UC-NRLF
$B 103 452

GRIFFIN'S SCIENTIFIC TEXT-BOOKS

LIBRARY
OF THE
UNIVERSITY OF CALIFORNIA.

Class

THE CHEMISTRY OF
GAS MANUFACTURE.

NET BOOK.—This book is supplied to the Trade on terms which will not allow of Discount to the Public.

CHARLES GRIFFIN & CO., LTD.

WORKS SUITABLE FOR MUNICIPAL AND COUNTY ENGINEERS, ANALYSTS, AND OTHERS.

THIRD EDITION, Revised. Fully Illustrated. VOLUME I.

THE CHEMISTRY OF GAS MANUFACTURE:

A Handbook on the Production and Purification of Illuminating Gas.

BY W. J. ATKINSON BUTTERFIELD, M.A., F.I.C., F.C.S.

"The BEST WORK OF ITS KIND."—*Journal of Gas Lighting.*

THE SECOND VOLUME, COMPLETING THE WORK,

Is in Active Preparation, and will deal with The Analysis and Testing of Gas; Photometry; Calorimetry; and the Use of Gas for Lighting (with and without the Aid of Mantles), Heating, and the Generation of Power.

Acetylene: The Principles of its Generation and Use. By F. H. LEEDS, F.I.C., F.C.S., Member of the Society of Public Analysts and of the Acetylene Association; and W. J. ATKINSON BUTTERFIELD, M.A., F.I.C., F.C.S. With Diagrams and Illustrations. 5s. net.

Water Supply: A Practical Treatise on the Selection of Sources and the Distribution of Water. By REGINALD E. MIDDLETON, M.Inst.C.E., M.Inst.Mech.E., F.S.I. With Four Plates and Numerous Diagrams. Crown 8vo. 8s. 6d. net.

Central Electrical Stations: Their Design, Organisation, and Management. Including the Generation and Distribution of Electrical Energy. By C. H. WORDINGHAM, A.K.C., M.Inst.C.E. SECOND EDITION. 24s. net.

Electricity Control. A Treatise on Electricity Switchgear and Systems of Transmission. By LEONARD ANDREWS, M.I.E.E., Ex-Member of Council, Incorporated Municipal Electrical Association, &c. In Large 8vo. Handsome Cloth. With Numerous Illustrations.

Sewage Disposal Works: A Guide to the Construction of Works for the Prevention of the Pollution by Sewage of Rivers and Estuaries. By W. SANTO CRIMP, M.Inst.C.E., F.G.S. SECOND EDITION, Revised and Enlarged. Large 8vo, Handsome Cloth. With 37 Plates. 30s.

Trades' Waste: Its Treatment and Utilisation, with Special Reference to the Prevention of Rivers' Pollution. By W. NAYLOR, F.C.S., A.M.Inst.C.E. With Numerous Plates, Diagrams, and Illustrations. 21s. net.

Road Making and Maintenance: A Practical Treatise for Engineers, Surveyors, and others. With an Historical Sketch of Ancient and Modern Practice. By THOMAS AITKEN, Assoc.M.Inst.C.E., M. Assoc. Municipal and County Engrs.; M. San. Inst. With Numerous Plates, Diagrams, and Illustrations. 21s.

Light Railways at Home and Abroad. By WILLIAM HENRY COLE, M.Inst.C.E., late Deputy Manager, North-Western Railway, India. Large 8vo, Handsome Cloth, Plates, and Illustrations. 16s.

Practical Sanitation: A Handbook for Sanitary Inspectors and others interested in Sanitation. By GEO. REID, M.D., D.P.H., Medical Officer, Staffordshire County Council. With Appendix on Sanitary Law, by Herbert Manley, M.A., M.B., D.P.H. ELEVENTH EDITION, Revised. 6s.

Sanitary Engineering: A Practical Manual of Town Drainage and Sewage and Refuse Disposal. By FRANCIS WOOD, A.M.Inst.C.E., F.G.S., Borough Surveyor, Fulham. Fully Illustrated. 8s. 6d. net.

Dairy Chemistry: A Practical Handbook for Dairy Managers, Chemists, and Analysts. By H. DROOP RICHMOND, F.C.S., Chemist to the Aylesbury Dairy Company. With Tables, Illustrations, &c. Handsome Cloth. 16s.

Milk: Its Production and Uses. With Chapters on Dairy Farming, The Diseases of Cattle, and on the Hygiene and Control of Supplies. By EDWARD F. WILLOUGHBY, M.D. (Lond.), D.P.H. (Lond. and Camb.), Inspector of Farms and General Scientific Adviser to Welford & Sons, Ltd. 6s. net.

Flesh Foods: With Methods for their Chemical, Microscopical, and Bacteriological Examination. A Handbook for Medical Men, Inspectors, Analysts, and others. By C. AINSWORTH MITCHELL, B.A., F.I.C., Mem. Council Soc. of Public Analysts. With Numerous Illustrations and a Coloured Plate. 10s. 6d.

Foods: Their Composition and Analysis. By A. WYNTER BLYTH, M.R.C.S., F.C.S., Public Analyst for the County of Devon, and M. WYNTER BLYTH, B.A., B.Sc., F.C.S. With Tables, Folding Plate, and Frontispiece. FIFTH EDITION, Thoroughly Revised. 21s.

LONDON: CHARLES GRIFFIN & CO., LIMITED, EXETER STREET, STRAND.

THE CHEMISTRY OF
GAS MANUFACTURE.

A PRACTICAL HANDBOOK

ON THE

PRODUCTION, PURIFICATION, AND TESTING OF
ILLUMINATING AND FUEL GAS,
AND ON THE BYE-PRODUCTS OF GAS MANUFACTURE.

BY

W. J. ATKINSON BUTTERFIELD, M.A., F.I.C.,
CONSULTING CHEMIST.

Third Edition, with Illustrations.

VOLUME I.
MATERIALS AND PROCESSES.

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

LONDON:
CHARLES GRIFFIN AND COMPANY, LIMITED;
EXETER STREET, STRAND.
1904.

[*All Rights Reserved.*]

TP751
B8
1904
v.1

GENERAL

A. I. L.

PREFACE TO THE THIRD EDITION.

The extensive revision and enlargement of this handbook, which the advances in the Gas Industry made imperative as soon as the Second Edition was exhausted, practically precluded its continued publication as a single volume. The manufacture and use of Acetylene, to which a chapter had been devoted in the last edition, could no longer be adequately or appropriately dealt with in such a manner, and a new handbook on "Acetylene" was, therefore, written by Mr. F. H. Leeds, in collaboration with the undersigned, and published some months ago. The revision of the rest of this work, as projected, entailed the re-writing of the major part of it, and in order neither to delay publication unduly nor to make too bulky a volume, it was decided to publish the portion treating of the Materials and Processes of Gas Manufacture before the completion of the revision of the remainder of the book. A second volume, covering the "Testing and Use of Gas," is now in course of preparation.

W. J. ATKINSON BUTTERFIELD.

Westminster, *June, 1904.*

141343

CONTENTS.

Chapter I.—The Raw Materials of Gas Manufacture.

PAGE
Classification, ... 1
Coal, ... 2
Cellulose, ... 5
Wood gas, ... 6
Peat, ... 7
Peat gas, ... 8
Lignite or brown coal, . . 9
Coal, ... 11
  Caking, ... 11
  Non-caking, ... 13
  Cannel, ... 13
  Sampling, ... 14
  Analysis, ... 16
    Nitrogen, ... 17
    Phosphorus, ... 17
    Sulphur, ... 19
    Ash, ... 21
    Arsenic, ... 25
    Moisture, ... 28
PAGE
    Density, ... 30
    Volatile matter and fixed carbon, ... 31
    Practical testing, . . 32
Anthracite, coke, &c., . . 39
  Anthracite, ... 39
  Coke, ... 40
  Retort carbon, ... 42
Oil, ... 43
  Petroleum, ... 43
    Origin, ... 43
    Distribution, ... 44
    Chemical composition, . 45
    Gas making varieties, . 47
    Examination, ... 47
  Shale oil, ... 55
  Bromine absorption, . . . 57
Carburine and other light oils, . 62
Naphthalene, ... 64

Chapter II.—Coal Gas.

Retorts, ... 66
Mode of setting retorts, . . 68
Actions in the retort furnace, . 69
  ,, in direct combustion furnaces, . . . 71
Moisture in the air supply, . 76
Control of direct combustion furnaces, ... 79
Producer for retort heating, . 83
Recuperation of waste heat, . 89
Spent gases, ... 93
Furnace bar cooling, . . . 93
Charging and drawing horizontal retorts, ... 94
Exit pipes, ... 96
Hydraulic main, ... 96
Condensers, ... 97
Exhausters, ... 100
Inclined retorts, ... 101
Mechanical stokers, . . . 102
  West's, ... 106
  Ruscoe's, ... 110
  Woodward & Crossley's, . 110
  Foulis-Arrol, ... 110
  Grein's, ... 111
  De Brouwer's, ... 111
  La Villette, ... 113
Continuous carbonizers, . . 114
Vertical retorts, ... 115
Carbonization products of coal, . 116

PAGE
Mill's theory of carbonization, . 123
Distribution of nitrogen, . . 123
Mond gas producers, . . . 125
Distribution of sulphur, . . 126
Quality and quantity of gas produced, ... 127
PAGE
Self-carburetting, ... 129
Calorific balance of carbonization, ... 131
Retort carbon, ... 133
Composition of crude coal gas, . 134

Chapter III.—Coal Gas—*Continued.*

PAGE
Impurities in coal gas, . . 137
Gas purification, ... 140
Washing or scrubbing, . . 140
Tar extractors, ... 141
Tower scrubbers, . . . 142
"Standard" washer-scrubber, 144
"New" washer-scrubber, . 146
Traces of ammonia, . . 148
Removal of carbonic acid, . 149
Mode of preparing and using lime, ... 150
Testing chalk and lime, . . 153
Removal of sulphuretted hydrogen, ... 156
Action of ferric oxide, . 156
Testing bog ore, . . . 158
PAGE
Purification value of ferric oxide, ... 161
Weldon mud, ... 164
Other purifying materials, . 168
Grids and purifiers, . . . 168
Scheme of purification, . . 172
Revivification of ferric oxide, 175
Use of Weldon mud, . . . 177
Removal of carbon disulphide, 178
Preparation and nature of sulphided lime, ... 179
Check vessels, ... 182
General view of the scheme of purification, ... 183
Modifications of the scheme, . 184
Purification with gas liquor, . 187

Chapter IV.—Carburetted Water Gas.

Carburetted water gas, . . 190
Intermittent system, . . 192
Action of carbon on water vapour, 192
Thermic exchanges of the reactions, ... 193
Conditions for producing water gas, ... 197
Lowe plant, ... 201
General view of the plant, . 201
Outline of the process, . . 204
Management of the plant, . 205
Products of the "blow," . . 208
Purification, ... 212
Composition, ... 213
Other plants, ... 214
Toxic action of water gas, . . 216
Uncarburetted water gas, . . 217
Dellwik-Fleischer process, . 218
Self-carburetting process, . . 219

Chapter V.—Oil Gas.

Oils used, ... 220
Pintsch's system, ... 220
Pope's system, ... 222
Keith's apparatus, . . . 222
Alexander & Paterson apparatus, 222
Steam in oil gas manufacture, . 222
Tatham process, ... 223
Peebles process, ... 225

Chapter VI.—Enriching by Light Oils.

Carburetting gas and air, . . 229
,, with carburine, . 229
Carburetting with petroleum spirit, . 231
,, ,, benzol, . 232

Chapter VII.—Final Details of the Manufacture and Sundry Schemes for Making and Enriching Gas.

PAGE
Dinsmore's process for carbonizing tar, ... 235
Self-carburetting process, . . 236
Acetylene as an enriching agent, 236
Station gas meters, ... 236
,, governors, ... 238

PAGE
Gasholder,. 240
Tank, ... 240
Framing, ... 241
Mode of using, ... 242
Telescopic, ... 242

INDEX, ... 245

LIST OF ILLUSTRATIONS.

FIG. PAGE
1. Apparatus for estimating ash of coal, ... 22
2. ,, ,, ,, ,, ... 23
3. ,, ,, ,, moisture in coal, ... 27
4. Experimental coal-testing plant, ... 33
5. Oil flashing point apparatus, ... 49
6. Mouthpiece with self-sealing lid, ... 67
7. ,, and lid, old pattern, ... 67
8. Klönne regenerative furnace, ... *facing* 69
9. Hasse-Didier regenerative furnace, ... 69
10. Furnace used in some London works, ... 70
11. Scoop for hand-charging of retorts, ... 94
12. Saddle for raising scoop, ... 94
13. Sectional view of exit pipes, ... 96
14. End view of horizontal condenser, ... 98
15. Beale's gas exhauster, ... 100
16. Donkin's gas exhauster, ... 100
17. West's manual stoking machines, ... 105
18. ,, compressed air charging machine, ... 108
19. ,, ,, ,, drawing and charging machines, . . . 109
20. De Brouwer charging machine,* 112
21. "Standard" washer-scrubber, ... 145
22. "New" washer-scrubber, ... 147
23. Haldane's double absorption tube, ... 155
24. Vessel for fouling samples of oxide, ... 162
25. Ordinary gas purifier, ... 169
26. Cross-section of three-floor purifying house, ... 170
27. Purifier grid, ... 171
28. Lowe carburetted water-gas plant, ... 203
29. The Maxim carburetting apparatus, ... 230
30. Simple governor, ... 233
31. Four-lift gasholder, ... 249

---

* The photograph from which Fig. 20 is produced was furnished by Messrs. W. J. Jenkins & Co., Ltd., whose name, as makers of the De Brouwer charging machine, was inadvertently not mentioned in the text.

THE CHEMISTRY

OF

GAS MANUFACTURE.

MATERIALS AND PROCESSES.

18

CHAPTER I.

THE RAW MATERIALS OF GAS MANUFACTURE.

The raw materials from which illuminating gas is produced are, from the manufacturing standpoint, best classified according to the methods in use for obtaining the gas from them. Adopting this plan of classification, the raw materials will be ranged under six heads:—

(1) For the production of coal gas.
(2) For the production of water gas.
(3) For the production of oil gas.
(4) For the production of air gas.
(5) For enriching gas of low illuminating power.
(6) For the production of simple gaseous hydrocarbons.

By "coal gas" is implied gas produced by the dry distillation of bituminous coal, or other solid carbonaceous matter, in a retort or oven heated externally; by "water gas," that produced by the action of steam on incandescent carbonaceous fuel; by "oil gas," that produced by the distillation of liquid hydrocarbons; by "air gas," air mixed with highly volatile hydrocarbon in the state of vapour or gas. The first is that which constitutes, or forms the basis of, the illuminating gas supplied in England and many parts of Europe; the second variety in combination with the third is extensively employed in the United States of America, and to a limited extent in Great Britain; while the third has special applications in various countries, but in few places forms the staple gas supply. "Air gas" similarly has special applications. The materials classed under the fifth head are of necessity subsidiary to those under the preceding heads. Under the sixth head fall the compounds of the metals with carbon, known as carbides, which interact with water to yield gaseous hydrocarbons. Some of them form the source of commercial acetylene, which has a wide application for special purposes. The manufacture and use of acetylene, however, stand apart from those of other common illuminating gases, and are therefore not dealt with in this work. There is a separate book on *Acetylene*, by the author and F. H. Leeds, F.I.C., F.C.S., published by Messrs. Charles Griffin & Co., Ltd. The materials ranged under each of the other heads are considered in order, beginning with the first and most important, which is—

COAL.

The word **coal** has an application sufficiently vague to preclude an exact definition of its meaning, though no one is without a tolerably clear conception of the nature of the substances to which it may legitimately be applied. They are invariably solid bodies whose chief constituent is carbon; hydrogen, nitrogen, oxygen, sulphur, and earthy material being present with it in varying but comparatively small proportions. Coal is the product of the decay of vegetable matter under the protracted influence of heat, pressure, and moisture. Opinions differ as to the amount of influence each of these agencies has exerted on the formation of the final product, but it would appear that they have in general been acting in unison. Bischof decides that the conversion of woody fibre into coal must certainly have been effected by the agency of moisture, and he gives a number of equations expressing the possible chemical changes. The course of the change must, however, be a matter of surmise in our present incomplete knowledge of the agencies that were at work. The bulk of the coal deposits is derived from the remnants of cryptogamic plants, which must have grown, even in northern latitudes, with an abundance and vigour unequalled at the present time in the Tropics. The majority of coal seams are formations of the Carboniferous age, and have become buried by later sedimentary deposits. A few instances of coal of a pre-Carboniferous age are known, and probably graphite is the ultimate product of the more prolonged working of the agencies which produced coal. Coal of more recent formation is also found. The process of decay of vegetable tissue appears to have been in action in all ages, and the less completely carbonized fibre is exemplified in the various kinds of lignite or brown coal, and the still more recent peat.

Some interesting and instructive remarks on the chemistry of coal formation have been made by J. W. Thomas.* The following is a summary of his conclusions:—Coal retains some water after long exposure in dry air; the quantity thus retained is, with certain exceptions, proportional to the age of the coal, being highest in lignite and lowest in anthracite. Some lignites contain 30 per cent. of water in the natural condition, but the better qualities do not hold more than 20 per cent., and this is reduced by air drying to 10 per cent. Such coals as are used for fuel in this country rarely contain more than 5 per cent. after being air dried. Steam and anthracite coals from dry seams do not hold more than 1 per cent. of moisture. The question is, How is this moisture held? If it is driven off by heat, and the dried coal afterwards exposed in a moist atmosphere, the moisture is re-absorbed at a very rapid rate. A portion of the water in coal is most obstinately held, and doubtless exists in chemical combination. There is probably no moisture in the deep dry steam and anthracite coals as they occur in their seams, but they are very hygroscopic to a certain point. The hygroscopicity of coal is likely to prove the key to the property of spontaneous combustion.

Coal contains gases, oily matters, and solids of the paraffin series. Watson Smith has shown † that liquid and solid paraffins exist ready formed in coal, but rarely exceed 1 per cent. in coals of the Carboniferous period. Good samples of coals contain from 0·5 to 10·0 per cent. of mineral matter, and from 0·5 to 4·0 per cent. of sulphur. The sulphur is generally present as pyrites or iron disulphide ($Fe\ S_2$) in coals of the Carboniferous age, but frequently in organic combination in lignites. It is not known how the 0·5 to 2·0 per cent. of nitrogen present in coal is combined. Some of the carbon is doubtless combined with hydrogen, but how much is thus combined and how much is free is not known. The oxygen present is usually deemed to be combined with hydrogen, but this is hardly likely to be the case with dry deep coals containing occluded marsh gas, in which coals it probably exists in some oxycarbon compound containing hydrogen.

Coal of the older deposits contains a very high percentage of carbon, and a very low percentage of hydrogen. The proportion of carbon gradually decreases, and that of hydrogen increases, as the more modern deposits are approached. The oxygen varies

---

* *Chemical News*, lxx., 91.

† *Journ. Soc. Chem. Ind.*, 1891, 975; 1893, 221.

for the most part in direct ratio with the hydrogen. The inorganic matter varies greatly in amount, and appears to be an intrusion from the alluvial deposits overlying the coal seam when they were in course of deposition. Its nature also varies considerably, according to the nature of the surrounding deposits. A knowledge of the proportions in which carbon, oxygen, hydrogen, and ash exist in a coal is useful for indicating its origin, age, and approximate value as a fuel, but for reasons given later must not be relied on too implicitly. The following table of the percentage composition of various samples of dry wood, coal, and bodies of nature intermediate between them, will indicate the continuity that exists in the series of natural decomposition products of cellular fibre:—

	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
,, 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	2·5	0·5	0·5	4·0

The following table, compiled by J. W. Thomas, shows the gradation and regularity of change, in physical and chemical properties, from the tertiary lignites of Bovey Tracey through the bituminous coals of South Wales to anthracite:—

Description.	Hardness.	Dryness.	Percentage of Water in Air-dried Sample (Hygroscopicity).	Percentage Composition of Dried Samples.					
				Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Soft lignite, . .	Soft.	Wet.	15·0	59·9	6·0	25·0	0·6	1·5	7·0
Compact lignite, .	Medium.	,,	10·0	66·7	5·5	20·0	0·8	2·0	5·0
Upper carboniferous coal, . .	,,	Medium.	6·0	79·5	5·5	4·5	1·5	3·5	5·5
Pennant coals, . ,	Hard.	,,	4·0	81·5	5·0	4·5	1·5	3·0	4·5
Semi-bituminous coal, . . .	,,	,,	2·5	84·2	4·5	4·0	1·3	2·0	4·0
Steam coal, . . .	,,	Dry.	1·5	87·8	4·2	3·0	1·0	1·0	3·0
Anthracite, . .	Very hard.	,,	0·5	91·7	3·5	2·5	0·8	0·5	1·0

Cellulose.—Impure cellulose is readily obtained from many fibrous substances, and is met with in commerce as jute. Purified cellulose is known as "cotton wool;" when washed free from fatty matters it is designated "medicated cotton." It is of interest to gas chemists as being a pure carbohydrate on which the progress of the process of carbonization can be watched; the action and products being uninfluenced by the presence of several complicated carbon compounds. This matter is of interest in elucidating the process of carbonization. The composition of wood varies according to the nature of the tree and the time of year at which it was cut. On exposure to air it loses a large amount of moisture; the percentage in freshly cut wood varying, according to its nature, from 30 to 50, and diminishing by nearly 20 per cent. on long-continued exposure to the air in a dry place. The chief constituent of wood is cellulose, and dry wood behaves very similarly to cellulose on dry distillation, but the products are more numerous and the reactions less clearly defined, being complicated by the other constituents of woody fibre. The ultimate composition of a few varieties of wood, dried at 100° C., is indicated in the following table:—

	Specific Gravity.	Carbon.	Hydrogen.	Oxygen (including Nitrogen).	Ash.
Oak, . .	0·75	49·3	6·1	43·0	1·6
Beech, .	0·58	48·0	6·1	44·8	1·1
Pine, .	0·42	49·1	6·3	43·6	1·0

On destructive distillation, wood gives up its water first, and then yields empyreumatic oils, pyroligneous or impure acetic acid, wood spirit, acetone, and a quantity of gas, while charcoal remains in the retort. The gas varies considerably in composition, according to the nature of the wood, the amount of water in it, and the temperature of distillation, but it invariably contains a large percentage of carbonic acid.

