to good fuel-oil.

The same type of boiler when fired with coal would have given an evaporative duty of between 9 lbs. and 10 lbs. of water from and at 212° F., the best Welsh steam coal being employed.

Description.	Calorific Value by Bomb.		Actual Evaporative Power in Practice, from and at 212° F.
	Calories.	B.Th.U.	lbs.
American residuum	10,904	19,627	15·0
Russian astatki	10,800	19,440	14·8
Texas	10,700	19,242	14·79
Burma	10,480	18,864	14·5
Barbadoes	9,899	17,718	14·2
Borneo	10,461	18,831	14·0
Shale oil	10,120	18,217	13 8
Blast furnace oil	8,933	16,080	12·0
Heavy tar oil	8,916	16,050	12·0

Where furnace space is ample the steam and air-injector burners are most effective and are largely used, the latter especially, from the high temperature given, being excellently adapted for smelting operations, the melting of glass and other operations of the same kind.

Liquid fuel burners of a slightly different character also are being introduced for metallurgical work, and are giving good results; some, like Höveler's burner, being in reality a huge oil spray blast blow-pipe in which the spray burns from the burner mouth and is driven as a flame into the furnace, such burners being especially adapted for rotary furnaces, melting-pots for metals, and other work requiring a very hot flame, which can be made oxidising or reducing at will.

From Cantor Lecture II., on 'Liquid Fuel," 1913, by Professor Vivian B. Lewes, F.I.C., F.C.S.

BENZOL AND ALCOHOL AS SUBSTITUTES FOR PETROL.

In France considerable attention has been paid to the utilisation of alcohol in motor cars, and so important was the use of alcohol considered in Germany before the war that the manufacture of alcohol by fermentation from potatoes was state-aided in order to keep labour on the land as far as possible; and alcohol for motor use became a commercial success, the benefits of which are being reaped at the present time when, the petrol supplies having been cut off, a petrol famine exists.

Our interest in petrol substitutes may be summed up as a desire to get a motor fuel cheaper than petrol; but if we desire to have an object lesson in what we could do if petrol and petroleum products failed, we have only to turn to Germany's plight at the present moment (March, 1915), and there the subject is found to be one of the most serious national importance.

The whole conduct of the war depends on motor traction—without it the movement of troops is hampered, the commissariat cannot be carried out properly, the supply of ammunition to the fighting line fails, and the red cross service is rendered inefficient. At the same time, there is practically a petrol famine, and what there still is must be kept for the fighting line and the air service. Under these conditions the experience the Germans have had in using alcohol as a motor spirit is proving of great value in meet-

ing the emergency. Every motor car in Germany has been adapted to burn alcohol as well as petrol by fitting suitable carburettors that could be adapted to either fuel, and when used with alcohol could be warmed up to give the power of starting. We have seen that the thermal value of alcohol is only a little more than half that of petrol, but that a higher compression is possible and that this makes the efficiency nearly the same. But the compression cannot be altered without serious alterations to the engine which would unfit it for use with petrol, whilst if the alcohol is used in the engine as arranged for petrol the power obtained would follow the ratio of their heating values. Nearly twice as much alcohol as petrol would have to be burnt to give the same power. In order to get away from these troubles without any more alteration than that of the carburettor, a mixture of alcohol with benzol in which naphthalene has been dissolved to give it higher heating power is used. The favourite formula is :—

95 per cent. alcohol	80 litres.
Benzol with 200 grammes naphthalene dissolved in it .	20 ,,
	100 ,,

And such a mixture, when used without any extra compression, gives five-sixths the power of petrol, whilst all the ingredients are made in the country.

It will be interesting to see in this connection how much motor fuel can be possibly made available in Germany.

In 1913 Germany produced 160,000 tons of benzol, of which 50,000 were exported. All exportation will now have ceased ; and if we suppose the production to have been maintained and one-third recovered from the crude benzol as toluene, this would leave, allowing for wastage, 100,000 tons of benzene, or a total of 25,000,000 gallons, which, with the amounts used at both fronts and in the towns, would be at most six weeks' supply if used alone.