Gas from pure forms of cellulose consists, apart from atmospheric constituents, almost wholly of carbonic acid and carbonic oxide. Less pure cellulose yields also methane and traces of other hydrocarbons and of hydrogen. These constituents are undoubtedly derived from the resinous constituents of the wood, or like impure forms of cellulose; perhaps the water in wood, &c., aids the formation of methane. In view of the theory promulgated in 1880-1882 by Cross and Bevan, that coals may be regarded as extreme terms of a series of natural condensation products of the celluloses, considerable importance attaches to the study of the gaseous products of the destructive distillation of celluloses, as a guide to the comprehension of the origin of the several constituents of coal gas. Cross and Bevan obtained from certain forms of cellulose by the action of sulphuric acid at 70° C. condensation products which separated as gelatinous hydrates. These products passed by spontaneous dehydration into black lustrous solids, which had all the characteristics of coals, and afforded chlorination products similar to those afforded by some coal. The researches of Cross and Bevan on cellulose and ligno-cellulose in relation to coal are referred to in the *Chemical News*, vol. lxxiv. (1896), p. 292, where a brief list of the more important literature on the subject is given. The connection between cellulose and the coal substance proper is a very interesting subject of study, and work in continuation of that done incidentally in the course of investigations on the celluloses and ligno-celluloses by Cross and Bevan is much needed. So far, the study of the carbonization of wood and coal has scarcely been attempted by gas chemists, through the instrumentality of preliminary investigations of the carbonization of nearly pure forms of cellulose. Such a study of the course of carbonization of bodies of varying degrees of complexity of composition would certainly lead to valuable results.

Wood Gas.—Wood gas is usually made as a necessary bye-product in the course of the manufacture of other staple products, and the effects of variations of the conditions of carbonization on the resulting gas have seldom been observed. Wood gas is used for illuminating purposes only under exceptional conditions, but its manufacture and composition are interesting to the gas engineer for the complete comprehension of the phenomena of the destructive distillation of carbonaceous material. A process for making gas from wood, in which the tarry products, as well as a large proportion of the charcoal, which ordinarily result from the destructive distillation of wood, are converted into gas, has been devised by Riché. The principal applications of such wood gas must be for fuel and power purposes. The Riché gas is non-illuminating when it is consumed in open flame burners, but, with the aid of a mantle, it is stated to give a light of 50 candle-power at a consumption of 5 cubic feet per hour.* Irminger has lately investigated the yield of gas from various descriptions of wood when carbonized in an experimental coal-gas plant.† The following are the more important conclusions to which his researches lead:—

The yield of gas was higher, and its calorific power better, when the temperature reached in the carbonization was 700° C.

---

* *Eng. and Mining Journ.*, 1900, 460.

† *Proc. Inst. Civil Engineers*, 1900, (4), 49.

after one hour than when it took two hours to attain 600° C. Fir-wood, charged into a retort heated to about 1,100° C., yielded over 17,000 cubic feet of gas per ton. The gas had a calorific power of 460 B.T.U. per cubic foot. The large yield of gas was secured at this high temperature at the expense of a diminished yield of the other products of the destructive distillation of wood. Irminger found that the crude wood gas, when consumed under a Welsbach mantle at the rate of 3 cubic feet per hour, gave a light of about 36 candle power.

Peat.—The first formed natural decomposition product of cellular fibre is known as peat, and is found in large quantities in the bogs of Ireland, the moors of Scotland and England, and in many parts of the Continent. In its natural state peat contains a varying but always large proportion of water, which is partly given up on exposure to the air in a dry place, but completely only when heated. Freshly dug peat frequently contains 80 or even 90 per cent. of water; when dried under cover by long continued exposure to the air, 12 to 30 per cent. of its weight is water, and this amount does not diminish on further exposure. Peat thus air-dried, on heating at 100° C. loses from 10 to 30 per cent. of its weight, by the loss of water chiefly, but also of small quantities of volatile hydrocarbons. The amount of ash contained in peat varies, of course, greatly according to its origin, but in the best varieties does not exceed 1·5 per cent. on the air-dried sample. 4 per cent. of ash is an average amount, and many peats in use contain nearly 10 per cent., but more than that is sufficient to condemn them for ordinary purposes. The specific gravity of peat is very variable, according to the amount of water and ash present, but also according to the state of aggregation, ranging from 0·3 to 1·20 in the dry state. The former specific gravity is only found with particularly fibrous specimens, the latter only with dense compact peat almost destitute of fibre. The quantity of water naturally contained in peat, and the difficulty and expense of its complete removal render peat valueless as a fuel where coal is reasonably cheap, and for the same reason it is seldom used for gas making. But in districts where coal is scarce peat is used with some measure of success for gas manufacture. For this purpose it is generally compressed and moulded into bricks of regular size, the moisture being as far as possible removed. Elaborate systems of drying chambers and shaping machines have been devised and are in use in towns bordering on the peat moors of Austria. The amount of water remaining in the peat after treatment seldom exceeds 10 per cent., and the specific gravity of the briquettes sometimes reaches 1·1. The composition of dried peat is fairly constant when the ash is eliminated from the analytical results.

Good Irish peat will be found to have approximately the following composition, water and ash being disregarded :—

Carbon,	61·0 per cent.
Hydrogen,	6·5 ,,
Nitrogen,	1·0 ,,
Oxygen,	31·5 ,,

The average composition of Bohemian peat from three different localities is, according to analyses by H. Bunte, as follows :—

Carbon,	41·39 per cent.
Hydrogen,	4·29 ,,
Oxygen, nitrogen, and sulphur,	25·95 ,,
Water,	22·71 ,,
Ash,	5·66 ,,

One pound of such Bohemian peat has a calorific power of 1,685 calories or 6,686 B.T.U.

Peat Gas.—Its constitution indicates that peat is formed from woody fibre by the elimination of hydrogen and oxygen as water, of carbon and oxygen as carbonic acid, and in less amount of carbon and hydrogen as marsh gas, the net result of these changes being a considerable increase in the proportion of carbon, and decrease in the proportion of oxygen. Were the process continued still further, a substance having the composition of lignite or brown coal might be expected to result. Peat being therefore virtually a body intermediate in nature between wood and coal, it might be expected to yield on destructive distillation, products intermediate in character and quantity, between those obtained from those two substances. Such is in reality the case, though the true relation of the products of destructive distillation of wood, peat, and coal to one another is frequently obscured by the quantity of moisture in the peat. This tends to lower the temperature of carbonization, and consequently the result is not comparable strictly with the result of the carbonization of coal as ordinarily carried out. Perfectly dry compressed peat yields at a red heat 11,000 cubic feet of gas per ton; after purification by lime the gas has an illuminating power of 17 to 18 candles. The coke retains the form of the peat, and amounts to nearly 9 cwts. per ton carbonized, while 15 gallons of tar are obtained, as well as a quantity of ammoniacal liquor. The crude gas from peat contains more carbonic acid than that from coal, and the amount increases with the water present in the peat, but the gas is less contaminated with sulphur compounds. The expense of drying the peat and of purification of the gas leave it out of question as a material for gas manufacture where coal is at all accessible, but the absence of the latter mineral in some parts of Europe has directed attention to peat for gas making.

It is possible to utilize peat gas for lighting by the aid of mantles, without first subjecting the gas to purification by means of lime for the removal of the large proportion of carbonic acid which it contains. It is necessary to remove all, or the greater part of, this carbonic acid, in order to render the peat gas an efficient illuminant when burnt in open-flame burners, and the cost of such removal is practically prohibitive. But, as in the case of wood gas, the gas may be utilized for lighting, without prior removal of the carbonic acid, if mantles are employed. In general, however, peat will not be distilled or carbonized with the object of obtaining gas for illuminating purposes as the primary product. But the gas which results as a secondary product when compressed and dried peat is distilled, as in Austria, for the sake of the charcoal or coke and tarry and nitrogenous products, or when the peat is carbonized, as in Russia, for the production of coke for use as fuel, may well be utilized locally for lighting by the aid of mantles. The compressed and dried peat of Austria yields, on dry distillation, about 35 to 40 per cent. of good dense charcoal, 25 per cent. of ammoniacal liquor, 6 per cent. of tar, and 29 to 30 per cent. of gas. The tar, on distillation, yields burning, "solar," and lubricating oils, paraffin, and 15 per cent. of pitch. The gas has been utilized at Salzburg for some years past.*

Lignite or **brown coal** is vegetable matter in a more advanced stage of decay than peat, and approaches more nearly the true coals in composition. In many lignites the forms of trees and plants are clearly visible, and indicate the nature of the vegetation that existed at the time the beds were formed. This consisted mainly of mosses, algæ, and other cryptogamic plants growing with a profusion no longer observed in the same latitudes. True lignite contains very little bituminous matter, but some of the brown coals are nearly as rich as ordinary bituminous coal, and, indeed, the two varieties merge almost imperceptibly into one another. Lignite is found only in small quantities in England and France, but large deposits occur in Germany and Austria, especially in Silesia, Saxony, and Bohemia. Its average composition is—Carbon, 69 per cent.; oxygen (and nitrogen), 20 per cent.; hydrogen, 5 per cent.; ash, 6 per cent. The lignite from the neighbourhood of Dartmoor has a specific gravity of 1·13, and gives on analysis :—

Carbon, ...	66·3 per cent.
Oxygen (and nitrogen), ...	23·4 ,,
Hydrogen, ...	5·6 ,,
Sulphur, ...	2·4 ,,
Ash, ...	2·3 ,,

---

* *Oesterr. Chem. und Tech. Zeitschrift*, 1899, Nos. 20-22.

The lignite found in several places in Hungary is rather different in character, and in the natural state has the following average composition :—

Carbon,	49·0 per cent.
Oxygen, nitrogen, and sulphur,	20·8 ,,
Water,	15·0 ,,
Ash,	11·0 ,,
Hydrogen,	4·2 ,,

One pound of this lignite has on the average a calorific power of 2,675 calories or 10,614 B.T.U.

Lignite from Buchberg, in Styria, has, according to H. Strache, the following composition :—

Carbon,	41·6 per cent.
Oxygen,	25·1 ,,
Water,	19·6 ,,
Ash,	8·1 ,,
Hydrogen,	4·7 ,,
Nitrogen,	0·6 ,,
Sulphur,	0·3 ,,

One pound has a calorific power of 1,677 calories or 6,654 B.T.U. It will be seen that this lignite, which is interesting as having been employed in carefully conducted gas-making trials, with a generating plant designed by H. Strache, differs considerably from the other lignites referred to, and resembles some descriptions of peat in composition. Its value as fuel is clearly very low.

In the natural state lignite generally contains a large amount of water, often amounting to 20 per cent. of its weight, and requires drying by exposure under cover to the air before it can be used profitably for gas making. The experience of English gas managers shows, however, that though a large yield of gas—in some instances 13,000 cubic feet per ton—may be obtained by the carbonization of lignite, the quality of the product is very poor, its "illuminating power" often being only 8 candles, and the coke is of little value. The tar, too, though valuable in itself, when mixed with ordinary coal tar causes difficulties in the working up of the latter which detract greatly from its value. The tar and ammoniacal liquor from lignite have a most objectionable odour, resembling, but more intense than, that of a decoction of cabbages. The brown coals of Germany and Austria are, however, somewhat extensively used in those countries for gas manufacture. They vary in colour from a dirty yellow to a dark brown, and are often found in proximity to and overlying strata of black coal. The specific gravity ranges from 1·15 to 1·35, and the yield of coke, which is of fair quality, from 25 to 45 per cent. of the coal carbonized. Some of these coals are rich in bituminous matter, and give, on distillation at a low temperature, burning and lubricating oils of marketable quality. The yield of gas does not, however, as a rule, exceed 9,000 cubic feet per ton, and often is only 7,000 cubic feet, while its quality is inferior to that of gas from ordinary black coal. The brown coals of Germany contain from 20 to 40 per cent. of water, which is only partially removed on exposure to the air in a dry place, but this air-drying is generally considered sufficient to render them fit for carbonizing. The fibrous samples contain more oxygen than the close kinds, but the average composition of the organic matter of the dry coals may be taken as—Carbon, 70; oxygen, 25; hydrogen, 5. There appears to be scope for the utilization of the poorer lignites for the manufacture of water gas and other types of fuel gases in places where better descriptions of raw material are scarce. The value and constituents of tar from lignite will be dealt with briefly in the sequel to this volume.

Coal.—The products of the partial natural decay of cellular fibre having been for the most part considered, we come to what may be regarded as the ultimate product of the natural decomposition of vegetable matter buried beneath the earth's surface, namely, coal. Reserving the richly bituminous cannels to the end of this section, and anthracite and anthracite coals (which are valueless for retorting) to the next section, there are still several varieties of coal to be considered. Many classifications of coal according to its properties have been proposed, but as there are no marked lines of demarcation, and coals intermediate between the classes adopted are known, it is evident that such divisions must be purely arbitrary and have no natural basis. A broad classification is, however, useful to indicate the value of particular coals for special purposes, and with this end in view they will be considered under the two heads of Caking and Noncaking Coals.

Caking coals are distinguished by softening or fusing on heating, and yielding on the expulsion of volatile matter by heat a carbonaceous mass of cellular structure presenting no evidence of the form or shape of the original coal. The production of this mass of coke does not appear to be dependent on the ultimate composition of the coal, but rather on the forms of combination of the elements existing in it, which are in turn determined by the conditions of formation and geological position. Hence we find coals of one district cake on heating, while coals of almost precisely similar elementary composition from another district do not cake. Caking coal usually is pure black, and fairly lustrous, having a specific gravity from 1·25 to 1·35. The organic matter of the coal contains from 80 to 90 per cent. carbon, 4·5 to 6·0 per cent. hydrogen, 5 to 13 per cent. oxygen, and 1·0 to 2·5 per cent. nitrogen. Caking coals give on dry distillation from 60 to 80 per cent. of coke, the average from good Durham gas coals being about 68 per cent. The amount of ash is, of course, very variable; it may be 2 per cent. or even lower, or reach 12 per cent. The average result of tests on fourteen representative samples of good Durham gas coal examined by the author is 7·5 per cent. of ash. Various hypotheses have been put forward to explain the caking property of the coals. Donath refers it to a structure of the carbon substance itself, different from that of the non-caking coal, but he has not brought forward adequate proof in support of his theory. A more generally accepted hypothesis is that certain bituminous compounds, the composition of which has not been determined, are decomposed when the coal is carbonized, and yield volatile products and carbon containing a little pitch-like material, which has a cementing action on the remaining constituents of the coke. Some theorists, however, deny that any such action can happen at coking temperatures, and attribute the union of the different particles of coal during carbonization to the splitting off of carbon from hydrocarbons undergoing dissociation, and its deposition in a network of fine capillaries, which gradually connect and bind together the mass. These theories do not appear at present to have any very definite practical bearing on the question of what determines the coking quality in coals. It may be said generally that the proportion of combined hydrogen is usually low and that of uncombined hydrogen high in caking coals. The coking quality frequently diminishes on continued exposure of the coal to the air. Those caking coals which are of comparatively recent formation yield the largest amount of gas; some of the caking coals of old formation, while yielding good coke, are very inferior for gas making. An obnoxious constituent of most caking coals is sulphur, which exists in them partially in combination with iron as pyrites, and partially organically combined. The bulk of the gas manufactured in this country is required to contain less than a certain small proportion of sulphur, consequently it is to the interest of the gas engineer to use coal which yields only a small amount of sulphur to the gas in order to save the expense of its removal from the latter. A certain proportion, varying with the kind of coal, of sulphur remains in the coke, and this must be deducted from the total sulphur in the coal to find the amount of so-called "volatile" sulphur that is delivered up to the gas on carbonization, and is the criterion on which the purity of a coal is judged by gas chemists. The form in which the sulphur is combined in the gas is of considerable but secondary importance. The sulphur in gas coals is rarely under 0·5 per cent., but should never exceed 2·5 per cent. The extent to which sulphur is harmful will be considered at length when the methods of estimating its amount in coal and coke are given. Phosphorus is sometimes present in coal, but the greater part remains in the coke. Arsenic also is found in very many coals. It is partly volatilized on combustion or carbonization, but the greater part of it remains in the coke. The total amount present may be as much as 0·05 per cent. Antimony is also present in small quantities in some coals. In the natural state caking coals contain from 1 to 10 per cent. of water.

Non-caking coals, when heated until all volatile matter is expelled, yield a coke which retains the form of the coal, or crumbles into small fragments. No fusion or softening of the coal is apparent, and the coke has not a deeply seamed surface or open cellular structure. The coal frequently has a slight brown tint; its specific gravity varies from 1·25 to 1·40. The ultimate composition of the organic matter of the dry coal is:—Carbon, 70 to 90 per cent.; oxygen, 10 to 18 per cent. (occasionally considerably less); hydrogen, 4·25 to 6·0 per cent.; nitrogen, 1 to 2 per cent.; and sulphur, 0·5 to 1·5 per cent. It is evident that non-caking coals do not differ markedly from caking coals in their elementary composition, and the classification must depend primarily on the behaviour on heating. Some non-caking coals of old geological formation, and having a high specific gravity, are very poor gas-making coals. The proportion of carbon is higher, and that of hydrogen less in these coals than in most caking coals. Other non-caking coals are of recent formation, and low specific gravity—1·25 to 1·30. These are good gas-making coals, but yield only 55 to 65 per cent. of their weight of coke, which is friable or small, and consequently of relatively little value. The proportion of carbon is lower, and the proportions of hydrogen and oxygen are higher (especially the oxygen) than in most caking coals. The yield of coke from non-caking coals is generally less than from caking coals; they contain, as a rule, more water, and about the same proportion of ash.

Caking coals are found in the following localities in Great Britain:—Northumberland, Durham, Yorkshire, Nottingham, parts of South Wales, North Wales, and Cumberland, and in smaller quantities in other parts.

Non-caking coals are found in the following localities:—Staffordshire, Derbyshire, Lancashire, parts of Yorkshire, South Wales, and Scotland, and in smaller quantities in other parts of Great Britain.

Cannel coal appears from its elementary composition to hold a position intermediate between the lignites and the bituminous black coals, but the conditions under which it was formed have caused different hydrocarbons to enter into its constitution, and it differs considerably from either of those varieties. Water appears to have been a more important agency in the formation of cannel from vegetable matter than in the formation of coal, and probably was the chief factor in determining the nature of the product. The organic matter of cannel generally has a composition falling between the following limits for each constituent:—Carbon, 70 to 85 per cent.; oxygen, 5 to 15 per cent.; hydrogen, 5·5 to 10 per cent.; nitrogen, 1 to 2·5 per cent.; sulphur, 0·5 to 2·5 per cent. Cannels vary in specific gravity from 1·1 to 1·4. They are usually of a dull black colour, sometimes inclining to brown, and split up in a manner resembling slate, the fracture being more or less conchoidal. On heating they decrepitate and burn with a white but strongly smoking flame. The percentage of ash in most of the cannels now obtainable in Great Britain is much higher than in good bituminous gas coals; in the best kinds it was formerly often as low as 2·0, but is now usually from 5·0 to 20·0. The ash is generally more white and free from iron than that of ordinary coal. In general the coke obtained is in the form of the cannel, or quite powdery, and is from its nature as well as its large content of ash comparatively valueless as a fuel. The yield of coke is from 30 to 70 per cent. of the weight of cannel carbonized, being largely dependent on the amount of ash in the cannel. Cannel coal is very widely distributed over the globe, but is not found in extensive deposits. Seams frequently crop up among deposits of common coal. Traces of its vegetable origin are very commonly visible in the impressions of leaves and plants remaining in the cannel. Some varieties, such as the well-known Boghead, are rather more correctly classed as bituminous shale than as coal; extensive deposits of a mineral of this nature are found in Australia. The evaluation and testing of cannel are carried out in a similar manner to the assay of ordinary coal for gas making, and will be considered with that.

Sampling of Coal for Testing.—The sampling of a cargo or consignment of coal is a most important preliminary to the testing of the coal, and if it is not properly carried out, the testing becomes to all intents and purposes useless, and probably misleading and harmful. Yet it is difficult to give precise directions for the proper sampling of a material which is dealt with in such large consignments, and is naturally variable in composition and size. Much must depend on the exercise of common sense by the person entrusted with the sampling. The particular conditions under which the sample has to be taken will necessarily affect the method employed. Where the sample is required, in the first instance, to be sufficiently large for carbonizing tests to be made on a working scale, the first steps in the sampling process are comparatively easy. Even when only a small sample is required for laboratory testing, it is most satisfactory to conduct the first stages of the sampling in the same way. The following hints may serve as a guide to the procedure—which must be adapted to the necessities of the particular case—which should be followed in order to secure a representative sample of a consignment or store of coal. When the coal is being discharged from a ship or barges, a shovelful should be thrown aside into a heap from every tenth bucket or skip raised. When the coal is in a train of railway waggons, a few shovelfuls should be taken from every second or third waggon as the side doors are opened for discharging it; part being taken from the bottom as well as from the top of the load in the waggon. These shovelfuls should be brought similarly into a heap. When the coal to be sampled is in a store heap, the sampling is less easily effected. If the heap is known to be all from one ship, and not to have heated in its interior or weathered much at its exterior, it may suffice to take shovelfuls systematically from different spots on the top and edges of the heap. But, as a rule, it will be necessary to dig or dip into the interior of the heap from the top and sides at regular intervals, and to mix shovelfuls taken therefrom with an equal number taken from the exterior of the heap. In all cases care must be taken that the portions taken contain a fair proportion of both large lumps and small coal. The number of shovelfuls taken from each bucket, waggon, or spot, as well as the number of either of these from which they are taken, must be determined by the bulk of sample required, but a system of regular rotation should always be followed. If the sample is required to be sufficient for two or three carbonizing trials in a full-sized retort, obviously it must amount to 1 or 2 tons. Where only a small sample, however, is ultimately required, it is still desirable to collect in the manner indicated about 5 cwts., or certainly not less than 2 cwts. The whole of the sample so collected is brought on to a hard floor and roughly broken until the pieces of maximum size are not more than about 3 inches thick. The whole is well mixed, then spread out in an even layer, which is divided into quarters. One-quarter is separated from the rest, broken to smaller size, mixed, spread out, quartered, and one-quarter taken and broken to yet smaller size, and mixed and quartered as before. The breaking and quartering are continued until a quarter of the desired size of the final sample for the laboratory tests is obtained. At any stage the three-quarters, which otherwise would be discarded, may be taken for carbonizing or other tests requiring a larger sample. The sample may at the outset or subsequently be run through a small breaking machine instead of being broken on a floor, but in no case must thorough mixing after each re-breaking be omitted. When the sample has been reduced by successive quarterings to a reasonably small bulk, it is well to break it until the whole of it passes through a sieve of suitable mesh, which must be reduced after each quartering until the desired degree of fineness of subdivision is attained. The whole of the operations of sampling should be carried out as quickly as possible, in a place free from much draught, and the final sample put in a well-closed jar or bottle. By the procedure described a sample truly representing the average composition of the coal sampled will be obtained. If less careful sampling is practised, the results of good analyses will not be trustworthy, and will usually differ from those obtained on a second similarly procured sample. Analyses, however carefully made, are of little commercial utility, if the sampling is untrustworthy, hence attention should always be directed in the first instance to securing proper sampling.

The Analysis of Coal.—It is often desirable for the gas manufacturer to ascertain the elementary composition of a sample of coal. The method of conducting combustions will have been learnt in the course of the students' ordinary laboratory training, and need not be here described. The following suggestions are applicable to the particular case of the analysis of coal, and may be of assistance to one who has not a special acquaintance with the testing of that mineral. In the estimation of carbon and hydrogen, lead chromate should be used in place of the copper oxide usually recommended for combustions of organic substances, and the forward portion of the tube containing it should be less strongly heated than is customary. Sulphur will not then be estimated with the carbon. Six inches of the fore part of the tube should be packed with finely divided silver, silver gauze, or lumps of pumice on which silver has been deposited, and this portion should be heated to bright redness. A modern type of gas furnace should be used for the combustion. Sulphuric acid pumice tubes will be found more reliable than tubes filled with calcium chloride for the collection of the water formed by the combustion. If calcium chloride is used, it must not contain free alkali, as is usually the case with commercial samples. Liebig or Geissler potash bulbs are generally preferred to soda-lime tubes for the collection of the carbonic acid; if soda-lime is used it should be freshly prepared and a large tube, or preferably two tubes weighed separately, employed. Wherever U-tubes are required those with hollow glass stoppers ground-in should be used instead of the old pattern with caoutchouc plugs; with the stoppers closed to the inlet and outlet tubes they remain constant in weight for any length of time.

Nitrogen in coal may be estimated either by Dumas' method of directly measuring its volume, or, more conveniently, by a modification of Kjeldahl's process. The latter is also a very good method for determining the nitrogen in coke. The modification of Kjeldahl's process commonly used is one made by Schmidt,* though certain small improvements have since been made by other analysts. The following is a description of this method of estimating nitrogen in coal:—About 1 gramme of the finely-powdered coal is placed in a Kjeldahl flask and 20 c.c. of concentrated sulphuric acid, free from oxides of nitrogen, poured in. The contents of the flask are then gradually raised to boiling, 10 grammes of potassium sulphate added, and the whole boiled until the colour disappears. If necessary, small amounts of potassium permanganate may be added from time to time in order to hasten decoloration, which should ensue in from two to three hours at the utmost. The contents of the flask are then transferred, with addition of water, to a 20-ounce flask; after cooling thoroughly, 100 c.c. of a 20 per cent. solution of caustic soda is added, and the mouth of the flask is connected to a spiral condenser, which delivers into 25 c.c. of decinormal sulphuric acid contained in a flask. The flask connections and condenser may be arranged as for the distillation test for the ammonia in gas liquor, and a piece of platinum foil may be placed in the still flask to prevent severe bumping. After boiling for twenty to forty minutes, according to the bulk of the liquid, the decinormal acid is removed and titrated with decinormal alkali, in order to ascertain the extent to which it has been neutralised by the ammonia derived from the nitrogen in the coal.

Both Sulphur and **Phosphorus** may be estimated by Carius' method, which consists in digesting the finely-powdered coal with strong nitric acid for three hours in a sealed tube at 200° C. The contents of the tube are diluted with water, and the sulphur estimated as barium sulphate by precipitation with barium nitrate in the usual manner. The filtrate is neutralised with ammonia, and ammonium chloride and magnesium chloride are added to precipitate the phosphorus, for ignition and weighing as magnesium pyrophosphate.

Phosphorus.—The amount of phosphorus is not usually determined in an analysis of coal; the amount generally present may be seen from the following results by Ad. Carnot.* In Newcastle and Boghead coal, traces only were found; in Lancashire coal, 0·02852 per cent.; in Wigan coal, 0·02246 per cent.; in Glasgow

---

* *Journ. Soc. Chem. Ind.*, 1886, 506.

† *Comptes Rendus*, xcix., 154.

coal, 0·00572 per cent.; in Commentry coal, 0·00163 per cent.; and in Commentry cannel, 0·04260 per cent. This investigator observed that phosphorus was present in the greatest quantity in the visible spores of cannel. Speaking broadly, European coal seldom contains more than 0·02 per cent. of phosphorus, but as much as 0·1 per cent. has been found in coal from the Alleghany River district of Pennsylvania. To determine phosphorus in coal and coke, F. L. Crobaugh ignites the powdered material, and fuses the ash with sodium carbonate containing 10 per cent. of potassium nitrate. The mass is taken up in warm dilute nitric acid, the liquid filtered, and ammonium molybdate added to the warm filtrate. The precipitate is thoroughly washed, dissolved in ammonia, barely neutralized with hydrochloric acid, and the phosphoric acid estimated by precipitation with magnesium chloride, and weighing as magnesium pyrophosphate. For full details, his paper in the *Journ. Anal. and Appl. Chem.*, vol. vii., p. 223, should be consulted. A slightly different method of estimating phosphorus in coal and coke, described by W. F. K. Stock,* is now more generally employed. It is as follows:—10 grammes of the coal or coke is ignited on a platinum dish or foil in a muffle until only ash remains. This is ground very finely in an agate mortar and transferred to a beaker, in which it is digested with 20 c.c. of brominized hydrochloric acid nearly at boiling for an hour, the beaker being the while covered with a watch glass. The latter is then removed, the hydrochloric acid evaporated as far as possible, 20 c.c. of water added, the solution filtered, and the filtrate and washings collected in a conical beaker. Their bulk should not be more than 45 c.c. There is then added 15 c.c. of a strong solution of ammonia, and the liquid is neutralized by gradual additions of nitric acid from a small pipette, the whole being kept nearly at boiling. After resolution, dilute ammonia is dropped in until a faint opalescence appears, which is got rid of by adding a few drops of nitric acid. To the slightly acid solution 2½ to 3 c.c. of strong nitric acid is added, and then 5 c.c. of a 10 per cent. solution of ammonium molybdate is emptied suddenly into it while it is agitated briskly. After a second or two, yellow ammonia-phospho-molybdate should settle out in a granular form. The flask is kept heated to about 90° C. and agitated for five minutes. The precipitate is then collected on a hardened filter and washed three times with nitric acid diluted with fifty times its volume of water. The filter and contents are dried in a water bath, the precipitate is brushed off the paper into a weighed watch glass and weighed. The weight multiplied by 0·163 gives the percentage of phosphorus in the coal or coke.

---

* *Journ. Soc. Chem. Ind.*, 1897, 305.

Sulphur in coal can be accurately determined by Nakamura's method. A small, but representative, sample of the coal is ground in an agate mortar until the whole of it will pass through very fine muslin. From 1 to 2 grammes of the powdered coal is weighed out accurately, and carefully mixed with about four times its weight of mixed dried alkaline carbonates (in the proportions of 13 parts anhydrous potassium carbonate to 10 parts anhydrous sodium carbonate) in a large platinum crucible. The crucible is partially covered and very slightly warmed over a spirit lamp. No odour or smoke should issue from the crucible. The heat is very gradually increased for two hours, at the end of which time the crucible may be just visibly red, and the contents should have gradually faded to a pale grey colour. If smoke or smell has been detected from the crucible at any time, a loss of sulphur will have probably occurred. The heat is increased to redness for an hour, and the white mass remaining in the crucible is extracted with water. The extract is passed through a filter paper, a little bromine water added, and the liquid boiled to expel the excess of bromine. It is then acidified with hydrochloric acid, and the sulphur precipitated in the usual way as barium sulphate. From the weight of barium sulphate obtained, that of the sulphur is found by the usual calculation (the weight of barium sulphate multiplied by $\frac{32}{233}$, or 0·1373, gives the weight of sulphur contained in it). From the weight of coal taken and the sulphur found, the percentage of sulphur in the coal is ascertained. This method of estimating sulphur in coal is perfectly reliable, but requires manipulative skill and patience on the part of the operator. An error is introduced if gas is used for heating the crucible instead of spirit, but it is not large if the gas has been freed from sulphur compounds, as in London, and may be disregarded, or blank experiments may be carried out and a deduction made accordingly. The results obtained by Nakamura's method will be trustworthy only if the coal is in very fine powder, and if the heat is applied and increased so moderately that no odour of hydrocarbon vapour can be detected in the products escaping from the crucible. The process depends on the slow, but perfect, oxidation of the whole of the organic matter of the coal—smoke or odorous vapours imply imperfect oxidation.

Another well-known method of estimating sulphur in coal is Eschka's, which has undergone many modifications at the hands of other analysts. The following is the modification which has been recommended for general use by the Committee on Coal Analysis appointed by the American Chemical Society :—* One

---

* *Journ. Amer. Chem. Soc.*, 1899, 1116; abstracted *Journ. Soc. Chem. Ind.*, 1900, 174.

gramme of the finely-powdered coal is intimately mixed with 1 gramme of light porous magnesium oxide and half a gramme of dry sodium carbonate in a thin platinum vessel of 75 to 100 c.c. capacity. The vessel is very gradually heated by a spirit flame (or flame of well purified gas), while the contents are constantly stirred until they cease to glow strongly. The heat is then increased until, after fifteen minutes, the bottom of the vessel is at a dull red heat. After the carbon has burned away, the contents of the vessel are transferred to a beaker, and the vessel is washed with about 50 c.c. of water, the washings also being received in the beaker; 15 c.c. of saturated bromine water is added, and the liquid oxidized by boiling for five minutes. The insoluble residue is allowed to settle, the supernatant liquid decanted, and the residue boiled a second and a third time with 30 c.c. of water. The filtrate, which should be about 200 c.c. in all, is acidified with 1·5 c.c. of concentrated hydrochloric acid, then boiled until the bromine is expelled. Then 10 c.c. of a 10 per cent. solution of barium chloride is added, at first drop by drop, to the hot liquid, and the precipitate of barium sulphate is filtered off and weighed in the usual way. In the case of coal containing much pyrites or sulphate, the residual magnesium oxide ought to be dissolved in hydrochloric acid, and the solution examined to see if it contains further sulphuric acid. This modification of Eschka's method has lately received very general adoption. It is as good as any other, and more rapid and less troublesome of execution than Nakamura's method.

A slightly different method of estimating sulphur in coal has been kindly brought to the author's notice by G. P. Lishman, of the Lambton Collieries, Ltd. The powdered coal is mixed with rather more than twice its weight of pure caustic lime, and transferred to a wide-mouthed porcelain crucible, which is then put in a muffle heated to barely visible redness. After the lapse of half an hour the heat is gradually increased to bright redness, at which it is maintained for about three hours, or until the black particles have entirely disappeared. The residue, when cold, is extracted with about 200 c.c. of cold water and a few drops of bromine water are added to the aqueous extract to ensure oxidation. The whole is digested for about twenty minutes at a temperature slightly below boiling, and then hydrochloric acid is added to slight excess. When the bromine has been expelled the liquid is filtered, and the sulphate in the filtrate is determined, as before, by precipitation with barium chloride. In this, as in other methods, coal needs more gradual heating than coke, in order that loss of sulphur by volatilization may be avoided. The method is more rapid, and requires less attention than Nakamura's, and the author can bear out Mr.

Lishman's testimony that it gives concordant results. It is, of course, essential that the lime used should be free from sulphur, and it may be necessary in many laboratories to prepare it for the purpose. Failing that, blank experiments should be first made with the purest lime at hand.

A method for the estimation of sulphur in coal depending on a totally different principle has been proposed by F. Stolba,* According to his instructions, about 1 gramme of the finely-powdered coal, accurately weighed, is mixed with 1 gramme of finely-powdered silver, and 1 gramme of pure dry potassium bicarbonate, and heated in a crucible with constant stirring for about twenty-five minutes, or until all dark particles have disappeared. A little ammonium nitrate is added to the residue when cool; it is again warmed, and, on cooling, extracted with dilute hydrochloric acid. The solid particles are removed by filtering, and the sulphur in the filtrate and washings determined in the usual way as barium sulphate. The results are accurate, and the method is more rapid than Nakamura's.

Many methods, based on heating the coal with a deflagrating mixture, have been proposed for estimating sulphur in coal, but though less tedious than the foregoing, they are not so reliable, and cannot be recommended for use in a gas works laboratory.

The ash or incombustible matter in coal is found by burning off completely all combustible matter in a fair sample. The determination of the ash in coal and coke is so frequently required that it may be described here, at the risk of encroaching on the ground covered by more general text-books. A fair sample of the coal or coke is roughly powdered, and a platinum boat (previously cleaned, ignited, and left to cool in a desiccator) is carefully weighed. Sufficient of the powdered coal to cover the bottom of the boat about one-eighth inch deep is put into it, and it is again weighed. The difference between the first and second weighings gives the weight of coal taken. A tube of porcelain, hard combustion glass, or fused quartz, of sufficient diameter internally to admit the boat readily, and about 2 feet long, is connected at one end to an aspirator, and supported horizontally in a gas furnace or over a series of Bunsen burners The boat is slipped into the tube, with a piece of thin platinum foil beneath it to prevent contact with the tube, if glass is used, and is left about 6 inches from the open end. The aspirator is set at work in order to draw a *gentle* current of air over the boat, and the furnace or burners are lit so as to heat the boat and an inch or so of tube beyond each end of it. The heat is raised as high as the tube, if glass, will stand without fusing, and maintained for some hours. When all combustible matter appears to

---

* *Listy Chemické*, xii., 203.

be burnt off the burners are turned out, and the boat removed as soon as possible to the desiccator. When cool it is weighed, replaced in the tube, heated for twenty minutes, and cooled and weighed as before. If the two weighings agree the combustion is over, and the weight of the boat is deducted from the weight of the boat and contained ash. From the weight of ash so found in a known weight of coal the percentage of ash in the coal is calculated. If the two weighings of the boat and ash are not identical, the heating must be repeated until two consecutive weighings agree. The concordant weighings are taken for calculating the ash in the coal. The arrangement of the apparatus is shown in Fig. 1.

In a still atmosphere the boat may project from the end of the tube instead of being placed within it. In that case a narrower tube is used, and the boat may be replaced by a piece of stout platinum foil bent boat-shape, and with one end doubled over to enter the tube. Two large Bunsen burners with flattened tops then play directly on the bottom of the foil, but the gas should not be turned so high that the flame envelops the contents, as free access of air is required for the combustion of the coal. Most coals require from six to eight hours to burn off by this method; they should always be reheated for half an hour after weighing to ascertain if any further loss takes place, and in the event of a diminished weight the heating must be repeated as stated above. Two tests should be made on each sample, and if the results are within 0·5 per cent. of one another, the mean may be taken to represent correctly the amount of ash in the coal. The arrangement just described is illustrated in Fig. 2.

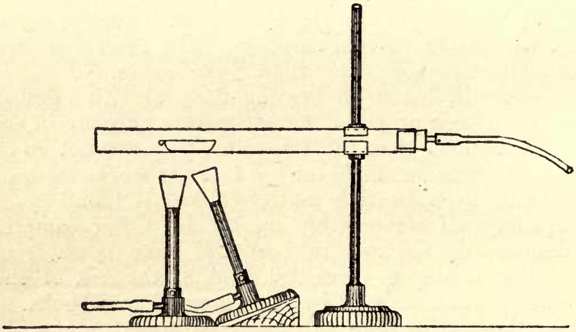


Fig. 1.—Apparatus for estimating ash by combustion in a gentle current of air.

The ash in coal may be more readily estimated by gradually heating a weighed sample of the finely-powdered coal to redness in a muffle until the carbonaceous matter appears burnt off, cooling in a desiccator and weighing the ash. Where a muffle is available this method is the readiest, and gives nearly as good results as the combustion tube method. For comparative estimations on a large number of samples the muffle method should certainly be adopted. Where the yield of coke from a coal is accurately known, and a sample of the coke is available, the ash is more conveniently estimated in the latter, and the percentage on the coal calculated therefrom. The sample used for the estimation must be moderately free from moisture, or spirting and consequent loss on first heating will occur.

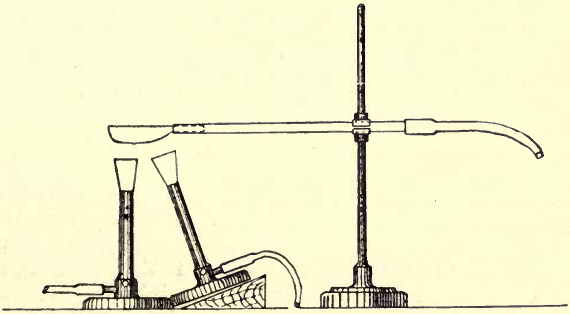


Fig. 2.—Apparatus for estimating ash by combustion in open air.

The Committee appointed by the American Chemical Society to report on coal analysis* recommended the following method of determining the ash in coal. The residue from the moisture determination (*vide* p. 29) is ignited in an open inclined crucible, at first over a low flame, until free from carbon. Any pyrites present is converted almost entirely to ferric oxide by the combustion. The weight of the ash is less than the weight of the mineral matter by five-eighths of the weight of the sulphur. The American Committee did not recommend a correction to be made in proximate analyses on this account, but they pointed out the necessity for such correction in calculating the calorific power of the coal from the analysis.

The ash in coke is estimated by the methods described above for ascertaining the ash in coal. The coke should be very finely powdered, but care must be taken that it is not exposed to a very strong draught during burning-off, or fine particles will be lost. An easy method of carrying out the estimation of ash in coke is to weigh a few grammes of the coke in a rather wide-mouthed

---

* *Journ. Amer. Chem. Soc.*, 1899, 1116 to 1132.

platinum crucible, and to heat the latter carefully over a powerful Bunsen burner. The crucible should be tilted to allow access of air to the hot coke, and the latter may be cautiously stirred at intervals with a stiff and smooth piece of platinum wire. The crucible should, however, not be exposed to draughts. After three hours' heating it may be removed to the desiccator and subsequently weighed; then re-heated for an hour and again weighed. If the two weighings differ, the heating must be repeated. This method of estimating ash is very simple and convenient, and if carefully carried out gives reliable results. The amount of ash found on the large scale in furnaces is always greater than the laboratory test indicates, in consequence of some carbonaceous matter being retained in it owing to its partial agglomeration.

The composition of the ash is seldom investigated by a gas works chemist, except where the coke is used for lime burning or other purposes on the works. The amounts of silica, alumina, ferric oxide, lime, and magnesia are then ascertained by the ordinary methods. The amount of sulphur remaining in ash is more often determined. For the purpose, about 1 gramme of the ash is accurately weighed, digested with *dilute* hydrochloric acid, to which a few drops of bromine water have been added, and the liquid warmed to expel the bromine. It is then filtered, and the sulphur estimated in the filtrate by precipitation with barium chloride in the usual manner. The percentage of sulphur in the ash is then usually calculated to percentage on the coke or coal for deduction from the total amount of sulphur in the latter, in order to ascertain the sulphur given off on combustion. Sulphur in ash is not detrimental to the value of a fuel, except in the case of coke for metallurgical uses. The remaining constituents of the ash affect to a very marked extent the amount of sulphur which remains in coke from caking coal. The coke will retain a very large proportion of the sulphur in the coal if the ash contains much iron. Consequently the gas obtained from coal containing much iron has a comparatively low content of sulphur compounds. Lime and magnesia in the ash also tend to retain sulphur in the coke. It is possible to remove by washing processes those portions of many coals which are richest in ash and sulphur, and thus, by the sacrifice of a small proportion of the coal, to improve the bulk of it in respect of purity. But such treatment of coal is seldom attempted when the supply is for ordinary gas works' use, though it is very usually applied in the case of supplies to coke ovens. Under circumstances in which the production of coke of good quality is of paramount importance, the cost of washing coal for gas making may be reasonably entertained. But, in general, the quality of the coke made on a gas works must necessarily be subordinated to other considerations—in particular, the yield and quality of the gas obtainable from the coal used.