The production of alcohol in 1913 in Germany was 3,750,000 hectolitres, or 82,500,000 gallons ; so that, supposing the whole of the benzol and alcohol made in the country were blended and the naphthalene, of which there is plenty, dissolved in it, the whole production of motor fuel possible would be a little less than the amount we imported last year, and would mean about a five months' supply at the present rate of consumption.

From Fothergill Lectures on "Motor Fuels," at Society of Arts in February and March, 1915, by Professor Vivian B. Lewes, F.I.C., F.C.S.

A NEW AMERICAN TYPE OF BURNER.

A new American type of burner, which has been specially designed in order to overcome the clogging of the orifice due to dirty oil, is known as the Coleman oil burner. In this burner air is fed from the main air chamber through a hollow brass stem ; the oil is fed around this circular stream of air ; and at the end of the brass stem, which controls the oil supply, the oil is forced into the air stream at a sharp angle. This causes a breaking-up of the oil into small particles, and produces a primary mixing with the air. A second and larger outer stream of air cutting through the primary mixture produces a further atomisation, and furnishes the proper combination of oil and air for complete combustion.

A quick means for clearing out any obstruction is provided by merely

turning the hand-wheel on the stem which opens the oil passage to full size. The construction of the burner permits not only the feeding of a very small or large quantity of oil, but also the complete control over the supply of air for combustion.

The burner connections provide for a ½-inch oil line and a 2-inch air line, giving a large range of feed of both oil and air. Air at 2 lbs. and oil at 5 lbs. per square inch pressure are commonly used, but burners of this type are in operation under a great variety of conditions as to pressure of oil and air.

From *Metallurgical and Chemical Engineering*, Vol. 18, p. 156.

EXPERIMENTS WITH NATURAL DRAFT OIL BURNERS IN U.S.A. NAVY.

Some interesting experiments in connection with natural draught oil burners for naval boilers have been carried out by Lieut. L. R. Ford, of the United States Navy, on the U.S.S. *Fulton*. The burners were of the "inside mixture" type, the air and oil being discharged into a mixing chamber in the tip, where the mixture was given a whirling motion before issuing into the furnace. The air was supplied by a compressor. It was found that excellent combustion could be obtained with these burners, but very close attention on the part of the firemen was necessary to obviate the dangers due to fluctuations in the air and oil pressures, with the consequent extinguishing of the flame. This defect, combined with the extravagant consumption of steam by the compressors, made it desirable to develop a method of using a mechanical atomisation system. A funnel-shaped diffuser was made of sheet iron, and attached to the end of a piece of 1¼-inch pipe, 4 inches long, by means of a hand clip, which permitted the adjustment of the diffuser along the burner or nozzle. The diffuser was made with an included angle of 90 degrees, and the diameter at the large end was 4⅝ inches.

A loose collar sliding on the burner shank supported one end, the other end being supported by the burner tip. The pipe was secured to the loose collar by a small screw. This arrangement permitted adjustment of the distance the burner tip projected into the diffuser. To remove the burner from its holder it was only necessary to take out the small screw, draw the pipe and diffuser off the end of the burner, then draw the burner out of its holder in the usual manner.

When the burner was lighted a most interesting action was observed. With the diffuser drawn back the flame would jump away from the burner, but when the diffuser was pushed forward, it would pick up the flame, and a short cone of clear flame would result. When adjusted to the best working position a halo of white flame appeared round the edge. The main body of the flame retained its conical shape, the cone extending back to the burner tip, but part of this flame seemed to draw out of the diffuser and curl down the edge. The combustion was very good, and further development was decided upon. By fitting a cone of heavy sheet metal into the furnace opening through which the burner was introduced, a noticeable improvement in the furnace conditions was obtained. The flame was short, of dazzling whiteness, and smoke was completely absent. The air flowing into the furnace by natural draught seemed to mix thoroughly with the fuel, due to the influence of the diffuser and the Venturi-shaped opening. In order further to promote the mixing of the air and fuel, it was decided to