Arsenic in coal and coke is best determined by a suitable modification of the Marsh test. The following is the procedure recommended by a joint committee of the Society of Chemical Industry and of the Society of Public Analysts*—certain details being, however, taken from a paper by A. C. Chapman.† One gramme of the finely-divided sample is intimately mixed with the same quantity of pure calcined lime or magnesia (with or without half its weight of dry sodium carbonate), and incinerated, by gradual increase of temperature, in a platinum vessel. The mass is extracted with hydrochloric acid, which has been previously purified and proved to be free from a determinable amount of arsenic. A flask, of about 200 c.c. capacity, is fitted by means of a bored rubber or ground glass stopper, with a tap funnel and a glass exit tube, which enters, and fits tightly by means of a rubber plug, a drying tube containing in order a roll of lead test-paper (as used for the detection of sulphuretted hydrogen in gas), a plug of cotton wool, a layer of granulated calcium chloride ("free from volatilisable arsenic"), and a plug of cotton wool. The drawn-out end of this drying tube is connected by a sound joint of rubber tubing, with a tube of hard glass $\frac{3}{8}$ inch in diameter, and drawn out at 4 to 6 inches from its anterior end to an internal diameter of rather less than 0·1 inch, or so that a wire of No. 13 B.W.G. will just pass into it. These tubes can be purchased ready for use from chemical apparatus dealers. All used for comparative purposes should be as nearly as possible of the same size. The tube is bent upwards beyond the constricted part, and terminates in a nozzle at which the issuing gas may burn. About 20 grammes of clean granulated zinc ("free from arsenic") are brought into the flask, and purified hydrochloric acid of a specific gravity of 1·10 is run in through the tap funnel in sufficient amount to produce a fairly brisk evolution of hydrogen. After a few minutes the hydrogen is lighted at the nozzle of the tube, and a good Bunsen burner is placed so as to heat the tube to a red heat for about an inch just anterior to the constriction. So much acid is run in—care being taken to avoid admission of air—through the tap funnel as is required to keep up the flow of gas for twenty minutes. If the materials used are as nearly as possible free from arsenic no mirror-like deposit will be produced in the tube. The acid extract of the incinerated mass obtained from the coal or coke is then run in through the tap funnel, but if the coal or coke is known to contain much arsenic only a suitable aliquot portion of the acid extract is taken. The test is

---

* *Journ. Soc. Chem. Ind.*, 1902, 95.

† *The Analyst*, 1901, 253.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

continued for twenty minutes after the addition of the extract, and the mirror which will have formed in the tube, if arsenic was present in the coal or coke, is, after disconnecting the apparatus, compared with the mirrors in a set of standard tubes prepared by introducing known quantities of arsenious oxide into the apparatus in previous tests made with materials otherwise free from arsenic. The set of standard tubes should comprise five, made with 0·00001, 0·000008, 0·000006, 0·000004, and 0·000002 gramme of arsenious oxide (As_4O_6) respectively. They should have been sealed up while still filled with hydrogen. The mirror obtained is compared with those in the standard set, and the standard which most nearly approaches it in density corresponds to the amount of arsenious oxide in the portion of acid extract used in the test. If this standard is one at either extreme of the set the test should be repeated with a portion of acid extract corresponding to a smaller or greater amount of the coal or coke, so that the mirror formed corresponds to one of the other three standards. By this means the comparison cannot be uncertain owing to the mirror being a little more or a little less dense than any one of the standards. The test should in all cases be repeated and only considered as trustworthy if concordant results are obtained. This test gives the total of the arsenic present in the coal or coke. In some cases it is required to know how much of the arsenic remains in the ash on the combustion of the fuel. For this purpose the ash from 1 gramme of the coal or coke is extracted with hydrochloric acid and the extract applied just as was the acid extract of the incinerated mass in the estimation of the total arsenic. The difference between the amounts of the total arsenic in the fuel and of the arsenic in the ash gives the amount of "volatile" arsenic. Only the "volatile" arsenic is seriously objectionable for most uses of the fuel.

The following amounts of arsenic have been found by A. C. Chapman (*loc. cit.*) in coal and in the coke and ash obtained therefrom :—

Sample.	Coal contains Parts of Arsenic per 100,000.			Coke contains Parts of Arsenic per 100,000.
	Total.	Non-volatile (in Ash).	Volatile (by difference).	
1	20	8½	11½	24
2	7	4	3	10
3	10	4	6	14
4	10	8½	1½	8½
5	13	10	3	16
6	11½	4	7½	8½

It will be seen that, except in the case of two out of the six samples, practically the whole of the arsenic in the coal remains

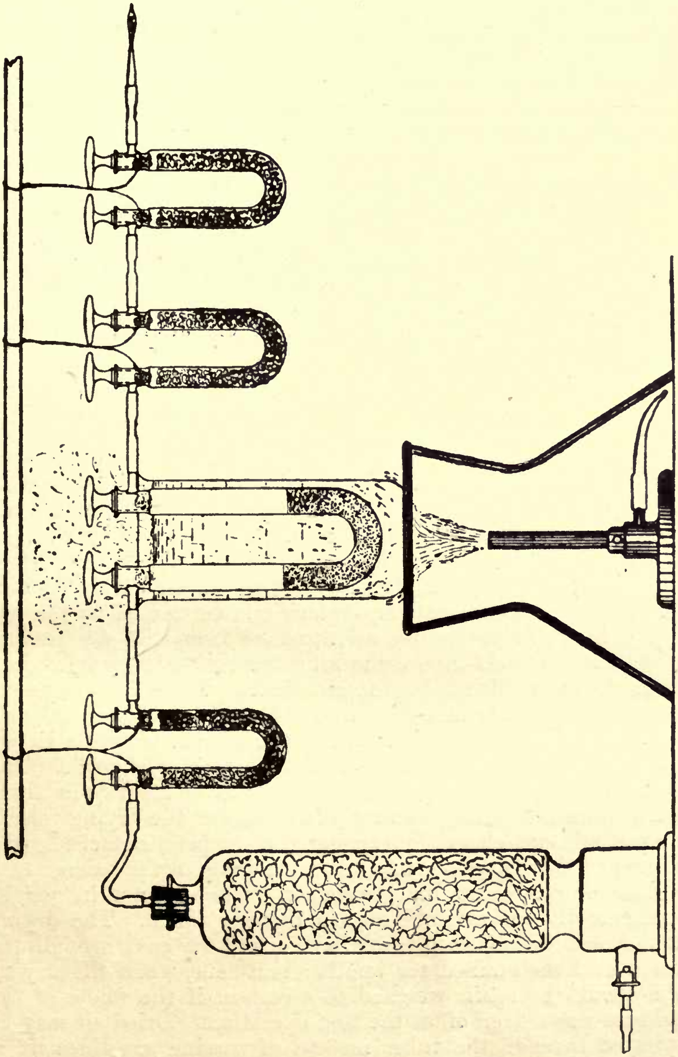


Fig. 3.—Apparatus for estimating amount of moisture in coal.

in the coke. The inference that in two cases some of the arsenic passed into the gas produced requires corroboration by further analytical proof. It is known, however, that gas liquor sometimes contains traces of arsenic. The arsenic present in coal seems to be almost invariably associated with pyrites.

Moisture in coal is not so readily determined with accuracy as is often supposed. When heated to 100° C. coal loses weight, but does not on continued heating attain a constant weight. The weight, after diminishing for some time, begins to increase, showing that an absorption of some kind is taking place. It is often recommended that a finely-powdered sample of coal should be dried in the water bath, being weighed at intervals, and the lowest weight obtained taken for the calculation of the percentage of moisture in the coal. But an error is certainly introduced here of unknown and varying magnitude, and the method cannot be commended. The coal on first heating at 100° C. appears to lose certain volatile hydrocarbons as well as water, but afterwards appears to increase in weight through oxidation of the fine particles of which it consists. It is, therefore, necessary in an analysis of coal to adopt some other method of determining the amount of moisture. The most reliable is the weighing in a drying tube of the actual water driven off. The apparatus for the purpose is shown in Fig. 3. A stoppered **U**-tube having the hollows of the stoppers filled with dried cotton wool is weighed carefully while empty. The coal, in powder, is then put into the tube, which is again weighed to find the amount of coal taken. Another **U**-tube is filled with lumps of calcium chloride (free from alkali) and weighed after displacing the air within by coal gas. A large tube of calcium chloride is connected to the gas supply, in order to remove all moisture from the gas passing through it. The **U**-tube containing the coal is suspended in a vessel of water which is kept in ebullition. The dried gas passes through this **U**-tube and then into the weighed calcium chloride tube, which is protected from access of moisture from the air by a small guard tube likewise containing calcium chloride. The dried gas is allowed to pass through the tubes for two or three hours, when the boiling water is removed, and the drying tube is in a few minutes closed by turning the stoppers, detached from the rest of the apparatus, and, after standing in the balance case or desiccator a short time, weighed. Its increase in weight represents the amount of water in the coal taken. The drying tube should be replaced, and the current of gas through the heated coal maintained for another half-hour, when the drying tube should be again weighed to ascertain if the whole of the moisture was driven off at the first operation. Dried air may be aspirated through the tubes instead of passing gas through, if more convenient. If gas is used, it may be burnt at a small jet connected to the last tube, and its rate of passage controlled thereby. The connections are made with *short* pieces of thick-walled caoutchouc tubing. If the **U**-tube containing the coal is weighed after the operation, it will generally be found to have lost more than the drying tube has gained in weight, especially if a current of gas has been used. It is well to place a weighed drying tube between the large drying tube and the **U**-tube containing the coal, to ascertain if the gas or air is perfectly dry.

Approximately correct estimations of the moisture in coal may be made more rapidly, and will be sufficiently exact for many purposes. In order that the results of such estimations on different samples of coal may be as far as possible comparable, it is advisable to adopt the same procedure precisely in all cases, The procedure recommended by the Committee appointed by the American Chemical Society to investigate the subject of coal analysis * is as good as any, and, for the sake of uniformity, might be adopted whenever the more exact method of estimation described above is not followed. The following is the procedure:—1 gramme of the moderately finely-powdered coal is dried in an open porcelain crucible for an hour at 104° to 107° C. This temperature is most conveniently maintained by means of a drying chamber, with a jacket containing toluene. The crucible and contents, after cooling in a desiccator, are weighed while covered. The Committee point out that coarsely and finely-powdered samples of the same coal generally give different results when the moisture is estimated by this method, especially when there is a high proportion of moisture. The coarse sample gives the higher and, doubtless, more correct result. This would be suspected to be the case from what has already been said with regard to the oxidation of finely-divided coal. Hence, wherever very finely-divided samples are used for the estimation of other constituents, the Committee recommend that a correction should be applied to compensate for the increased weight of the samples, due to its finely-divided condition. For this purpose the moisture is estimated in the toluene bath on both coarse and fine samples of the coal. If it were found to be, *e.g.*, on the coarse sample 12·07 per cent., and on the fine sample 10·39, the correction to be applied to the result of an estimation of, *e.g.*, volatile matter would be as follows:—Suppose the volatile combustible matter be found to be 34·25 per cent. of the finely-powdered coal, then the correct percentage, based on the moisture in the coarse sample, would be—

$$34{\cdot}25 - \left(34{\cdot}25 \times \frac{12{\cdot}07 - 10{\cdot}39}{100 - 10{\cdot}39}\right) = 33{\cdot}61.$$

---

* *Journ. Amer. Chem. Soc.*, 1899, 1116; *Abstract Journ. Soc. Chem. Ind.*, 1900, 174.

In the same manner a correction may be applied in other cases.

Drying *in vacuo* gives higher results than the simple drying at 104° to 107° C.—viz., by about 0·37 per cent.—but the American committee do not recommend its employment. If really exact results are required, the collection and weighing of the water driven off from the coal must be resorted to, and failing that, drying at 104° to 107° C. seems the best plan for general use.

The **density** or specific gravity of coal is generally referred to water at 60° F. as unity. It may be readily ascertained by two methods. In the first, three or four representative pieces of the coal, each from 1 to 3 cubic inches in bulk, are weighed in turn, first in air and afterwards while immersed in water at 60° F. The difference between the two weighings represents the weight of the volume of water displaced by the coal, and, consequently, if this is expressed in grammes, approximately the volume of the coal in cubic centimetres. The weight of a certain volume of coal being known, and the weight of the same volume of water at 60° F. (the substance which is the unit of density), the specific gravity of the coal is found by dividing its weight by the weight of water at 60° F. which it displaces. This is usually expressed by saying that the specific gravity is found by dividing the weight in air by the difference between the weight in air and the weight in water. Certain precautions are necessary to obtain a correct result. The lump of coal should be carefully brushed (before weighing) with a dry camel's-hair brush in order to remove all dust and loose particles. It should be suspended for weighing by a hair or a silk thread looped round it. When immersed in water it must be again carefully but lightly brushed to remove all adhering air bubbles. As one lump is not likely to be a representative sample of the coal, the specific gravity of at least three pieces should be taken, and the average returned as the specific gravity of the coal.

The second method of taking the specific gravity of coal is by means of the specific gravity bottle, commonly used for determining the densities of liquids. A few grammes weight of the roughly-powdered coal is put into the bottle and distilled water added until the coal is completely covered. It is then allowed to stand for ten hours to allow adhering bubbles of air to escape, and the coal to become "wetted"; this part of the procedure may be hastened by placing the bottle under diminished pressure by means of an air pump. The bottle is then filled with water, and weighed with the usual precautions exercised in taking the specific gravity of liquids, including the observation of the temperature of the water immediately after weighing. The weight of water at 60° F. contained by the bottle is, of course, known. Then the specific gravity of the coal is found by dividing the weight of coal taken by itself, less the difference between the weight of water and coal contained in the flask and the weight of water normally contained by it. Or expressed symbolically—

$$\text{Specific gravity} = \frac{W}{W - W_1 + W_2}$$

Where W = weight of coal taken, W_1 = weight of coal + sufficient water to fill the bottle, and W_2 = weight of water at 60° F. completely filling the bottle.

The **volatile matter** and **fixed carbon** in coal are sometimes determined in the laboratory, but the results obtained are at best only approximate. Several proposals have been made to render the determinations of value for comparative purposes by conducting them under certain fixed conditions. The most obvious plan is to heat the coal until all appearance of evolution of gas ceases, and then to weigh the carbon (and ash) remaining. Unfortunately this method does not give a constant value, the variation with the same coal being as much as 3 per cent. Heinrich's test is more accurate and has been extensively adopted. About 2 grammes of the roughly-powdered coal is heated in a platinum crucible for three and a-half minutes over a Bunsen burner, which at the end of that time is changed for a large Bunsen with air blast, with which the heating is continued for a second three and a-half minutes. If the same burners are used for every test, and the time is measured accurately, the variations are slight, and the method gives good comparative results. Rather better is Lewis T. Wright's method. According to his instructions 2 grammes of the finely-pulverized coal is taken in an even layer on the bottom of a thin platinum crucible, which is covered and heated by a powerful gas flame (maintained at the same height in all experiments). The heating is stopped one minute after gases cease to issue; the crucible is allowed to cool in the desiccator and is weighed without the cover. The results are nearly constant for the same class of coal.

The Committee of the American Chemical Society, which investigated the subject of coal analysis,* has recommended the following method of determining the volatile matter in coal:—One gramme of freshly-powdered, undried coal is heated for seven minutes, over the full flame of a Bunsen burner, in a platinum crucible of 20 to 30 grammes weight, while the crucible is covered with a well-fitting lid. The crucible is supported on a pipe-clay triangle so that the bottom is 2½ to 3 inches from the

---

* *Journ. Amer. Chem. Soc.*, 1899, 1116; Abstract, *Journ. Soc. Chem. Ind.*, 1900, 174.

top of the burner, while the flame, when burning free, is 8 inches high. It should be protected from draughts. The Committee found that the mechanical loss, due to the rapid heating, which occurred in the case of some non-caking coals, was insignificant. The fixed carbon in the coal is found by deducting the percentage of ash from the percentage of coke left in the determination of the volatile combustible matter.

According to R. K. Meade and J. C. Attix,* heating the coal in a platinum dish over a Bunsen, and finally over a blast flame in a current of nitrogen or hydrogen, gives more concordant results for the volatile combustible matter. These analysts point out that, in the case of coke or anthracite, a blast flame must be applied after the Bunsen flame in order to obtain correct results.

When the volatile matter and fixed carbon are given in an analysis of coal, the method by which they were determined should invariably be stated, or the figures will be of little value. When the sulphur is determined in addition, the weight of volatile matter and fixed carbon should be corrected accordingly, and the moisture likewise should be deducted from the volatile matter.

The usual laboratory tests applied to coal have now been enumerated and described. The deductions which may be drawn from the results of such tests will be considered with the results of the **practical testing of coal** for yield of gas and coke under conditions approximating to those obtaining on the large scale in a gas works. A small plant, capable of working off a charge of a few pounds of coal, is generally fixed in the vicinity of the laboratory and a photometer room on the works. With judicious interpretation of the results, the tests are most useful, and enable judgment to be pronounced on a small sample of coal in a very short time.

The setting should consist of a cast-iron ⌓-shaped retort, 3 feet in length, 5 inches wide, and 4 inches high, with direct coke or gas firing, and dampers to the flues to regulate the draught. The retort should project about 4 inches from the setting, and be provided with a 2-inch ascension pipe leading to the condensing tubes, which may conveniently be attached to an adjacent wall. Ten tubes, 7 feet in length and 1 inch in diameter, form a suitable air condenser, if tolerably far distant from the setting. Cocks should be provided for running off the tar and liquid into a trough beneath, and the tops of all the condenser tubes and of the ascension pipe should be provided with screw plugs, which may be removed for cleaning at intervals, or

---

* *Journ. Amer. Chem. Soc.*, 1899, 1137; Abstract, *Journ. Soc. Chem. Ind.*, 1900, 175.

when stoppages occur. The washer is usually omitted from this experimental plant, and the gas passes directly from the condenser into the purifiers, which may be conveniently about 15 inches square and 8 inches deep; each purifier has two

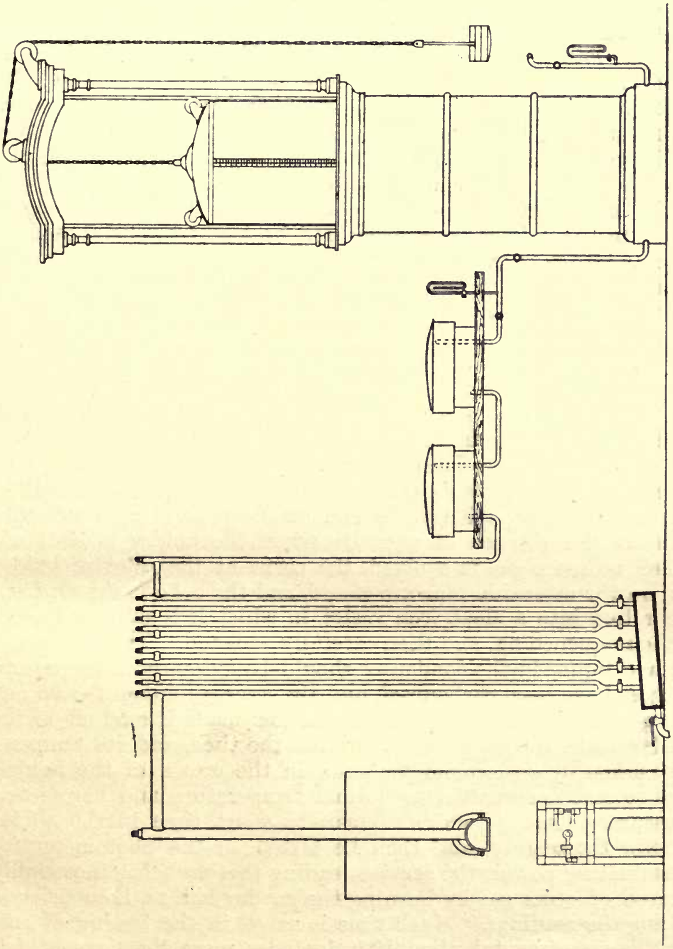


Fig. 4.—Experimental coal-testing plant.

trays, and each tray is charged with moist, slaked lime to the depth of 2 inches. The outlet of the second purifier leads to the gasholder, which should have a capacity of 15 cubic feet. An accurately graduated scale should be fixed to the holder to indicate the contents at any height in cubic feet and hundredths of a cubic foot. The outlet of the gasholder should lead into the photometer room and have a service to the photometer, and, if possible, one leading to the laboratory. It is essential that these services should be as short as possible—*i.e.*, not more than 20 feet in length. Such an experimental plant is shown in Fig. 4. The charge commonly used is $2\frac{1}{4}$ lbs. of coal, which is approximately the thousandth part of a ton and is generally reckoned at that. It is, however, desirable to have a special weight of 2·24 lbs. (exactly $\frac{1}{1000}$ of a ton) kept for the purpose. Ordinary shop scales in good condition may be used for weighing out the charge. The latter, which should be a fair sample of the bulk, is carefully placed in a scoop about 30 inches in length. The retort should be at a bright-red heat, and the lid should be covered where it will touch the mouthpiece with damp clay, in readiness for closing the retort tightly. The apparatus should be cleared of air by a preliminary charge, the gas being driven back from the holder and burnt at the mouth of the retort, the ascension pipe being closed by a cock in it as soon as the holder is grounded. The charge is quickly put into the retort, the lid fixed and ascension-pipe cock opened as quickly as possible. The holder should be weighted so that a pressure-gauge attached to the inlet pipe gives a level reading. The charge will take about twenty minutes to work off; if a pressure-gauge is attached to the inlet of the purifiers the end of the process can be readily seen by the absence of pressure when the holder is shut off. When no more gas is evolved, the cocks at the inlet of holder and on the ascension pipe are closed, and the coke is drawn from the retort into a clean iron vessel, in which it is shut up to cool without quenching, and then carefully weighed. The amount of tar and liquor in the condenser should be measured after several charges have been carbonized, and the average amount from one charge calculated. The quantity of gas made is read off on the holder scale, the gauge being level at the time, and its temperature taken by a thermometer sunk in the crown of the holder. The volume is corrected to normal temperature and barometric pressure. The gas should remain a short time in the holder to mix thoroughly, and then be tested on the photometer for illuminating power, the service leading thereto being thoroughly cleared of other gas by burning the gas for half an hour prior to taking the readings. Much time is saved in the testing of coal by this experimental plant if it includes more than one holder, so that a charge can be worked off while the gas from a former charge is being tested. Coal-testing plant of this type is made, with slight modifications, by several makers of apparatus. A compact and convenient form, for firing with coal gas, is made by Fletcher & Co., of Warrington.

The yield of gas obtained will be higher than may be expected on a large scale with the ordinary fireclay retorts by about 3 per cent. For rich coals and cannels the retort should be as hot as possible, and care should be taken that a suitable burner is used for testing the gas. The sulphur in the gas may be estimated by Harcourt's or the Referees' method, as described in Volume II. The amount of coke will be virtually the same as that obtainable on the large scale. A sample of the coke should be reserved for the determination of its content of sulphur. The liquor will be deficient both in strength and quantity owing to the absence of proper scrubbing facilities. The illuminating power of the gas will be higher than may be expected in ordinary working with an exhauster and high heats. The product of the "illuminating power," and the quantity of gas made, should be found and expressed either in candles per ton, or pounds of sperm per ton. The latter is the basis generally adopted, and is founded on the light evolved by sperm as consumed in the standard candle defined by the Gas Works' Clauses Act, 1871, and other gas Acts. This candle has a normal consumption of 120 grains, or $\frac{3}{175}$ of a pound of sperm per hour. In testing, the gas is burnt at the rate of 5 cubic feet per hour, or corrections are made to express the candle power at that rate nominally. Consequently the number of cubic feet of gas made per ton of coal must be divided by five in order to find their equivalent in lighting units. The number so found, multiplied by the candle power, and the result multiplied by $\frac{3}{175}$ (the lbs. of sperm per candle per hour), gives the value of the coal in pounds of sperm per ton. Or pounds of sperm per ton of coal

$$= \frac{\text{cub. ft. of gas per ton of coal} \times \text{illuminating power in standard candles} \times 3}{5 \times 175}$$

Or, more briefly, the value of a ton of coal in pounds of sperm

$$= \text{cub. ft. per ton} \times \text{illuminating power in standard candles} \times 0{\cdot}00343 \text{ nearly.}$$

G. P. Lishman has indicated several precautions which tend to make the testing of coal in experimental plant as trustworthy and useful as possible.* He recommends that tests on a sample of coal of known sperm value be interpolated between the testings of the coal under examination, so that differences due to temporary variations in the heat of the retort, the efficiency of the condensers, &c., may be allowed for according to their observed effect on the standard coal. On gas works it is not

---

* *Journ. of Gas Lighting*, lxxix., 1492.

always easy to obtain samples of coal of uniform value, which will serve as a standard, though actually consignments from certain pits do not vary greatly and have been used as standards at some large works for years past, just as in many works Lesmahagow cannel was at one time regarded as a standard cannel. At the pits' mouth it is, of course, often possible to obtain more uniform standard samples by adopting as the standard coal that from a particular seam of approved quality. In this case the average sperm value of the standard coal when carbonized under ordinary working conditions, if known, may be taken as the standard of comparison, and the results obtained from the coal under examination corrected according to the ratio of the results obtained from the standard coal under similar conditions and those obtained from it under ordinary working conditions. By such correction of the experimental results, a close approximation to the actual results which may be expected from the coal under ordinary gas works' conditions of carbonization may be secured.

The results of tests of coal should be tabulated with as full details as possible. The following particulars should be stated in every case:—Weight of charge (unless a certain weight is invariably adopted); time occupied in working off charge; weight of coke obtained; coke calculated in pounds per ton of coal carbonized, or percentage by weight on the coal; cubic feet of gas made; temperature of gas and barometric pressure; calculated volume of gas per ton of coal, corrected to normal temperature and pressure; illuminating power of the gas, expressed in standard candles; and value of the gas from a ton of coal reckoned in pounds of sperm. At least six tests should be made with each sample of coal under investigation, and the average result calculated under each of the above heads. Further, the liquor and tar from three or more tests should be measured in fractions of a gallon, and the quantity of each per ton of coal calculated. The strength of the liquor by Wills' test (Vol. II.) should be ascertained, and the amount per ton of coal calculated into the equivalent number of gallons of 10 ozs. strength, which is the standard strength generally adopted. Since, however, the measurement of the tar and liquor made on a small scale is accomplished with difficulty, and the results are not accurate, it is very commonly omitted in coal testing. In the laboratory, tests should be made to furnish the following particulars:—The specific gravity of the coal; the percentage of moisture in the coal; the total sulphur in 100 parts of the coal, and in 100 parts of the coke; the volatile sulphur—*i.e.*, sulphur yielded to the gas, calculated from these figures and the percentage yield of coke; the percentage of ash in the coke; the percentage of ash in the coal, calculated from the above and the known yield of coke, or estimated directly; the percentage of moisture in the coke. With the exception of the estimation of sulphur and moisture in coke, which is treated in the next section (p. 41), the methods of making the above tests have been described. The gas is often examined directly for impurities and various constituents; the tests applied will be found described in Volume II.

The following examples will indicate the method of tabulating results, and the figures that may reasonably be expected from certain kinds of coal (see p. 38). Now that the sperm candle itself is giving place to other standards of light, having, however, a definite relation to the average light afforded by the sperm candle, it is likely that the gas-making value of coal will be more usually expressed in "candles per ton" than in "pounds of sperm per ton." Results expressed in the latter term may be converted into "candles per ton of coal" by multiplying them by 58⅓.

Coal that has given satisfactory results in the small experimental plant described above and in the laboratory testing is frequently tested on an ordinary working scale before being purchased in quantity. For this purpose a small plant of from one to six full-sized clay retorts is erected and furnished with the usual complement of scrubbers, exhausters, purifiers, &c., in size proportioned to the number of retorts. The whole plant constitutes a diminutive gas works, and can be readily erected by the constructing engineer so as to resemble as nearly as possible in working the ordinary settings and plant of the particular works. Provision should be made for close observation of the manufacture, and the careful measurement of the quantities of gas, liquor, tar, and coke yielded. For convenience of testing, such an experimental plant should be near to a photometer room and laboratory. The results obtained will be strictly comparable with those furnished with the larger plant of the gas works, but in general slightly less favourable to the coal. On the other hand, the small iron retort installation gives gas of a higher illuminating power than gas made on the works from similar coal would possess, and a deduction from the iron retort figures under this head of about 4 per cent. will give the probable result to be attained in ordinary working. The reduction of illuminating power on the large scale is due to the thorough scrubbing the gas receives, some of the illuminants being washed from it thereby. In comparing results of working on the large and small scale, it must be remembered that heat passes more rapidly through the iron than through the clay retort, and that the latter can be worked at a higher temperature than the former. The

DESCRIPTION OF COAL.	Weight of each Charge.	Time in Working off.	Coke. Percentage by Weight.	Gas made per Ton of Coal, Corrected Volume.	Illuminating Power. Candles.	Pounds of Sperm per Ton of Coal.	Gallons of Liquor, 10 Ozs. Strength.	Specific Gravity of Coal.	Moisture in Coal.	Sulphur in Coal.	Sulphur in Coke.	Volatile Sulphur in Coal.	Ash in Coal.	Ash in Coke.	Moisture in Coke.
	Lbs.	Mins.		Cub. ft.					%	%	%	%	%	%	%
Lesmahagow Cannel,	2·24	23	46·3	11,888	31·22	1272·5	19·5	1·21	2·13	0·83	0·85	0·44	7·02	15·20	2·1
Durham Caking Coal (1), . .	2·24	21	69·9	10,616	16·88	614·4	25·4	1·27	2·21	1·71	1·98	0·32	5·11	7·31	3·2
Durham Caking Coal (2), . .	2·24	25	71·4	10,382	14·75	525·0	26·1	1·29	3·71	1·51	1·03	0·74	7·88	11·03	2·7
Silkstone (Yorkshire),	2·24	28	63·0	10,512	15·90	573·0	26·3	1·27	2·02	1·13	1·01	0·49	4·85	6·90	4·3

"candles per ton," or "pounds of sperm per ton," increase slightly with the volume of gas made, and consequently with the heat employed in carbonization, within the limits of customary gas works temperatures. The amount of work done per retort, or per mouthpiece, if through retorts are employed, or per superficial foot of interior surface of retort, if the size of the retorts is not uniform, is the best guide to the proper degree of heat to be employed in carbonizing to obtain the highest value from a given coal. These general indications of the considerations which determine the selection or rejection of a sample of coal for gas making will suffice for the present purpose.

ANTHRACITE, COKE, &c.

Incandescent carbon decomposes water vapour with the production of equal volumes of hydrogen and carbonic oxide. If the carbon is not at a sufficiently high temperature, another action takes place resulting in the formation of carbonic acid and hydrogen. The gas produced by the first reaction is known as water gas, but in practice it is usually contaminated by small quantities of carbonic acid produced by local occurrence of the second reaction owing to unequal or insufficient temperature of the carbon. As the carbon is the active material in the production of water gas, it is evident that the ideal substance for the manufacture is pure carbon. This is unobtainable in quantity and at a price consistent with economical production of gas on a large scale, consequently the manufacturer must be content with the most highly carbonaceous fuel to hand at a low price. The particular fuel which fulfils this condition will depend on the local conditions, but in comparing fuels it must be remembered that their value for water gas manufacture is almost solely determined by their carbon content. The density of the fuel and the nature of its other constituents affect its value for the purpose in a less degree. In some few cases, it may be expedient to use fuel of low carbon content in a water-gas generator, but they are exceptional. The water-gas generator is no more a legitimate receptacle for every description of waste or inferior fuel than is the carbonizing retort, and far less so than boiler furnaces or gas producers. The economy of the common practice of supplying the water-gas generator with any waste coke, which cannot be readily disposed of otherwise, is more than questionable. It entails a serious reduction in the quality and quantity of the gas made, a greater expenditure of labour, and often extensive derangement of plant and working routine.

Anthracite.—Certain varieties of coal known generically as anthracite contain a large amount of carbon, and consequently rank as suitable materials for water-gas production. They do not show very great variation in composition or in physical properties, and occur in extensive deposits in many parts of the world. Anthracite may be regarded as the ultimate natural decomposition product of woody fibre, and generally exhibits no traces of the forms of the plants from which it was derived. Eliminating the ash or residue remaining on combustion, the percentage of the chief constituents of anthracite is :—Carbon, 90 to 95 ; hydrogen, 2 to 4·5 ; oxygen, 2 to 5. The specific gravity varies from 1·3 to 1·9, generally being from 1·4 to 1·5. The amount of ash left by anthracite is usually less than 5 per cent. of its weight. Immense deposits of anthracite are found in the United States, especially in Pennsylvania. This anthracite is close and compact, has a specific gravity of about 1·45, and contains from 2 to 10 per cent. of ash. It is largely used for the production of water gas. On an average it will contain 91 per cent. of carbon. Anthracite is found in large quantities in South Wales. It is less dense than that from Pennsylvania, its average specific gravity being 1·35. As a rule, it does not contain more than 2 per cent. of ash, and its percentage of carbon is about 91. Other localities where anthracite occurs in tolerable quantities are France, Saxony, Chili, Brazil, and South Russia.

Coke.—When the volatile matter is removed from bituminous coal by destructive distillation, the residue consists almost entirely of carbon, and the inorganic bodies which will remain as ash on its combustion. This residue, known as coke, is produced in large quantities as a bye-product in the manufacture of coal gas, and also is made in specially-constructed ovens on a large scale for metallurgical purposes. The products of the two processes differ somewhat both in composition and in physical properties. The ovens in which coke is produced as the main product are much larger than gas retorts, and some forms are worked at a higher temperature, while in others a more prolonged exposure to heat is given. Considerable modifications of the original forms of ovens have been made of late years to enable ammonia, tar, and benzol to be recovered as bye-products, and the gas evolved to be utilized ; the properties of the coke produced have been slightly affected thereby. It is, however, more compact than gas coke and contains less sulphur, and consequently supersedes the latter for metallurgical uses. For the manufacture of water gas on ordinary gas works it is hardly likely to come largely into use, though it would serve well. Gas coke being a bye-product, can generally undersell oven coke, and especially where water gas is made for addition to coal gas, the coke produced in the manufacture of the latter is ready to hand for the production of the former. It must be remembered, however, that gas coke is inherently less suited for making water gas than anthracite or good oven coke, and that its employment requires a deeper generator, and greater expenditure of time and labour on clinkering. It is evident that coke for gas making must be as free from ash as possible, but where a water-gas plant is subsidiary to a coal-gas installation, it is of necessity of a quality dependent on the coal used in the latter. The best coke from the retorts should, however, be invariably used, and the percentage of ash contained in it should not in any case exceed 10. It should be in lumps of uniform size, 2 to 3 inches in diameter, all dust and breeze being carefully screened from it. Coal that is fit for gas making will not, as a rule, give coke containing an excessive amount of sulphur, and as the latter will be present in the water gas mainly in the form of sulphuretted hydrogen, its removal from the gas will not cause difficulty. The coke must be free from excess of moisture; it should not lose more than 2 per cent. in weight on heating for three hours at 100° C. The ash in coke is estimated by the method described on p. 23.

The total **amount of sulphur** in coke is estimated by the gradual heating of about 2 grammes of the finely-powdered coke with four times its weight of mixed alkaline carbonates, to which, when in a state of fusion, twice its weight of potassium nitrate is slowly added. The mixture is kept in a state of fusion for a few minutes longer, then allowed to cool, and extracted with dilute hydrochloric acid, and the sulphur precipitated and weighed as barium sulphate in the manner described in Volume II. Stolba's method for the determination of sulphur in coal (p. 21) is applicable to coke, the heating being continued a few minutes longer. The results are accurate. The method of the Committee of the American Chemical Society for the determination of the sulphur in coal (*ante*, p. 19) is also applicable to coke. It resembles, however, in many particulars a method specially worked out for coke by W. F. K. Stock, and described fully by him.* This method is as follows:—1 gramme of the finely-powdered coke is mixed in a round bottomed platinum capsule with about 1 gramme of half-hydrated caustic lime, moistened with 1 c.c. of water, rapidly dried, and heated in a muffle to bright redness until all carbon disappears. The half-hydrated lime is prepared by calcining marble, dividing the caustic lime obtained into two equal portions, one of which has exactly the amount of water needed to form calcium hydrate [$Ca(OH)_2$] added to it. The two portions are then mixed. The mixture so obtained does not lose through spattering when water

---

* *Journ. Soc. Chem. Ind.*, 1897, 305.

is added to it. The capsule is removed from the muffle, and when cool its contents are extracted with 20 c.c. of cold distilled water in a 6-oz. conical beaker, and 5 c.c. of saturated bromine water is added, followed by 7½ c.c. of pure concentrated hydrochloric acid. The whole is boiled for five minutes, and then filtered until a bright red filtrate is obtained. The beaker is washed three times into the filter, and the latter is washed three times. The filtrate and washings are boiled, and 10 c.c. of a 5 per cent. solution of barium chloride are run in gradually from a pipette, and the boiling is continued for thirty minutes. The beaker is then kept so that the contents are nearly at the boil for three hours. The precipitate of barium sulphate is filtered off, washed, ignited, and weighed in the usual manner. It is customary to deduct from the sulphur in coke the amount of sulphur in the equivalent quantity of ash, to obtain the amount actually given off on combustion. The method of determining the amount of sulphur in an ash is given on p. 24. The sulphur in coke, which is evolved as sulphur dioxide on its combustion, may also be directly estimated. A weighed amount of coke is roasted in a boat within a combustion tube in the manner described for the estimation of ash on p. 22, but a bulbed tube containing solution of bromine or iodine is placed between the combustion tube and the aspirator. The products of the combustion of the coke are thus drawn through the solution, and any sulphur dioxide present is oxidized by the halogen to sulphuric acid, which can be afterwards estimated in the usual manner. A known volume of standard iodine solution may be used in the bulb tube, and titrated with standard solution of thiosulphate after the combustion of the coke is completed. The loss of iodine by the standard solution shows the amount of sulphur dioxide oxidized, and from that the amount of sulphur can be calculated. This method is rapid of execution if the standard solutions are at hand. The following equations show the reactions involved :—

$$SO_2 + I_2 + 2H_2O = H_2SO_4 + 2HI.$$
$$I_2 + 2Na_2S_2O_3 = 2NaI + Na_2S_4O_6.$$

The **specific gravity** of coke is not often determined, except where it is required for metallurgical purposes. It may be ascertained by slight modifications of the methods given for coal on p. 30, the vacuum pump being used to remove air bubbles adhering to the coke when submerged. The methods of estimating the specific gravity and porosity of coke will be more fully discussed in the sequal to this volume.

Anthracite is tested for impurities, &c., in precisely the same manner as bituminous coal.

Pure Carbon.—Of experimental interest only is the use of almost pure carbon for gas making. Where quantities of retort scurf are at disposal, it may be broken to lumps of 4 to 8 cubic inches, and used in the water-gas generator either alone or mixed with coke. When broken sufficiently small, and with the use of a powerful blast it forms an excellent material for manufacturing pure water gas. Being practically pure carbon, it is wholly combustible, and gives a gas free from impurities. Its limited production and value for other purposes preclude its use on a large scale.

OIL.

Petroleum.—Chief among liquid hydrocarbons available for the production of illuminating gas is petroleum or earth oil. This natural product of the decomposition of vegetable and probably animal remains varies greatly in character and composition, and consequently in fitness for gas making. In many cases the crude oils as extracted from the earth may be used without preliminary treatment, but, as certain distillates and the residuum from processes worked for the purpose of obtaining oil suitable for other ends frequently serve for gas manufacture, the subject naturally divides itself, from the gas manager's point of view, under two heads:—(1) Crude oils; (2) the products of distillation or treatment of crude oil or oil-bearing rock.

The **origin of petroleum** has for years been a subject of controversy among experts, and even now opinions are divided. Here it will suffice to say that the bulk of petroleum appears to be of vegetable origin, though strong evidence of the presence of animal remains exists in many cases. By the heat of the earth destructive distillation of the vegetable or animal remains deposited in certain strata has ensued, and the distillate has found a convenient storage in the sand rocks whence it is now obtained. The rocks in which the oil had its origin are termed shales, and belong for the most part to the Devonian age. The deposits generally underlie the coal strata, and there is abundant evidence that the petroleum is not a product of the action of heat on the coal deposits, a convenient theory of its origin much espoused some years ago. A feature of the oil-bearing rocks is their contiguity to mountain ranges; the oil districts lying almost universally a short distance from the foot of extensive ranges of hills and running parallel to them. This association of productive oil fields with mountains is well illustrated by the oil districts of Pennsylvania, California, the Caucasus, and Galicia. The oil frequently flows out at the earth's surface, in obedience to the laws of hydrostatics, by reason of the pressure exerted by the oil contained in adjacent rocks of greater elevation; or, in other cases, where quantities of gas are stored in the natural reservoirs above the oil, the latter may find an outlet in some spot below the level of the gas by reason of the expansive force of the gas exerted on the surface of the oil. In general, the oil is obtained at the earth's surface by boring and pumping; if the boring strikes the upper part of the cavity, gas only escapes for some time. This natural gas, stored up in the oil-bearing rocks, has been extensively used in the United States for lighting and heating, but in some cases the supply is now failing, and towns hitherto dependent on it are forced to erect installations of gas-making plant. The natural gas consists chiefly of methane, and hence is especially valuable for heating purposes. Natural gas has lately been discovered at Heathfield, in Sussex, and is used for lighting purposes in the neighbourhood. Petroleum as it issues from the wells varies in colour and consistency according to the locality, but in general is of a deep, dirty green colour by reflected light, and reddish-brown by transmitted light. The specific gravity varies very considerably; the lightest oils usually come from deep wells.

Distribution.—Petroleum is found in large or small amount in almost all parts of the globe, but the chief oil-bearing districts are enumerated below:—

In the south of Russia, from the Caspian to the Black Sea, is an immense oil field, which extends eastwards to Afghanistan. The oil is heavy, having a specific gravity from 0·850 to 0·885, and frequently contains water, and a large amount of solid matter in suspension. The town of Baku, on the Caspian, is the centre of the oil industry of the district, and the bulk of the oil raised is distilled there. The Balakhani fields, the most productive of the neighbourhood, are about 8 miles from Baku, whither the oil is conveyed by pipe-lines. There is a railway from Baku to Batoum, on the Black Sea, to which port the oil is taken in tank wagons, or by a pipe-line, for shipment to other countries in tank steamers. The United States of America embrace several oil districts, the most important of which is the Pennsylvanian field, which stretches from the State whence it takes its name northwards into New York State. The oil varies in specific gravity from 0·770 to 0·880, and varies considerably in colour, green and deep amber prevailing. The Bradford field is the most prolific in this district. The State of Ohio has large oil deposits; the most important being that of the Lima field. This oil is black, has a specific gravity from 0·820 to 0·840, and contains much sulphur. The crude oil is very extensively used in the manufacture of carburetted water gas. There are also oil districts in Wyoming, Illinois, Kentucky, Indiana, West Virginia, Texas, and many other parts of the United States. Californian petroleum is worked chiefly for local use, and has a specific gravity from 0·840 to 0·880. In Canada there is a field of about 200 square miles in Ontario. The oil from it is black and largely charged with sulphur compounds; the specific gravity is from 0·830 to 0·880. There are large oil fields in Peru and other parts of South America. Peruvian oil varies from 0·785 to 0·835 in specific gravity. In Mexico oil very similar to that of Pennsylvania is found. In Europe there are extensive fields in Galicia, Roumania, and Hungary. The specific gravity of Galician petroleum ranges from 0·800 to 0·900. In Hanover and other parts of Germany oil is found in small quantities. Japan, Burmah, India, and Persia contain oil deposits which are worked to a small extent for local use, while petroleum from Borneo is imported into this country. Petroleum is also found in Egypt and Algiers, but it is heavily loaded with sulphur, as is the oil from Texas.