impart to the incoming air a rotary motion, and to do this the conical openings in the furnace front were modified by riveting helical fins of thin sheet metal around the inner surface in the shape of a helix. A circular baffle-plate, adjustable longitudinally, was fitted to regulate the air supply, and the whole burner was constructed so that it could be moved in and out of the opening. Means were provided to maintain an even pressure of the oil to the burner. The influence of the helical vanes on the air was very marked. The flame from the burner was very short and white, and the gas in the furnace quite clear. As soon as the brick walls in the furnace became heated up all sign of smoke disappeared. When the diffusers were adjusted to produce the halo round the edges the halo remained permanent. There was an entire absence of smoke, and steam was made rapidly. The most surprising results were the low oil pressure required to maintain the steam pressure, and the wide range of pressure through which the burners could be operated smokelessly. Whereas previously an oil pressure of 200 lbs. per square inch had been required, it was now found that the steam necessary to meet the normal demand could be generated with an oil pressure of 50 lbs. to 100 lbs.

From *Engineer*, London, September 29th, 1916.

STATISTICS OF OIL-FIRED PLANTS IN U.S.A.

As showing the extent to which liquid fuel has been adopted in U.S.A. for steam raising in power and central heating installations, the figures and information given by H. W. Bellou in a paper read at the Worcester meeting of the American Society of Mechanical Engineers in June, 1918, may be quoted.

In New England alone 60 power plants producing 83,000 H.P., and 100 low pressure steam plants for heating systems were stated to be fired with fuel oil, and one-half of this boiler H.P. was located in Rhode Island. According to the author, no difficulty is experienced in pumping oil as warm as 130° F. with a 10-foot lift. About nine-tenths of these oil fuel installations are substitutes for coal in existing plants. There is no other method of increasing the capacity of a boiler plant so quickly and cheaply as by substituting oil for fuel, and in a number of cases the change to oil has made it possible to shut down one or more boilers. The simplicity and automatic action of oil meters as compared with the cumbersome methods of weighing coal are appreciated, and the keeping of power plant records is simplified. A few plants have accomplished automatic regulation of the oil feed, but hand control is almost universal.

The saving of labour due to oil firing as compared with coal has been given an exaggerated importance. Other than fixed charges, 80 to 90 per cent. of the boiler room costs are in fuel, leaving little to be saved in labour. Crude petroleum may be divided into two classes—that with a paraffin base and that with an asphalt base. The first is so valuable for its derivatives that its price will always be prohibitive for fuel. The extremely heavy grades of asphalt base oils from Mexico are practically the only fuel oils now available in New England. The present rapid increase in their use is but a lucky incident in the marketing of a great natural product. Immense as is its absolute volume, the insignificance of its relative volume as a source of world-wide fuel has thus far been the main obstacle to the adoption of Mexican fuel oil on the high seas. That obstacle is rapidly dis-

appearing, and regrettable though it be, it is inevitable that its very virtues for this purpose will ultimately deprive the power plants of New England ot fuel oil.

From Report in *Power*, New York, June, 1918.

FURNACE CONSTRUCTION AND REGULATION OF FUEL-OIL BURNERS.

Professor Bramc, in a paper read before the Institute of Petroleum Technologists in 1917, stated that experience showed that ample combustion space was necessary. Given that, with sufficient length from front to back to allow of combustion being practically complete if the air admixture is satisfactory, no special arrangements were required beyond a lining of firebrick in the front part of the furnace. Any deficiency in length, as, for example, with a fire-bridge in a short-furnace boiler with combustion space beyond, could be rectified by a firebrick-lined extension of the front of the furnace.