The **chemical composition of petroleum** from various sources has not been sufficiently made out to enable definite conclusions to be drawn from the results at present obtained. But it is certain that it differs very considerably according to the locality from which the oil is derived. Thus, petroleum from one district will be largely made up of hydrocarbons of one series, while petroleum from another district will consist chiefly of homologues of a totally different series of hydrocarbon compounds. The nature of the bulk of the hydrocarbons in an oil largely determines the products obtained from it on destructive distillation, consequently a brief statement of the composition of the chief varieties of petroleum, as far as present knowledge admits of it, is given. Pennsylvanian petroleum consists chiefly of hydrocarbons of the paraffin series. The lowest members of the series, methane and ethane, though gaseous, are found either in close association with, or dissolved in, it. There have been isolated from it all the higher normal hydrocarbons of the series up to $C_{13}H_{28}$, as well as several isomers and some higher members. The aromatic hydrocarbons, benzene and its homologues, are present in very small amount, if at all, in the original petroleum, but occur in Ohio, and still more largely in Canadian petroleum. They are found in distillates as products of (local) destructive distillation. Very small quantities of naphthenes and olefines are found in American (Pennsylvanian) petroleum.

Russian or Caucasian petroleum consists chiefly of homologous hydrocarbons known as naphthenes and polynaphthenes. These are isomeric, but not identical with the olefines. Markownikoff and others have isolated these hydrocarbons from Balakhani petroleum from C_7H_{14} to $C_{15}H_{30}$ inclusive. They are isomeric and probably identical with the hexa-hydrogen addition compounds of the hydrocarbons of the aromatic series. Some of the members of the aromatic series, notably some having the general formulæ $C_{10}H_{14}$ and $C_{11}H_{16}$, have been found in Russian oil, as also hydrocarbons of the general formula C_nH_{2n-2}. Olefines have been found in small amount, but paraffins are virtually absent.

The oil from Bibi Eibat, however, contains notable proportions of paraffins, especially in the lighter fractions. The oils, indeed, from different fields in the Caucasus vary considerably in composition, but naphthenes predominate in all. The Grosny field yields oil fairly rich in aromatic hydrocarbons. Naphthenes also occur in Galician petroleum, which, however, contains more paraffins than the Caucasian products. German petroleum also consists mainly of paraffins. The lighter portions of Roumanian petroleum consist of paraffins and other open-chain hydrocarbons; the higher fractions of aromatic hydrocarbons and naphthenes. The South American oils which have been examined generally resemble Caucasian petroleum. Texas petroleum has a high specific gravity, 0·92 to 0·96, and contains large amounts of sulphur—from 1 to 2½ per cent. of the oil. It has a very disagreeable odour, largely due to sulphuretted hydrogen. It consists mainly of cyclic hydrocarbons of the general formulæ C_nH_{2n-2} and C_nH_{2n-4}. The bulk of the oil cannot be distilled under atmospheric pressure without considerable decomposition ensuing. Californian petroleum ranges in specific gravity from 0·84 to 0·89, and varies considerably in composition, but contains a relatively small amount of paraffin. The lighter fractions of many samples are chiefly methylenes or naphthenes, as in Caucasian oils, but the higher fractions contain homologues and derivatives of benzene in larger amount, even naphthalene being sometimes present in appreciable quantity. Oxygen and nitrogen compounds also are well represented. Japanese petroleum varies very much in specific gravity (from 0·82 to 0·99) and composition, according to the field from which it is derived. It consists generally of methylenes or naphthenes, and contains more of the higher paraffins and less of aromatic hydrocarbons than Californian petroleum. Borneo petroleum ranges in specific gravity from 0·89 to 0·92, and consists mainly of methylenes and aromatic hydrocarbons. Distillates of the solar oil grade derived from Canadian, Galician, Bornean, and Texan petroleum are now offered in this country for gas making. The foregoing particulars of the composition of petroleum from different sources may be amplified by reference to recent researches, of which those by Markownikoff on Russian, and by C. F. Mabery on Pennsylvanian, Californian, Japanese, and Texan oils will be found especially instructive (*vide*, *inter alia*, *Journ. Soc. Chem. Ind.*, 1900, 502, 1002; and *Amer. Chem. Journ.*, xix., 796; xxii., 553; xxiii., 253, 264, and 297).

The chief gas-making oils belong to one of these classes, with the exception of the oils distilled from bituminous shale in Scotland and elsewhere. Unlike most petroleum oils, this shale oil contains a notable quantity of olefine hydrocarbons, mixed with smaller amounts of paraffins. The brown coals and shales of Saxony, Thuringia, and Bohemia yield, on distillation, oils which consist of saturated hydrocarbons, with a smaller proportion of olefines.

Gas-making Petroleums.—Some few oils are available for gas making in their natural state, but the bulk of crude oils require distillation before use. In the United States certain oils, such as that of the Lima field, are used without treatment in the carburetted water-gas plants, but these are not available in this country. Russian crude oils leave, as a rule, too much solid residue on distillation to be used for gas making in the ordinary forms of apparatus. But, in the distillation of crude petroleum, shale, and brown coal for the production of burning and lubricating oils, certain fractions of the distillate cannot be relegated to either of these classes, and are reclaimed from the category of waste products only by their suitability for gas manufacture. Thus, a bye-product in the manufacture of illuminating oil avails for the manufacture or enrichment of the rival illuminating agent—gas. The essential points of a good gas-making petroleum are freedom from water, and from solid residue on distillation, and reasonably small content of sulphur compounds. The specific gravity and volatility of the oil are of importance, but can only be considered in relation to the particular form of apparatus in which it is to be used. The flashing point is indirectly of importance in indicating the precautions to be observed to prevent inflammation during transport or storage. The burning point test has a similar import. The nature of the hydrocarbons constituting the oil has to be considered with the practical test of the amount and quality of gas yielded by it, and gives a general indication of the most suitable method and temperature to be employed in the manufacture.

Method of Examination.—The laboratory examination of an oil to determine its fitness for gas making embodies the operations described hereunder. The specific gravity of the oil and its temperature at the time of taking the specific gravity are ascertained. A hydrometer with an open scale serves for taking the specific gravity if the instrument is known to be correctly calibrated. The scale should be sufficiently open to allow reading accurately to within 0·0005; and the thermometer should be in the oil when the reading is being made, and be read immediately after the hydrometer. Failing the use of an accurate hydrometer, the specific gravity must be taken in the ordinary way with a specific gravity bottle, but the high coefficient of expansion of petroleum renders careful and rapid working necessary, and care is requisite to obtain correctly the temperature of the oil at the time of weighing. By either method it is desirable that the specific gravity should be taken at the standard temperature, usually 60° F. When this is impossible it should be corrected to that temperature by means of the coefficient of expansion of the oil, which may, in general, be taken at 0·00036 per degree Fahrenheit as an average value for petroleum oils. Oil is frequently bought and sold by weight, which is calculated from its volume and specific gravity, hence the accurate determination of the latter has special importance in many cases.

The flashing point of burning oil is determined in this country by the apparatus devised by Sir Frederick Abel and adopted as the standard by the Board of Trade. For oils of low flashing point it is equal, or superior, to any of the forms of apparatus adopted in other countries. A description of the method of making a determination with it is given with each apparatus, and there will be little divergence in the results obtained by different operators if the directions are implicitly followed.* Most oils suitable for retorting have, however, fairly high flashing points, and the determination can be made with moderate accuracy in a much simpler apparatus. This consists simply of a cylindrical copper vessel, about 3 inches in diameter and 3 inches deep. The lid overlaps the top of the cylinder, but a flange $\frac{3}{4}$ inch deep attached to it fits within the cylinder, and keeps the lid in position. The lid is perforated in two places; one hole is for the insertion of the thermometer held by a perforated cork fitting the orifice, the other is covered by a small lid pivoted to the cylinder cover, so that the opening can be exposed by sliding the lid from it, and can be covered again immediately after each application of the test-flame. The oil to be tested fills the cylinder to a height of 2 inches, and the bulb of the thermometer is immersed in the liquid when the cover is in position. Heat is applied to the bottom of the cylinder by means of an Argand burner, and a sand bath, so that the temperature of the oil rises about 1° F. per minute. As each degree on the thermometer scale is reached the opening in the cover is exposed and a small gas flame passed over it. If no flash is observed, the opening is closed until the next trial is made. The temperature at which the flash is first observed is noted, and recorded as the flashing point of the oil. If it is wished to confirm the result, a fresh

---

* Details of the apparatus will be found in Redwood's *Treatise on Petroleum* (Charles Griffin & Co., Ltd.), where also the method of using is fully described.

portion of the oil must be taken for a second determination, as oil that has once flashed will not again flash at its original flashing point. The gas flame used for testing should be $\frac{3}{8}$ to $\frac{1}{2}$ inch in length, and is readily obtained by fusing the end of a piece of hard glass tube until the orifice allows only sufficient gas to pass through at its ordinary full pressure to give that length of flame. For accurate determinations heating the cylinder in an air, water, or oil bath may replace direct heating by an Argand burner. The apparatus should be protected from air currents during the determination. It is illustrated in Fig. 5. A more elaborate apparatus for determining the flashing point of gas oils is the Pensky-Martens, which is extensively used on the Continent. The oil is gently agitated by small wings on a rotating vertical spindle, while the vapour in the space above the oil is more strongly agitated by a larger fan on the same spindle. The oil container is heated through an air bath, and its top is provided with a perforation for a thermometer, and a neat device for admitting the flash jet as required. The test is conducted very similarly to one with the Abel apparatus. The Pensky-Martens apparatus gives very concordant results with the oils of high flashing point, for which it has been devised. The flashing point is usually stated in the Fahrenheit scale in this country.

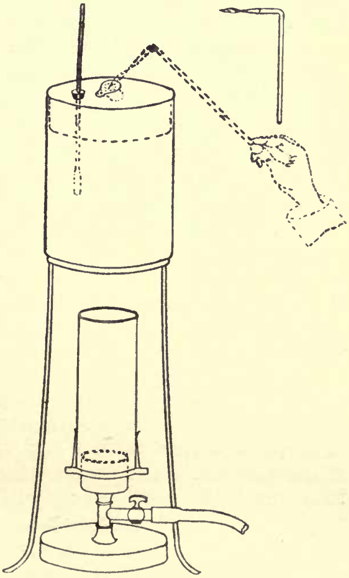


Fig. 5.—Oil flashing point apparatus.

The distillation of a sample of oil gives much valuable information as to its properties. For most purposes it may be conveniently carried out in the laboratory in the manner here described. A glass spheroidal flask with a glass tubulure fused in its neck, of capacity twice the volume of the oil to be distilled is taken, and a thermometer is inserted in the neck by means of a tightly-fitting perforated cork, so that the bulb of the thermometer is on a level with the mouth of the tubulure. The latter is connected to a Liebig condenser. The neck of the flask is lightly held by a clip, and the bottom rests on wire gauze, while the sides of the flask are jacketed with the same material or asbestos cloth to protect them from air currents. Heat is applied by means of an Argand or rose burner at first, though towards the end of the distillation a more powerful burner may be needed. A convenient quantity of oil for distillation is 500 c.c., though 250 c.c. will often suffice. The flask should be weighed before and after the oil is put in it, and thus the weight of the oil taken is known. The heat should be regulated so that the distillate *drops* from the end of the condenser at a uniform rate, and does not come from it in a stream. The temperature is read on the thermometer when the oil begins first to pass over, and afterwards as each fraction of the distillate is removed. The distillate is usually collected in fractions amounting to 10 per cent. of the volume of oil under distillation. This is a simpler plan than the alternative one of measuring the volume of distillate collected between certain arbitrarily fixed temperatures, and generally gives more informative results. The specific gravity of each fraction is ascertained approximately. The distillation is pushed until increased heat drives over no more oil, and no residue, or coke only, remains in the flask. When cool the flask is again weighed, and the weight of the residue so found enables its percentage (by weight) on the oil to be calculated.

With oils of which the heavier portions volatilize only at very high temperatures, the alternative of stopping the distillation when the thermometer records some predetermined temperature —*e.g.*, 360° C. (680° F.)—may be adopted. In that case the weight of the residue remaining in the flask when the distillation is stopped is ascertained and its specific gravity is determined. A comparison of the figures thus obtained with those pertaining to a standard heavy gas oil will indicate whether the oil is likely to yield over much carbonaceous residue on cracking in gas-making plant. The maximum amount of residue left when the distillation is stopped at 360° C. (or some other stated temperature) is sometimes prescribed in specifications for the supply of gas oil. It has the advantage of being more readily and accurately determined than the amount of solid residue remaining when the distillation is carried as far as possible, but is a less valuable criterion of the behaviour of the oil when used for gas making.

The weight of each fraction of the distillate can be found by direct weighing, or from the specific gravity. The total of the weights of the distillates and the weight of the residue should amount nearly to the weight of oil taken; the deficiency, which should not exceed 1 per cent., may be recorded as "loss on distillation." It is due to some of the more volatile distillate escaping condensation and to the production and escape of gas by cracking of portions of the oil at the higher temperatures. With many oils it is desirable to use two thermometers—one for temperatures from 20° to 150° or 200° C., the other (nitrogen filled) for higher temperatures. A thermometer which has been used at high temperatures is not accurate for low ones. The amount of water, if any, which comes over, and settles beneath the oily distillate, should be observed. The colour of each fraction should be recorded, and a piece of moist lead paper held above the outlet of the condenser at intervals to find if sulphuretted hydrogen is evolved at any stage of the distillation. The degree of blackening gives an indication of the amount of sulphur in the oil. A note should be made of all observations, and the results of the distillation should be recorded in the manner indicated by the record of the distillation of a typical Russian gas oil given on p. 61. The determination of the amount of sulphur in gas oil is seldom made, but can be carried out by Carius' method, or by a slight modification of the fusion methods for sulphur in coal, or by burning the oil in a suitable lamp, and passing the products of combustion through a washer of hydrogen peroxide or other suitable oxidizing agent, and estimating the sulphate as the barium salt. (*Cf.* the Referees' method of estimating sulphur in gas by burning, as described in Volume II.)

A good oil for gas making should be free from water, and leave less than 1 per cent. of coke on distillation. A crude oil will generally contain fractions distilling below 100° C., but the distillates now so largely employed for gas making will be free from so light fractions. A natural oil generally contains water, though sometimes only in small quantities, and there is great divergence in the boiling points and specific gravities of the fractions of distillate from it. A good gas-making distillate oil, on the other hand, will exhibit a gradual and fairly uniform rise in the temperatures of distillation of its fractions. Rapid blackening of lead paper should not take place until near the end of the distillation. Only the tenth fraction should be decidedly dark in colour. Oils containing more residual coke than 1 per cent. may be used in certain methods of oil gas manufacture, but are not desirable in any plant containing chequer work chambers or small outlet pipes. Provided the distillation results do not condemn an oil, it is tested for yield and quality of gas in a small oil-gas apparatus. It is not of great importance which of the numerous forms of apparatus in common use is adopted, but the same should be used during a series of experiments, and comparisons made with tests of a standard oil in it. Paterson's, Keith's, Pintsch's, or Avery's apparatus may be used; Chapter v. should be consulted for details of manipulation. The apparatus should be of a size to work off a gallon of oil in about three hours. The heat of the retort or tubes must be regulated according to the nature of the oil under trial; tests should be made at different temperatures to find that most favourable to the oil. The temperature should be observed with a Le Chatelier or other good pyrometer, but where this is impossible a practised eye can judge it with fair accuracy. Not less than half a gallon of oil should be gasified at each test; the gas should pass through two lime purifiers (2 feet square by 1 foot deep, two shelves) and then through a meter, the index of which should be read before and after the test to find the quantity of gas made. The temperature of the meter should be observed several times during the experiment, and the mean temperature and mean barometric pressure taken for correcting the volume of gas to normal conditions. From the meter the bulk of the gas passes to a works holder, but a small stream of it is led to a 15- or 20-feet holder for testing purposes. The pipes should be thoroughly cleared of air before this sample is collected, and the stream should be such that the holder is filling throughout the test. The sample is tested for "illuminating power" in the ordinary way, but it will generally be necessary to try several burners to find that most favourable to the oil. The highest candle power found with any burner should be taken for calculating the value of the oil. The method of testing for illuminating power is described in the Chapter on Photometry (Vol. II.) Care must be taken that the gas in the small holder is thoroughly mixed; if there is any doubt about it being so the whole of it should be burnt in the photometer, tests taken at regular intervals, and the average of these tests taken as the illuminating power. It is also very instructive to observe the effect of an addition of a small percentage of the oil gas on the illuminating power of a sample of coal gas. As a general rule, American oils give the best results when gasified at a lower heat than shale oils, and the latter at a lower heat than Russian oils. The results of the tests should be calculated to give the number of candles produced by the gas from a gallon of oil burning at the rate of 1 cubic foot per hour. As this rate is usually too low for oil gas, the candle power at the actual rate of consumption is taken, and the nominal candle power at the rate of 1 cubic foot per hour is arrived at by calculation (see Vol. II.). The product of the number of candles at this rate, and the volume of gas per gallon of oil, gives a figure which represents the "candles per gallon" obtained from an oil. This figure multiplied by $\frac{3}{175}$ (see p. 35) gives the pounds of sperm per gallon of oil. The pounds of sperm per gallon divided by the specific gravity of the oil, and the result divided by ten, gives the pounds of sperm per pound of oil. The results of oil tests are usually stated either in "candles per gallon," or "pounds of sperm per pound" of oil. The method of tabulating the results is shown by the examples on p. 62.

It is possible also to obtain useful information on the gas-making properties of an oil by destructive distillation on a much smaller scale. For this purpose it is convenient to run into an iron or fused quartz vessel heated, in a gas or charcoal furnace, to a suitable carbonizing temperature, which is checked by a Le Chatelier or other pyrometer, 1·6 ozs. ($\frac{1}{100}$ of a gallon) of the oil, from a graduated bottle or burette. The gas evolved passes through a slight water seal and a gauze screen to a collecting vessel, which may conveniently afford a measurement of the volume of the gas. It may readily be made of a large glass aspirating vessel, or a carboy provided with inlet and outlet tubes, so disposed as to form a siphon acting under a constant head. A thermometer and a pressure-gauge should also be inserted through the plug which closes the mouth of the carboy or aspirator, which should be previously graduated in $\frac{1}{2}$-pints ($\frac{1}{100}$ of a cubic foot) on a scale on one side. If the graduation is carried out with the carboy on a perfectly horizontal stand, the graduations will at once give the volume of gas contained at any time with sufficient accuracy for most practical purposes, provided the carboy is always used on a stand similarly levelled. It is convenient to have an additional tube through the plug, terminating just below it, to serve as an outlet tube for the withdrawal of gas for analytical purposes. This tube will be closed with a screw clip when the vessel is being filled, and the inlet tube will be similarly closed, or by a tap, at other times. It is convenient to have a T-piece on the inlet connection, so that the flow of gas may be diverted at will. Thus gas making may be begun before and continued after the gasification of the 1·6 ozs. of oil, and the gas from the latter merely diverted to the collecting vessel. By this plan the gasification may be controlled by varying the conditions, on a preliminary supply of oil, until the requisite conditions are established. It is then easy to keep these conditions constant throughout the subsequent gasification of the 1·6 ozs., so that the gas produced therefrom is uniform in character. If an attempt is made, on the other hand, to gasify only the 1·6 ozs. of oil, it is certain that the heat and other conditions of gasification will vary, and the gas will not be uniform in character. The volume of gas formed from the 1·6 ozs. of oil is read off, after standing for half an hour, and corrected to normal conditions of temperature and pressure. If the scale is graduated in $\frac{1}{2}$-pints, and exactly 1·6 ozs. of oil are gasified, the figures represent directly the yield of gas in cubic feet per gallon of oil. The water in the collecting vessel should be saturated with similar oil-gas from preliminary runs.

The percentage of hydrocarbons in the gas is ascertained by analysis. The other constituents of the gas and its density may also be determined, but for most purposes it is sufficient to know the proportion of hydrocarbons. It is, of course, also quite feasible to make a rapid determination of the illuminating power of the gas, in a small flat-flamed burner, by driving the gas through a short connection direct to the burner, and measuring the rate of consumption by means of the graduations on the collecting vessel. Such a determination, however, is not of much value when the oil is required for making gas for enriching coal gas or carburetting water gas.

The results—*i.e.*, the volume of gas per gallon of oil, and the percentage of hydrocarbons in the gas—must not be applied as a direct measure of the gas-making value of the oil on a large scale. They can be fairly applied only for comparison with the results of the gasification, under similar conditions, of a sample of oil of known gas-making value. Hence it is necessary to keep a stock of such a standard gas oil, and to gasify 1·6 ozs. of it immediately before or immediately after the gasification test of the oil under examination. It is then possible to state the gas-making value of the latter oil in terms of the standard oil. A good sample of Russian solar distillate, of about 0·870 specific gravity, will serve as a suitable standard oil. The number of cubic feet of gas made per gallon of oil, multiplied by the percentage of hydrocarbons in the gas and divided by 100, gives the cubic feet of hydrocarbons obtained per gallon of oil. This figure should be worked out for each oil, and used as the basis of comparison.

Several well-known and fixed grades of oil have been thoroughly tried for gas making. Of these certain Russian distillates have come into special favour in this country on account of their good qualities and low price. In the distillation of crude oil at Baku about 5 per cent. of benzine and gasolene is obtained, and then about 27 per cent. of oil fit for the manufacture of burning oil. The residue is not always distilled further, but is disposed of for liquid fuel under the name of **astatki** or **masut**. But where lubricating oils are manufactured the distillation is pushed further, and a fraction amounting to about 15 per cent. of the crude oil, and having a specific gravity of about 0·870 is next obtained. This is known as **solar oil**, and being too heavy for use as an ordinary burning oil and too fluid for lubricating purposes, it was formerly a drug on the market, and was generally used with residues as fuel. It has a flashing point of about 200° F., and is, therefore, particularly well suited for transport to a distance. This oil, or a distillate from it, has been recently extensively used for gas making, and gives excellent results. The lubricating oils distil over after the solar oil, and amount to over 30 per cent. of the crude oil. About 15 per cent. of residue, which is used as fuel, remains in the still, the quantity of oil unaccounted for having been lost as vapour or otherwise during distillation. Russian solar oil for gas making should be free from water, have a specific gravity from 0·860 to 0·885, and a flashing point from 120° to 250° F. The residue of coke left on distillation does not usually exceed 0·5 per cent. of the weight of the original oil. When distilled the oil begins to pass over at a temperature of 130° C., and the early distillates are nearly colourless. The remainder are pale straw to amber, the last only being deep brown. Very little sulphuretted hydrogen is evolved during distillation. The details of an actual distillation are given on p. 61. Russian solar oil works best at a medium red heat, or at about 900° C., and at that temperature gives, in most forms of pure oil gas apparatus, a yield of about 1,150 candles per gallon.

From the Scotch shale distilleries comes an oil of very similar grade, unsuitable for burning or lubricating, and largely used for gas making. This intermediate shale oil has a specific gravity from 0·840 to 0·870, and its flashing point is generally above 150° F. It does not begin to distil over under 120° C., generally at about 150° C. The distillates are nearly colourless, and the residue of coke is less than 1 per cent. on the oil. The oils are generally amber or pale brown in colour, and with a strong green or blue fluorescence. Sulphuretted hydrogen is evolved tolerably freely during the distillation. The oil gives the highest "candles per gallon" at a rather dull heat, but if the gas is to be subjected to great pressure or cold, a bright red heat must be used to obtain a maximum yield of permanent gas. At a moderately dull red heat, about 800° to 900° C., a good Scotch intermediate oil yields about 1,200 candles per gallon. The crude paraffin oil from the shale stills is not suitable for use in most forms of gas apparatus.

The oil works of Saxony and Thuringia produce a gas oil having a specific gravity from 0·880 to 0·900. It is reddish-brown, with a blue fluorescence. It flashes about 190° F., and on distillation leaves a residue of coke less than 0·5 per cent. of the weight of the oil. It gives a considerably lower yield of gas than Scotch shale oil. Eisenlohr,* however, has pointed out that these oils can be much improved for gas making by previous washing with sulphuric acid, which removes the "unsaturated hydrocarbons." This removal could not, of course, be carried out on a commercial scale, but the observation is valuable as indicating that paraffins are the most important

---

* *Zeits. für angewandte Chemie*, 1898, 549.

gas-making constituents of the brown-coal or lignite oils. The unsaturated hydrocarbons removed by the sulphuric acid cannot, however, have been mainly of the true olefine series.

In the United States of America certain crude oils are extensively used for gas making. Their specific gravity is about 0·830. As the oil flashes at or little above the ordinary temperature, it is unsuited for transport to a distance. It gives the best result at a moderately low heat. In consequence of the much larger yield of burning oil, American oils produce less intermediate oil on distillation than Russian petroleum affords.

Nevertheless, oil of the solar distillate grade from Pennsylvania is sold in this country for gas making, and the lighter grades are also frequently offered. The Pennsylvanian solar oil ranges from 0·840 to 0·855 in specific gravity, and is generally less highly coloured and more nearly free from water than Russian solar oil. The carbonizing temperature most suitable for the Pennsylvanian oil is slightly lower than that which answers best for Russian oil. Not much practical experience has yet been had with the solar grades of oil from Galicia, Borneo, and Texas, but they all appear to require a higher temperature for gasification to best advantage than that which answers for Russian oil. Borneo oil, in particular, must be treated at a high temperature.

The nature of the hydrocarbons constituting the oil affects the composition of the gas formed from it by destructive distillation at various temperatures. The nature of the gaseous products of decomposition of the hydrocarbons of different series will be considered further subsequently, but it is desirable here to indicate how far and by what means it is possible readily to ascertain the nature of the chief component hydrocarbons of a mineral oil, and thus to infer the origin of the oil. The foregoing remarks on the principal component hydrocarbons of the oils from the more important fields will have indicated, however, that an exhaustive investigation of the composition of a mineral oil is not readily carried out, and that in most instances it has never been completed, though skilled research chemists have devoted much time to the study of the composition of mineral oils. Little, therefore, can be accomplished in this direction in the less exhaustive examination which must generally suffice for technical purposes.

Paraffins (C_nH_{2n+2}) and naphthenes (C_nH_{2n}) (cyclohexanes, &c.) behave very similarly towards most reagents. They are not acted upon by nitric or sulphuric acid to an appreciable extent, nor by bromine in the dark or diffused daylight. In sunlight bromine forms substitution products and hydrobromic acid. Half the bromine entering into the reaction is found as hydrobromic acid. Olefines (C_nH_{2n}), on the other hand, react with nitric or sulphuric acid, and are attacked at once even in the dark by bromine. The result of the action of bromine is the formation of an additive compound, the molecule of which contains two bromine atoms. No hydrobromic acid results from the action of bromine on olefines. Acetylenes (C_nH_{2n-2}) resemble olefines in reacting with nitric or sulphuric acid or bromine. Bromine forms with them an additive compound, the molecule of which contains four bromine atoms, while no hydrobromic acid is produced. The naphthylenes (C_nH_{2n-2}) (cyclo-hexenes, &c.) are far more readily acted upon and oxidized than the naphthenes, while the cyclic hydrocarbons having the general formula of terpenes (C_nH_{2n-4}) are even still more easily attacked and oxidized. Benzenes (C_nH_{2n-6}) are not attacked in the cold by ordinary concentrated sulphuric acid, but are converted into nitro-compounds by concentrated nitric acid, and into brominated derivatives by the action of bromine in the dark or in diffused daylight. Thus, it may be stated broadly that while the normal paraffins resist the attack of oxidizing agents more strongly than hydrocarbons of any other series, they are in this respect not greatly superior to the simple naphthenes or polymethylene hydrocarbons. Next in point of resistance to attack come in order the iso-paraffins, the benzenes, and the naphthenes having methyl groupings in the molecule. Then follow the ethylenes, naphthylenes, acetylenes, &c.

Only a very rough differentiation of the several classes of hydrocarbons can readily be made by analytical methods, when the hydrocarbons occur in such variety as in most mineral oils. The hydrocarbons may be roughly divided for analytical purposes into those which absorb bromine in the cold in diffused daylight or the dark, and those which do not. The paraffins and the naphthenes are practically the only hydrocarbons which are not acted upon by bromine under these conditions, though some aromatic hydrocarbons are not very readily attacked. The extent to which a mixture of hydrocarbons, such as a mineral oil, consists of either paraffins or naphthenes or other hydrocarbons may, therefore, be approximately determined by its "bromine absorption," which must, of course, be ascertained under clearly defined conditions. Where, in a mixture, the whole of the hydrocarbons which absorb bromine belong to one series, the determination of the bromine absorption would, in conjunction with the mean combining weight of the mixture (of which the vapour density and boiling point must be ascertained), admit of a computation of the proportion of the hydrocarbons of that series in the mixture. The complexity, however, of the composition of mineral oils renders such a computation out of the question, and hence all that can practically be done is to determine and state the "bromine absorption" as grammes of bromine taken up by 100 grammes of the oil. For comparative purposes such a determination is often of value in identifying the nature or source of a sample of oil. As, however, distillation of many descriptions of gas oil results in decomposition or cracking of some of the constituent hydrocarbons, and consequent formation of other hydrocarbons differing from the original in their capacity for assimilating bromine, determinations of the bromine absorption of distillates or fractions of the oil do not necessarily throw light on the composition of the original oil. For instance, some oils consisting mainly of naphthenes are cracked to a considerable extent on distillation, and the bromine absorption of the distillates would be very much higher than that of the original oil. Hence, the application of the results of bromine absorption determinations must be made with discrimination.

The following method of determining the "bromine absorption" of an oil is substantially that of Allen and Leffmann.* which is a modification of the process of Mills and Snodgrass. The carbon disulphide used must throughout be rendered anhydrous by keeping in it a few lumps of granulated calcium chloride.† A known weight of from 0·3 to 1·0 gramme of the oil is either directly weighed, or taken from a solution of known strength of the oil in carbon disulphide, in a dry stoppered separating funnel, and made up to about 75 c.c. with carbon disulphide. A solution of about decinormal strength is made by dissolving 2 c.c. of bromine in 750 c.c. of carbon disulphide, and 25 c.c. of this solution is run into the separating funnel, which is closed and shaken. If the mixture becomes colourless, further known volumes of the bromine solution must be added until the red coloration persists. The funnel is then kept in the dark for a quarter of an hour. An excess of aqueous solution of potassium iodide is then added, and the vessel is shaken, and its contents titrated with decinormal solution of sodium thiosulphate (made by dissolving 24·8 grammes of the crystallized thiosulphate in water and making up to a litre). The end of the reaction is best observed by adding a little starch solution. Next, an equal volume of the solution of

---

* *Commercial Organic Analysis*, vol. ii., part ii., 25 and 94.

† M'Ilhiney (*Journ. Amer. Chem. Soc.*, 1899, 1084) uses carbon tetrachloride in place of carbon disulphide and one-third normal solution of bromine, instead of decinormal. This and many other modified methods of determining the bromine absorption have been more usually applied to vegetable and animal oils, and have not been extensively tried on mineral oils. The same remark applies to the determination of the "iodine" absorption of oils.

bromine, to which potassium iodide is added in excess, is titrated with the sodium thiosulphate. The difference between the figures for the two titrations, expressed in cubic centimetres and multiplied by 0·008, gives the number of grammes of bromine absorbed by the hydrocarbons in the quantity of oil taken, and by calculation the number of grammes of bromine absorbed per 100 grammes of oil is found. It is well to work throughout by gaslight, and the period of fifteen minutes should be closely adhered to. Some other period—*e.g.*, thirty minutes—may be taken, but the same time must be adhered to in all cases where comparative values are required, as the extent of absorption generally increases with the time.

Shale oils generally have a high "bromine absorption," which decreases as the density and boiling point of the oil rise, while Pennsylvanian and Caucasian petroleums give relatively low values, though in the case of Caucasian distillates the results are much affected by the cracking which generally occurs during distillation. Cracking causes the "bromine absorption" to be high, owing to olefines and aromatic hydrocarbons having been formed from the naphthenes in the original oil. As the aromatic hydrocarbons are comparatively useless for gas making, a Caucasian or similar oil which has a high "bromine absorption" value will, as a rule, be an inferior gas oil.

The results of gas-making trials of typical gas oils are given at the close of this Section. With the exception of petroleum, few oils are worthy of consideration for gas making. The price of animal and vegetable oils is prohibitive; the only others available are the dead tar oils and blast-furnace oils. As tar is a product of destructive distillation at a high temperature, it is evident that it will not be greatly altered in character by exposure to a high heat, and the same observation applies in a less degree to blast-furnace oil. A considerable portion will merely volatilize and condense again unchanged on contact with a cool surface. The light benzene hydrocarbons will act thus, likewise naphthalene and other aromatic hydrocarbons. The dead oil from coal tar, which remains after the extraction of phenols and naphthalene from the middle oils of the tar distiller, contains a certain amount of gasifiable hydrocarbons, and is sometimes used for gas-making. A high heat is required to produce a permanent gas from it, and the illuminating power is always low. Coal tar "green" oil yields about 350 candles per gallon. Oil tar as deposited in the condensers and syphons of an oil-gas installation contains about a quarter of its volume of intermediate oil which, when separated by distillation and freed from naphthalene, may be put through the apparatus to produce gas. When, however, the oil has been properly treated in the oil-gas plant, this intermediate tar oil will give a yield of only about 300 candles per gallon, and the gas will be liable to deposit its illuminating constituents very readily.

Hirzel has proposed to take as a standard gas oil with which results from other oils may be readily compared, one which gives a yield of 60 cubic metres of gas per 100 kilogrammes of oil; the gas, at a consumption of 35 litres (1·236 cubic feet) per hour, having an illuminating power of 7·5 standard German candles. Expressed in English terms, such an oil would be one of which 1 ton would yield 21,530 cubic feet of gas, having an "illuminating power" of 31·86 candles. This gives 137,190 candles per ton, which is considerably lower than the value of most gas oils in use in this country. A standard of comparison for gas-making oils, such as Hirzel has proposed, would frequently be of service. Probably the best practical method of stating the value of a sample of oil for gas making is to give it in terms of some typical gas-making oil, such as, *e.g.*, a homogeneous Caucasian solar distillate having a specific gravity of 0·870, or a homogeneous Pennsylvanian distillate having a specific gravity of 0·830. Thus, if it is stated that a sample of oil, such as might be obtained from the Texan or Californian distilleries, would have only 85 per cent. of the gas-making value of the aforesaid Caucasian distillate, a prospective buyer is more truly informed of its value to him than by a statement that the oil is capable of yielding a certain number of "candles per gallon." The "candles per gallon" vary very greatly with the mode and temperature of gasification, or with the plant used and the skill of the gas maker. Thus, at one gas works the 0·870 Caucasian oil may be made to yield 1,600 candles per gallon (in a carburetted water-gas plant), and at another only 1,200 candles per gallon. Those in charge of either works would know what duty was to be expected, *under their own conditions of working*, from an oil which was stated to have only 75 per cent. of the gas-making value of the 0·870 Caucasian oil.

RESULTS OF THE EXAMINATION AND DISTILLATION OF A SAMPLE OF RUSSIAN GAS OIL.

The oil was of the class known as "Solar" distillate, and was of a clear, deep amber colour, with a green fluorescence. The specific gravity was 0·8705 at 60° F., and the oil flashed at 210° F. One litre (measured at 60° F.) of the oil was taken for distillation in a glass tubulated retort, the distillate being collected in fractions of 100 c.c. (10 per cent. of the volume of the oil). The flask used weighed 244·6 grammes.

No. of Fraction.	Approximate Volume.	Colour, &c., of Fraction.	Limits of Temperature between which the Fraction Distilled over.	Specific Gravity at 60° F. of Fraction.	Weight of Fraction.	Percentage by Weight on the Original Oil.
	c.c.		° C.		grms.	
I., ...	100	Clear, colourless; no water	126 to 242	0·8205	82·05	9·43
II., ...	,,	Clear, colourless	242 ,, 266	0·8490	84·90	9·75
III., ...	,,	,, ,,	266 ,, 285	0·8565	85·65	9·84
IV., ...	,,	,, ,,	285 ,, 297	0·8605	86·05	9·89
V., ...	,,	,, ,,	297 ,, 308	0·8655	86·55	9·94
VI., ...	,,	,, ,,	308 ,, 319	0·8705	87·05	10·00
VII., ...	,,	,, ,,	319 ,, 330	0·8755	87·55	10·06
VIII., ...	,,	Clear, tinted	330 ,, 346	0·8800	88·00	10·11
IX., ...	,,	Clear, pale straw	346 ,, 366	0·8870	88·70	10·19
X., ...	94	Clear, brown	366 ,, 395	0·9005	84·65	9·72
Solid Residue (see below),	...	...	...	...	2·70	0·31
Loss on Distillation = .	...	...	...	...	...	0·76
						100·00

The flask, after all the volatile matter had been expelled, weighed 247·3 grammes. Deducting from this the net weight of the empty flask, the weight of the residue is found to be 2·7 grammes. It was of the nature and appearance of a friable, porous coke. Sulphuretted hydrogen could be detected in the vapours of the 9th fraction, and was readily observed towards the close of the distillation.

RESULTS OF GAS-MAKING TRIALS OF VARIOUS OILS.

Description of Oil.	Its Specific Gravity at 60° F.	Volume of Gas made per Gallon of Oil. At 60° F. and 30 ins. Cubic Feet.	Average Illuminating Power, using the most appropriate Burner and rate of Consumption. Standard candles per cubic foot per hour.	Candles per Gallon of Oil.	Pounds of Sperm per Pound of Oil.	Mean Temperature of Retort.
Russian solar distillate,	0·873	81	12·65	1,025	2·01	Medium red heat (about 900° C.)
Russian solar distillate,	0·884	104	10·58	1,100	2·13	Bright red heat (about 1,000°C.)
Scotch shale oil,	0·855	91	13·24	1,205	2·41	Medium red heat (about 900° C.)
Scotch shale oil,	0·862	111	9·44	1,048	2·09	Bright red heat (about 1,000°C.)
American paraffin oil,	0·801	85	13·26	1,127	2·43	Dull red heat (about 780° C.)
American paraffin oil,	0·833	103	11·15	1,148	2·36	Medium red heat (about 900° C.)
Oil tar distillate,	0·987	65	4·25	276	0·48	Bright red heat (about 1,050°C.)

CARBURINE AND OTHER LIGHT OILS.

In the distillation of crude petroleum for the preparation of burning and lubricating oils, a certain amount of very volatile liquid is usually obtained in the early stages. This is kept apart from the burning oil, the flashing point of which it would lower unduly. At one time of very limited use as a solvent, &c., and frequently left to run to waste, or burnt beneath the stills, it is now extensively used for enriching poor gas or carburetting air. The most volatile fractions condensed from Pennsylvanian petroleum are known as **cymogene** and **rhigolene**; the former is only obtained by condensation in ice, and is stored with difficulty in air-tight vessels capable of resisting considerable pressure; the latter is the next higher fraction, and boils at about 14° C. These fractions are so difficult of transport on account of their extreme volatility that they do not find their way into the market for carburetting purposes. Practically the **carburine** which finds its way on to the market in such large quantities is a mixture of all the hydrocarbon distillate from Pennsylvanian petroleum which comes over under about 160° C., and is condensable by ordinary means. Besides some rhigolene or petroleum ether, it contains **gasolene** and **benzine**, as the next higher fractions are called. **Ligroin** and **petroleum spirit** are names given to the next higher distillates, and the carburine commonly used for gas enriching is made up of more or less of each of these products. **Petrol** or **motor spirit** is a similar mixture. The chief constituents of these light petroleum products are, as may be anticipated from their source, light paraffin hydrocarbons. Gasoline consists chiefly of pentane, with smaller amounts of butane and hexane. Carburine has a far larger proportion of hexane, and appreciable quantities of higher homologues. Gasoline boils at about 38° to 42° C., and carburine at from 60° to 75° C. The specific gravity of the carburine in general use varies from 0·675 to 0·685, averaging about 0·680, while that of gasoline averages 0·650. Petroleum spirit, having a specific gravity of about 0·700, and boiling at from 90° to 100° C., consists largely of heptanes. It is not sufficiently volatile for general use in cold carburetting, but under certain conditions has sometimes been successfully applied.

Mixtures of light unsaturated hydrocarbons do not appear to have been practically used for carburetting. The more volatile fractions of petroleum other than Pennsylvanian are now, however, sometimes sold as carburine or petroleum spirit in this country. Recently benzene, and more commonly one of the commercial mixtures known as 90 or 50 per cent. benzol, have been used as agents for cold carburetting. Until lately it was generally supposed that gas could not carry a sufficient volume of the vapour of benzene to render this hydrocarbon of use, but practical experience and theoretical considerations unite to demand recognition for it. Benzene boils at 80·5° C., and has a specific gravity of 0·885 at 15° C. 90 and 50 per cent. benzols contain toluene, which boils at 110° C., and has a specific gravity of 0·871 at 15° C. The xylenes are also present in commercial benzols in small quantity, as well as traces of non-aromatic carbon and some sulphur compounds. The benzene mixture most in favour for carburetting is "90 per cent. benzol," which contains about 70 per cent. of benzene and 25 per cent. of toluene (see Vol. II.). This mixture distils almost wholly between the temperatures of 82° and 112° C. Its specific gravity is generally from 0·882 to 0·885. Special grades of benzol, alleged to be peculiarly suitable for gas enrichment, are also on the market.

The lighter fractions of the "hydrocarbon" from the Pintsch and similar oil-gas compressing plants form a very good carburetting medium for coal gas. This hydrocarbon consists largely of benzene and toluene, with smaller quantities of unsaturated hydrocarbons (see Vol. II.). A distillate from oil-gas "hydrocarbon" has been expressly prepared for carburetting in the cold. The light oils deposited from carburetted water gas in holders and mains have a very similar composition to the oil-gas "hydrocarbon," and may also be successfully used to carburet coal gas.

It is evident that the number of substances practically available for carburetting is very limited, and their respective merits are easily determined. There is a limit to the amount of vapour of any hydrocarbon that a gas can hold at any given temperature, expressed by the vapour tension of the hydrocarbon at that temperature. Practically, therefore, the gas must afford the desired illuminating power when the vapour of the enriching hydrocarbon is not present in it to the saturation limit at any temperature to which the gas will probably be exposed. Prudence and experience both indicate that it is well to work with a very wide margin in this respect. At 32° F. the vapour tension of benzene is 25·3 mm. of mercury, which is equivalent to a percentage of 3·3 volumes of benzene vapour in gas at 760 mm. and that temperature. Gasoline (chiefly pentane) will mix with gas to the extent of 10·7 per cent. by volume, and carburine (hexane principally) to 8·0 per cent. by volume at 32° F. These materials have very different enriching values, according to their differing molecular composition, and at present their values are found empirically. They will be considered in the chapter on Enriching by Light Oils (p. 229) from a working standpoint. Some useful deductions, both from theoretical and practical data, are to be found in a paper by T. S. Lacey in the *Transactions of the Incorporated Institution of Gas Engineers* for 1892,* and in an article by Dr. H. Bunte in the *Journal für Gasbeleuchtung* in 1893, p. 442.† An exhaustive summary of the value of hydrocarbons of different series as illuminants, is to be found in the first of a series of articles dealing with the "Enrichment of Coal Gas," which appeared in the *Journal of Gas Lighting* in 1897. The articles run through the eight numbers of that paper from September 7 to October 26 inclusive, and constitute a good concise treatise on the enrichment of coal gas.

A material which is serviceable for enriching gas at temperatures above those of the atmosphere is naphthalene. Inasmuch, however, as this material, when condensed from the gas by exposure to lower temperatures, is deposited as a highly voluminous solid (unless liquid solvents are present) which obstructs pipes and vessels in which it is deposited; and, as it naturally occurs in coal gas, it becomes important to know the proportion of naphthalene vapour which gas can retain at low as well as at

---

* *Journ. of Gas Lighting*, lix., 903.