In water tube boilers the requirement of ample combustion space was if general easily met, but great attention was required to the path of the flame and hot gases in order to attain uniform heating. If proper baffling between the rows of tubes was not introduced, the efficiency and endurance on the boiler was adversely affected. Again, water circulation depended on uniformity of heating. The wide-angle cone from most pressure atomisers was particularly well suited to this type of furnace.

It is most important to note that good results can only be obtained with oil fuel if strict attention is given to the draught and air regulation, and if CO_2 recorders are employed and their readings are constantly checked by independent tests with an Orsat apparatus. As a contributor to that excellent American journal *Power* has recently pointed out, a higher evaporative efficiency is generally obtainable with oil firing than with coal firing because complete combustion can be obtained with a smaller excess of air. But closer regulation of the dampers is necessary with oil, because there is practically an uninterrupted passage for air into the furnace, there being no fuel bed to check its flow. In most plants the front damper or ashpit doors are used for air control, while the breeching dampers are left wide open. One excuse for this is that of safety, for if the breeching dampers were used and should accidentally be closed entirely, an explosion would be likely to occur; but the real reason usually is that of accessibility. In one plant using the ashpit door regulation, it was difficult to obtain 10 per cent. CO_2 at the top of the last pass (B. and W. boilers), and it was decided to provide a convenient means of operating the breeching dampers from the boiler front. The dampers were then kept in such a position that just enough air would be admitted to prevent smoke, and 15 per cent. CO_2 was often obtainable at the top of the first pass, and from 12 to 14 at the damper.

RECORDS OF ACTUAL STEAM-RAISING RESULTS WITH FUEL OIL.

A modern steam power plant was completed recently at the U.S. Navy Yard, Mare Island, California, to supersede old equipment for furnishing compressed air and electric power. The plant was installed by the Edge

Moor Iron Company, of Edge Moor, Delaware, U.S.A. The new equipment included two 5,000 cubic feet steam-driven air compressors; two 500 kw. and one 1,000 kw. turbo-generators; eight 450 H.P. water tube boilers, equipped with superheaters; a complete oil burning system; and the necessary auxiliaries. The tests were made under the direction of a board of naval officers, and owing to the pecuniary penalty involved, great care was taken to assure the reliability of all the results. The correctness of the testing apparatus was determined by, or in the presence of, the representatives of both the government and the contractor. The water was weighed in all the tests, and in the test for efficiency, the fuel oil was weighed. The following are the more important figures:—

Economic Results.

Water apparently evaporated under actual conditions—per lb. of oil as fired	13·77 lbs.
Equivalent evaporation, from and at 212°—per lb. of oil as fired	15·80 ,,
Equivalent evaporation, from and at 212°—per lb. of pure oil	15·87 ,,
Equivalent evaporation—per lb. of oil based on a standard calorific value of 18,500 B.Th.U.	15·62 ,,

Efficiency.

Efficiency of boiler based on calorific value of oil with water vapour due to hydrogen uncondensed	87·1 per cent.
Efficiency (as ordinarily given) based on calorific value of oil with water vapour condensed	81·6 ,,

Smoke Observations and Gas Analysis.

Gases issuing from stack were just barely visible during entire test.	
Minimum percentage of CO_2 at damper tested by Orsat apparatus	12·5 ,,
Maximum percentage of CO_2 at damper tested by ditto	13·4 ,,

Steam Required by Burners.

Steam used by burners to atomise 1 lb. of oil as fired	0·32 lb.
Percentage of steam generated used by oil burners for atomisation	2·33 per cent.

The efficiency obtained in this test was remarkably good, especially as the firing was carried out by the regular government fireman, who depended entirely on his eyesight for guidance in making the adjustments necessary for good combustion.

From *Engineering News*, New York, May, 1913.

INDEX.

A.

ABEL flash-point apparatus, 93
Acetylene, 176
Advantages of oil fuel, 130
Air, composition of, 6
  impurities in, 6
  minor constituents of, 6
Air-gas producer, 43
Air to gas in burners, ratio of, 196, 212
Alcohol, 303
  advantages of as a fuel, 307
  as a fuel, 100, 314
  calorific value of, 304
  combustion of, 309
  denaturated, 306
  enriched, 310
  for motors, 315
  manufacture, 303, 316
  methylated, 306
  produced during fermentation, 303, 316
American oil, 85
Ammonia, fixed, 154
  free, 154
  liquor, 154
Animal to vegetable life, relation of, 24
Anthracite, 32
  composition, 32
  size for generators, 266
Applications of water gas, 237
Area required for suction plant, 281
Ascension pipe, 145
Astatki, 90
Atoms, 52, 57
Atomic weight, 54, 57
Atmospheric condensers, 146
  burners, 194
  pollution, 23
Auto-carburetting, 253
Aydon, Wise and Field's oil burner, 117

B.

BAKU oil district, 68
Barff's oil furnace, 115
Batswing burner, 179
Bench of retorts, 149
Benrier's generator, 275
Benzene, 311, 314
Bischof's generator, 261
Bituminous coal, 38, 144
Blast furnace gas, 46, 263
  oil, 99
Bomb, Mahler, 65
Boutillier generator, 284
Boys calorimeter, 74
Briquettes, peat, 296
British Thermal Unit, 59

Buire - Lencauchez generator, 272
Bunsen burner, 193, 212
air and gas ratio in, 196
cause of non-luminosity, 202
temperature of, 209, 212
Burners, gas, batswing, 179
bunsen, 193
cockscomb, 179
duty of, 251
incandescent mantle, 181
inverted, 181
regenerative, 180
union jet, 179
Burners, oil, 108
Aydon, Wise and Field, 117
Coleman, 333
General characteristics of, 328
Holden, 120
Kermode, 329
Körting, 117
Orde, 121
Rushden and Eeles, 120
Swensson, 117

C.

Calorie, 58
Calorific value, 60
calculated, 60
determined, 64
Calorimeters, 64
Boys, 74
Darling, 69
Mahler, 65
Simmance-Abady, 80
Candle power to calories, relation of, 188
Capitaine suction plant, 278
Carbon, 55
Carbon bisulphide, 182
Carbon dioxide, 13
and animal life, 25
and vegetation, 26
in combustion, 12
properties, 13
Carbon monoxide, 14
toxic character of, 15
limits in coal gas, 257
Carburetted water gas, 45
composition, 246
Flannery, 243
Humphreys-Glasgow, 245
Kramers and Aarts, 241
Loomis, 243
Lowe, 242
Springer, 243
Van Steenburgh, 238
Carburetting coal gas, 167
Cavendish, experiments of, 4
Cellulose, 27
calorific value of, 59
Charcoal, 29
Checked combustion, 14
in stoves, 219
Chlorophyll, 26
Choke damp, 35
Clowes' flame-cap test, 105
Coal, 32
calorific value of, 285
composition of, 34
formation of, 32
gas given off by, 35
hydrogen in, 33
oxygen in, 33
varieties of, 32
Coalite, 23
Coal gas, 141
as a fuel, 186

Coal gas—*contd.*
calorific value, 187
carburetting, 167
composition, 164
manufacture, 141
purification, 156
Coal gas and coal, relative cost of, 210, 218
Coal tar, 97
Cockscomb burner, 179
Cohesion, 51
Coke, 37
Coke gas, 43
Combustion, 8
complete, 12
heat of, 60
nature of, 8
products of, 12
rapid, 12
slow, 12
Composition of
air-producing gas, 43, 225
carburetted water gas, 246
coal gas, 164
coke gas, 43
Dowson gas, 267
Mond gas, 272
natural gas, 46
producer gas, 43, 225
semi-water gas, 45
suction gas, 278
water gas, 44, 224
Condensers, atmospheric, 146
Cooking stoves, 219
Cost of power, 286, 314
Creosote, 99
Crude oil, 88

D.

Dangers of water gas, 248
Decay of vegetation, 30
Dellwik water gas, 233
Denaturated alcohol, 306
Density of gases, 52
Determination of calorific value 58
Diastase, 302
Distillation of wood, 29
Dowson gas, 264
Dowson suction plant, 277
Duff-Whitfield generator, 284
Durr liquid fuel system, 115
Duty of gas burners, 251

E.

Eames' liquid fuel system, 115
Eeles' oil burner, 120
Elements, 48, 57
Energy from the sun, 300
Engines, gas, 221
Enrichment of coal gas, 166
Equations, 53
European water gas process, 226
Evaporative value, 63
Explosions in coal mines, 35

F.

Fahnehjelm comb, 240
Fermentation, 302, 317
Fire, 8
Fire damp, 35
Fischer calorimeter, 71
Flame, 16
bunsen, 194
chemical actions in, 175
luminous, 174
non-luminous, 181
Flame-cap test, Clowes, 105
Redwood, 105

Flash point, 92
Abel apparatus for, 93
Pensky-Marten apparatus for, 94
Flueless stoves, 210
Fog, 121
Fuel, 24
Fuel gas, 225
poor, 258
Fuel oils, 84, 137
composition, 42
suitability of, 137
Fuels, thermal value of various, 285
Furnace, liquid fuel, 132
Eames, 115
Foote, 113
Nobel, 112
Richardson, 111
Sims and Barff, 115
Furnace, regenerative, 149
space, 132

G.

GAS, blast furnace, 46
calorific determination of, 74
coal, 141
Dowson, 264
generator, 258
Mond, 270
natural, 46
producer, 225
semi-water, 264
Siemens, 262
suction, 277
water, 44, 223
calorific value, 166
coal gas, 141
composition, 164, 182
Gas, increasing yield of, 169
manufacture, 141, 166
purification, 156, 182
standard of value, 166
supply, new bill, 170
Gas coal, 144
liquor, 154
oven, 172
tar, 97
Gas engines, 221, 286
Gaseous fuel, 42
Gas from blast furnace, 46
coke, 43
slack, 43
Gas generators, 259
Berrier, 275
Bischof, 261
Boutillier, 284
Buire-Leucauchez, 272
Capitaine, 278
Dowson, 267
Duff-Whitfield, 284
Mond, 270
Pintsch, 275
principle of, 259
Siemens, 262
Gas stoves, efficiency of, 215
Gassing, 15
Gas supply, new bill, 170
Generator gas, 258
Graphite, 33

H.

HEAT of combustion, 60
of formation, 60
radiant, 124, 211
radiated in a furnace, 124
theory of, 50
units, 59
Heating by coal gas, 218
Heavy oil, 99

Holden oil burner, 120
Humphreys-Glasgow plant, 245
Hydrocarbons, 56
Hydrogen, 47
  combustion of, 47
  in coal, 33
Hydraulic main, 146

I.

Ignition point, 9
Illuminating power in relation to calories, 166, 188
Illuminating power of coal gas flames, 166
Illuminating power of coal gas burners, 251
Illuminating power of oil lamps, 111
Impurities in air, 6
  coal gas, 156
Incandescence, temperatures of, 16
Incandescent mantle, 166, 181, 182
Incomplete combustion, 14
  products of, 14
Inerts in coal gas, 171
Internal combustion motors, 221, 314
Inverted gas burners, 181

K.

Körting oil burner, 117
Kramers and Aarts water gas process, 241

L.

Lamp oil, 90
Lamps, illuminating value of oil, 111
Latent heat of steam, 61
Lavoisier's work on combustion, 8
Lebon, 142
Le Chatelier thermo-couple, 206
Leeds forge, 226
Lignite, 32
Lime, purification by, 160
  manufacture of, 162
Limestone, 162
Liquids, calorific determination of, 74
Liquid fuel, 84, 137
  comparative values of, 137, 334
  consumption of, 335
  economy of, 333
  for locomotives, 123, 328
  for steamships, 132, 334
  furnaces for, 334
  in the navy, 133, 140, 331, 333
  United States experiments, 134, 327, 331, 333
Liquid fuel systems—
  Aydon, Wise and Field, 117
  Dürr, 115
  Coleman, 333
  Eames, 115
  Foote, 113
  general principles of, 328
  Holden, 118
  Kermode, 329
  Körting, 117
  Nobel, 112
  Orde, 121
  Richardson, 111
  Rushden and Eeles, 120
  Simms and Barff, 115
  Swensson, 117

Liquor, ammoniacal, 154
Lloyd's regulations for oil fuel, 100
Low temperature carbonisation, 23
Lowe water gas process, 242
Luminosity of flame, 174

M.

Mahler bomb, 65
for liquids, 74
for gases, 74
Marine suction plant, 278
Matter, three states of, 49
constitution of, 57
Mecker gas burner, 222
Methane, 35
calorific value, 60
in mines, 35
Methane-hydrogen gas plant, 255
Methylated alcohol, 306
Mineral oil, 84
Mixing water gas with coal gas, 172
Molecular weight, 54
Molecule, 52
Mond gas, 270
Motors, internal combustion, 221

N.

Natural gas, 46
Navy, use of liquid fuel in the, 133
Nitric acid from air 23
Nitrogen, 7
in coal gas, 155
properties, 7
Nobel's troughs, 112
Non-luminosity in flames, cause of, 198

O.

Objections to carburetted water gas, 245
Oil, 84
atomisation of, 328, 331
combustion of, 88
composition of American, 88
Russian, 88
consumption in furnace, 126, 334
crude, 88
early history of, 84
fields, 87
fuel, 84
in America, 84
Derbyshire, 87
in Russia, 86
lamps, 108
production of, 41, 87, 107
shale, 96
theories of formation of, 40
wells, 84, 87
Oil burners—
American types, 328, 329, 333
Aydon, Wise and Field, 117
Coleman, 333
general principles of, 328
Holden, 118
Kermode, 329
Körting, 117
Orde, 121
Rushden and Eeles, 120
Swensson, 117

Oil fuel, 84, 328—334
comparative values of, 137, 140
consumption of, 333
for locomotives, 123
for naval use, 133, 140, 331, 333
steam raising, tests of, 334
Orde's oil burner, 121
Oxygen, 7
consumption of, 26
in combustion, 8
in coal, 145, 247
properties, 7

P.

Peat, 30, 295
briquettes, 296
calorific value of, 297
compared with coal, 298
Pensky-Marten apparatus, 94
Pentane, 102
Petrol, 102
combustion of, 309
costs of, 314
Petroleum, 84
products of, 89
Phenoloid, 99
Pintsch suction gas plant, 275
Platinum lining for calorimeters, 83
Poisoning by carbon monoxide, 15
Power costs, 286, 314
Priestly's work, 3
Producer gas, 225
Products of combustion, 12
in gas stoves, 213
in motors, 308
Purification of coal gas, 160, 182

R.

Radiant heat, 124, 215
Radiation of heat in a furnace, 124
Radium, 57
Rapid combustion, 11
Ratio of gas to air in a bunsen burner, 196
Redwood's flame-cap test, 105
Regenerative burner, 180
furnace, 149
retort firing, 149
stoves, 210
Regulations, Lloyd's, for oil fuel, 100
Relation of animal to vegetable life, 24
illuminating power to calories, 188
Residuum, 90
Respiration, 25
Retorts, coal gas, 148
Retort charging machine, 150
Revivification, 163
Richardson's furnace, 111
Rushden and Eeles' oil burner, 120
Russian oil, 86

S.

Safety lamps, 36
Saturated hydrocarbons, 56
Scrubbers, 146
Semi-water gas, 45
Shale oil, 96
Siemens gas, 262
regenerative furnace, 261
Simms and Barff oil furnace, 115