† Abstracted in *Journ. of Gas Lighting*, xlii., 717.

high temperatures. According to R. W. Allen's researches,* the vapour tension of naphthalene is as shown below, and the proportion of naphthalene vapour which gas can retain, calculated from the vapour tension, is also stated :—

Temperature.	Vapour Pressure.	Volume of Vapour retained by 100 Volumes of Gas.
Deg. Fahr.	Mm. of Mercury.	
32	0·022	0·0029
50	0·047	0·0062
59	0·062	0·0082
68	0·080	0·0105
86	0·135	0·0178
104	0·320	0·0421
140	1·830	0·2410
176	7·400	0·9740
212	18·500	2·4300

The application of naphthalene for enriching gas near the burners, under the Albo-carbon system, will be dealt with in the sequel to this volume.

---

* *Journ. Soc. Chem. Ind.*, 1900, 209.

CHAPTER II.

COAL GAS.

Retorts.—The ordinary gas manufactured in the gas works of England is made by the destructive distillation of coal in retorts externally heated. The dimensions, shape, position, and material of the retorts used have varied considerably since the early days of gas making, and even now the opinions of technical men are at variance on some of these points. In the matter of material there is now small latitude, fireclay of some description being invariably used. The iron retorts of the early days of gas manufacture are incapable of resisting the high heats at which it is now customary to carbonize coal, and the cost of renewals alone would be prohibitive. They are no longer found, except in small experimental works. Fireclay retorts are manufactured in many parts of the country, those from the Stourbridge district being specially well known. The shape and size of the retorts differ with the description of setting adopted. Where the retorts are set horizontally in works of moderate or large size they are usually about 20 feet in length, with a mouthpiece attached to each end. They are burnt in three (or sometimes four) portions, two of which have one of their ends provided with flanges for the reception of the mouthpieces, while the middle portion has flush ends for joining up to the outer sections in the setting. The customary cross-section of retorts is ⌓-shape, the flat side forming the bottom of the retort when set. But retorts of oval or even circular cross-section are often used. Circular retorts do not give such high results in gas made, though the oval-shaped retorts rank with the ⌓-shaped in this respect. The dimensions of the ⌓-shaped retort vary, but often are:—Extreme width internally, 20 inches; extreme height internally, 13 inches; thickness of walls, 3 inches; length, 20 feet—made up in three sections. Retorts having a cross-section 22 inches by 16 inches are, however, common in some large works. The flange for the mouthpiece is 4 inches thick, and extends 9 inches on the retort. In small works the retorts are usually only half the length of the above, and have one end closed. They are usually burnt with the ends open, and in one piece, the back being put on in the setting. They are adopted only where the number of stokers does not allow of charging from both ends simultaneously. Wherever this is possible, through 20-feet retorts are used, as they are more economical of heat and give less trouble in scurfing. Specially designed retorts are required when they are not set horizontally; these will be briefly noticed when inclined settings are considered. The retort mouthpieces are always of iron, and generally of the same cross-section as the retort, though occasionally they are made for a ⌓-shaped retort and a circular lid. The back of the mouthpiece carries a flange, by which it is bolted to the retort, with a packing of some suitable cement, often a mixture of fireclay and iron turnings. In the top of the mouthpiece is the socket for the lower end of the ascension pipe. The front of the mouthpiece is faced to receive the lid, which is likewise faced. Self-sealing retort lids are now universal, Morton's pattern being very largely adopted. Luting is unnecessary with self-sealing lids, and in Morton's design, with Holman's eccentric bolt fastener, manufactured by Tangyes, Limited, the lid is not removed from the mouthpiece on opening, but swings round on a hinged cross-bar. On closing the lid, turning the lever actuating the eccentric bolt forces the faced surfaces of lid and mouthpiece into air-tight contact. This design of mouthpiece and self-sealing lid is shown, for ⌓-shaped retorts, in Fig. 6. Various modifications of this lid, intended to avoid sagging and facilitate automatic sealing, have been introduced. The old-fashioned lid and mouthpiece had lugs projecting from the latter, to one of which the cross-bar was hinged, the other having a notch into which the free end of the cross-bar fitted. Through the middle of the cross-bar passed a

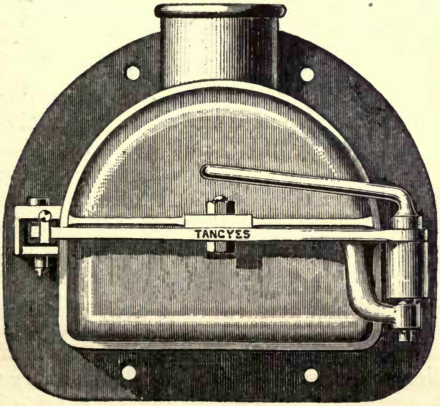


Fig. 6.—⌓-shaped mouthpiece, with Morton's self-sealing lid.

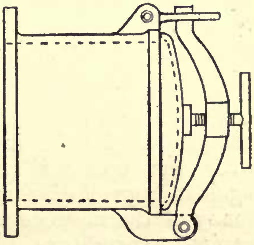


Fig. 7.—Mouthpiece and lid, old pattern.

screw actuated by a cross handle, to force the lid down on to the planed lip of the mouthpiece. These lids required the use of luting material to make a tight joint, and have now been almost entirely superseded by self-sealing ones. Fig. 7 shows this old style of mouthpiece and lid. Several patents have been taken out for self-sealing lids, but the simplicity and ease of working of Morton's pattern, described above, have brought it into very general use.

Mode of Setting Retorts.—The retorts are set in beds of from three to nine, or even twelve, heated by one furnace. In large works nine retorts are generally put in each bed, though sometimes the number is only seven or eight. The retorts are supported by the front walls of the ovens, and a number of transverse walls built in the oven. The number of these varies in different settings, but the retorts very commonly have throughout their length supporting walls about 2 feet apart. The dimensions and arrangement of the oven vary not only with the number of retorts in the bench, but also with the description of furnace adopted. Generator furnaces on the regenerative principle are now almost universally used, but the number of systems of applying it is legion. In some few works direct firing is still in use, but it is uneconomical of fuel. In others a compromise is made by using a shallow generator and admitting a small supply of secondary air. Regeneration has been frequently condemned on the score that the saving of fuel is insufficient to compensate for the increase in the initial cost of the settings over the cost of plain generator furnaces. This charge against regenerative settings was well founded in the case of many of the more complicated systems, which involved a large capital expenditure, but was not justified as far as those of reasonably simple construction were concerned. A simple arrangement of flues and air passages may involve a small sacrifice of efficiency over a more complicated design, but the loss is more than compensated for by the reduced cost of erection. Regenerative retort settings have formed the subject of innumerable patents and considerable litigation, but the more important patents have now expired, and the principles involved are common property. The alternating Siemens regenerative furnace was first tried, but the changing of the valves, though apparently a matter of ease, proved troublesome, and it was generally regarded as too complicated for economical working. The continuous system of recuperation as distinct from the alternating one of Siemens was applied by Laming to heating gas retorts with some measure of success. Sir W. Siemens then took up the Didier furnace, and it was largely used; Valon altered the Liegel somewhat, and it became well known as his

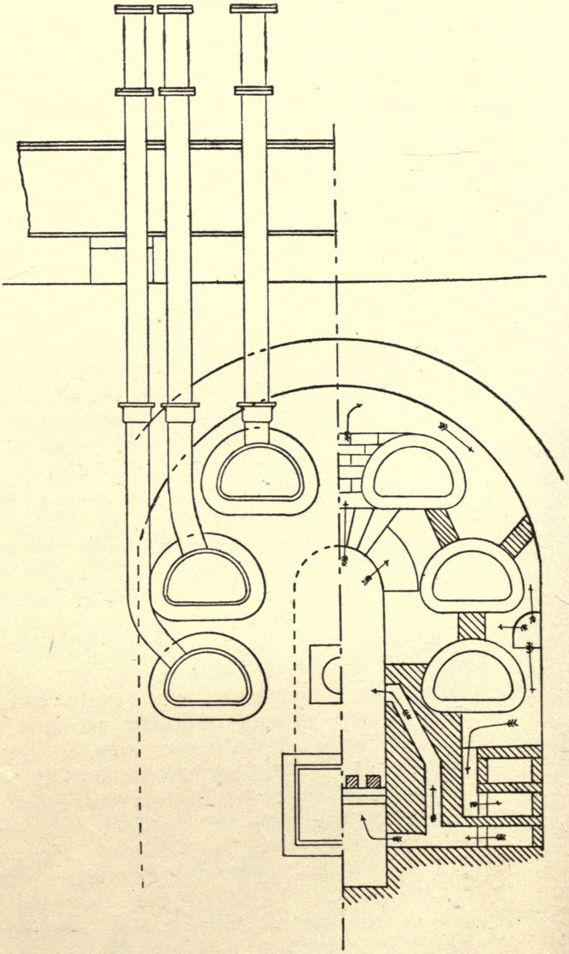
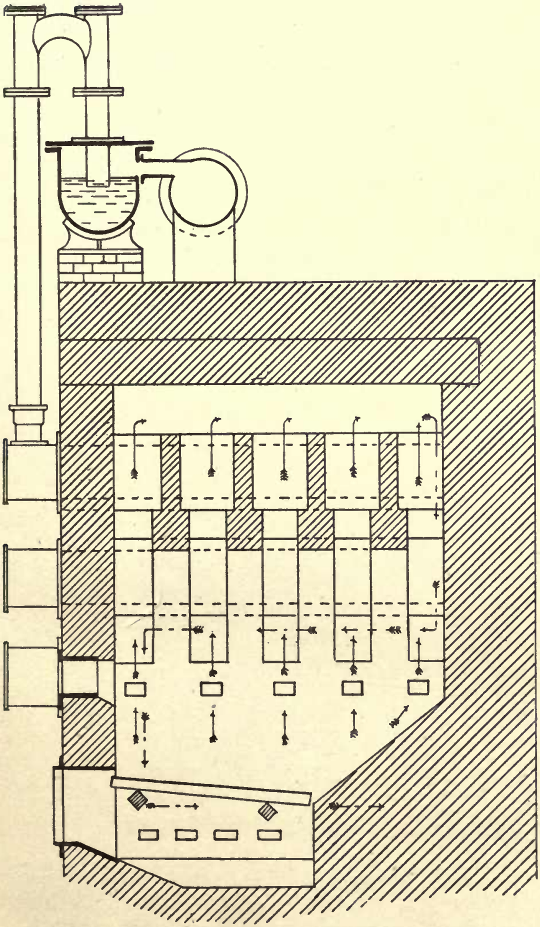


Fig. 8.—The



regenerative furnace.

own. Other furnaces of notoriety were the Schilling and Bunte and the Klönne. The regenerative furnaces in use in this country, though often not precisely on any one of the above-named systems, must in general be regarded as modifications of one or more of them. Those in which the generator is quite detached from the settings fell out of favour for a time, but are now being used again. The tendency, however, is still to have a separate furnace for each bed of retorts. The designs of the Klönne and Hasse-Didier, as well as of a furnace in use in some of the London works are shown in Figs. 8, 9, and 10 respectively.

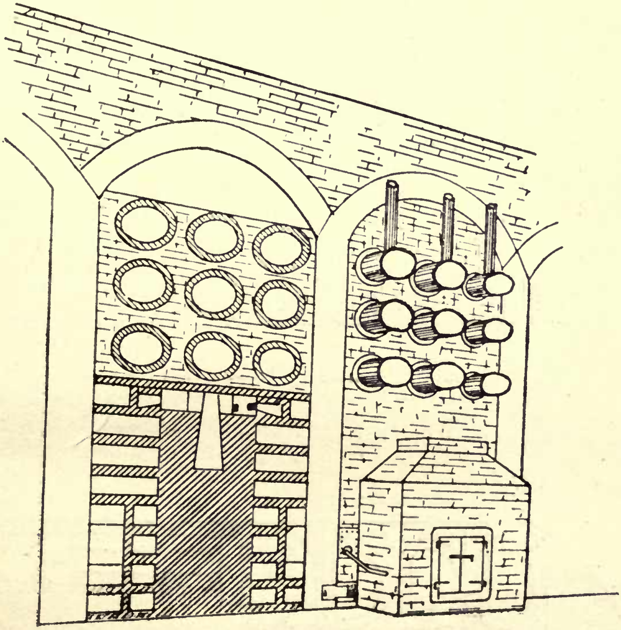


Fig. 9.—The Hasse-Didier regenerative furnace.

Hislop's regenerative setting is much used in some parts of this country.

Actions in the Retort Furnace Proper.—Coke is the fuel universally used in the retort furnaces, and the amount consumed, the composition of the producer gas, and temperature attained in the combustion chamber or setting are naturally affected by the quality of the coke—*i.e.*, by the proportion of carbon or other combustible matter in it. Hence a statement of the amount of coke consumed in carbonizing a ton of coal is of

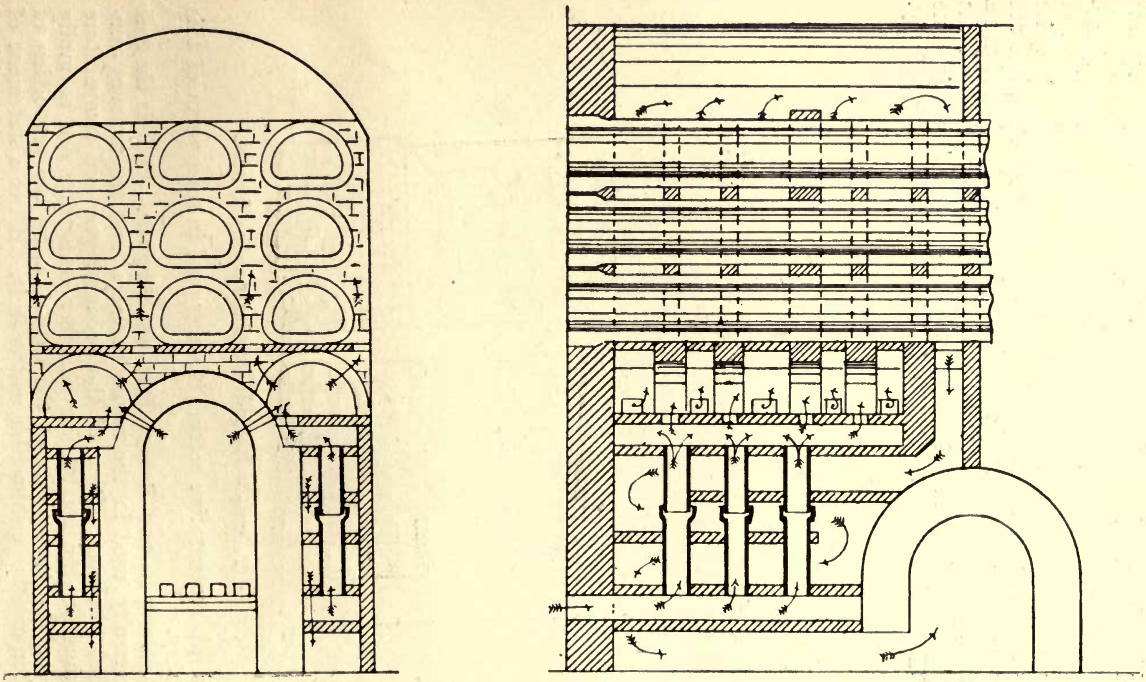


Fig. 10.—Furnace used in some London works.

little value as a measure of the efficiency of the furnace and setting, unless the quality or composition of the coke is also given. Generally the wisdom of using only coke of good quality in the retort furnaces is recognized, and it is a question only of constructing, and controlling the working of, the furnace and setting to the best advantage. The ultimate object of the combustion of the coke in the furnace is to impart to the coal undergoing carbonization as large a proportion as possible of the heat which perfect combustion of the coke would liberate, while a sufficiently high temperature for proper carbonization is consistently maintained. The maintenance of such a temperature is a *sine qua non*, and the fuel consumption or efficiency of the furnace must be subordinated thereto. It is implied herein that each and all the retorts in which the coal is carbonized are uniformly heated, so that all the coal is subjected to the proper carbonizing temperature.

It is comparatively easy to construct a furnace in which the consumption of coke will heat retorts to a sufficiently high temperature to carbonize coal contained in them, but it is somewhat difficult to ensure that that temperature shall prevail fairly uniformly throughout each of a number of retorts heated from the same furnace. Nevertheless, without sacrificing this essential of a good retort furnace, there is wide scope for the exercise of skill and knowledge in the construction and working of the furnace in order to secure as high a degree of efficiency, or, in other words, as low a consumption of coke per unit of coal carbonized, as possible. The consideration of certain general principles of combustion and heating will assist in forming useful conclusions as to the manner in which a high efficiency may be attained in a retort furnace.

Actions in Direct Combustion Furnaces.—When coke is directly burned on a grate below the retorts, and the flames and products of combustion play directly on the latter, the grate must be supplied with sufficient air to burn the carbon of the coke wholly to carbonic acid, as the heating value of any carbon which is burnt so that carbonic oxide is produced will be in large measure wasted, so far as the purpose of heating the retorts is concerned. Unit weight of carbon on combustion yields 8,080 units of heat (calories) when carbonic acid is formed, but only 2,473 units of heat when carbonic oxide is formed. Hence, in order to obtain in the furnace itself as high a temperature as possible by the combustion of the coke, sufficient air must be supplied to the furnace to provide the volume of oxygen required to form carbonic acid from the carbon of the coke consumed. One pound of carbon requires 29·86 cubic feet (at 0° C. and 760 mm.) of oxygen or 143·5 cubic feet of air for its combustion to carbonic acid, of which 29·86 cubic feet are formed, making, with the nitrogen, &c., of the air, 143·5 cubic feet as the total volume of products of combustion. The products of combustion of carbon, when it is burned wholly to carbonic acid without excess of air, should, therefore, contain 20·8 per cent. of carbonic acid. That, in fact, the products of combustion of coke in a retort furnace never do contain 20·8 per cent. of carbonic acid (and 79·2 per cent. of nitrogen, &c.) is due to several disturbing influences. The more important of these are the practical difficulty of supplying neither more nor less than the precise volume of air required for the combustion of the carbon of the coke to carbonic acid, and the presence in the air supplied of moisture derived mainly from the evaporation of water kept beneath the grate with the primary object of keeping the fire bars cool. There are other less important influences, such as the presence of other combustible bodies besides carbon in the coke.

With regard to the influence of the volume of air, if the volume supplied is less than is required for the combustion of the carbon wholly to carbonic acid, some carbonic oxide will be formed. One pound of carbon requires 14·93 cubic feet (at 0° C. and 760 mm.) of oxygen, or 71·75 cubic feet of air, for its combustion to carbonic oxide, of which 29·86 cubic feet are formed, making, with the nitrogen, &c., of the air, 86·7 cubic feet as the total volume of products of combustion. The products of combustion of carbon, when it is burned only to carbonic oxide, should therefore contain about 34·7 per cent. of carbonic oxide and 65·3 per cent. of nitrogen, &c. A mixture of this composition constitutes ideal producer gas, which will be referred to again shortly.

On the other hand, if the volume of air supplied to the furnace is greater than is required merely to supply the amount of oxygen which would convert the whole of the carbon to carbonic acid, the surplus air passes through the furnace to the chimney without affecting the nature of the products of combustion, which will consist of a mixture containing 20·8 per cent. of carbonic acid and 79·2 per cent. of nitrogen, &c., associated with the excess of air. But the surplus air acquires in its passage through the furnace to the chimney a high temperature by the absorption of heat which must ultimately have been derived from the combustion of the coke in the furnace. The heat so absorbed is wholly wasted, so far as the direct object of supplying heat to the coal undergoing carbonization is concerned, unless provision is made by a system of regeneration or recuperation for its more or less complete recovery. The products of combustion proper also necessarily leave the furnace and enter the chimney at a high temperature, acquired from heat ultimately derived from the combustion of the coke. This heat also may be more or less completely recovered by a system of regeneration or recuperation. In the first instance, however, the extent of the loss of heat in the chimney gases, or products of combustion, may be computed for the ordinary furnace, which is without any system of recuperation. Afterwards, the extent to which this loss can be diminished by the application of such a system will be considered, and the advantage which can accrue from that application will thus be seen. In the first instance also, it will be assumed that only the carbon of the coke comes into account, and that the air supplied is free from moisture.

Taking, first, the ideal conditions under which 1 lb. of carbon is burnt by means of 143·5 cubic feet of air, and the products are 29·9 cubic feet of carbonic acid and 113·6 cubic feet of nitrogen, &c. (in round figures). Now, the products of combustion issue from an ordinary retort furnace at a temperature of about 975° C., or about 1,800° F. To raise 1 cubic foot of nitrogen, oxygen, or carbonic oxide to this temperature requires about 9 calories, or 36 B.T.U., while 1 cubic foot of carbonic acid requires about 15·6 calories, or 62 B.T.U. Hence, the heat carried away by the products of combustion from 1 lb. of carbon under these conditions will be as follows :—

29·9 × 62, ... = 1,853·8 B.T.U.
113·6 × 36, ... = 4,089·6 ,,
Total, . . . = 5,943·4 ,,

Or, say, in round figures, 5,940 B.T.U. The combustion of 1 lb. of carbon to carbonic acid furnishes 3,665 calories, or about 14,550 B.T.U. Hence, of the heat furnished by the combustion of the carbon, $\frac{5,940 \times 100}{14,550}$, or nearly 41 per cent., is absorbed and carried out of the furnace by the products of combustion or chimney gases. Systems of recuperation aim at recovering as much as possible of this heat and returning it to the furnace.

The next point is—To what extent is the percentage absorbed by the chimney gases of the heat furnished by the combustion of the coke increased or diminished when the volume of air supplied is enlarged or reduced. The effect of a larger supply of air than ideal conditions involve may first be ascertained. The following tabular statement shows, for different amounts of air in excess of ideal requirements (column 1); (*a*) the normal volume of the products or chimney gases when 1 lb. of carbon is consumed to carbonic acid (column 2); (*b*) the heat (in B.T.U.) carried away by those products leaving the retort furnace at about 975° C., or 1,800° F. (column 3); and (*c*) the percentage which this heat is of the total heat furnished by the combustion of 1 lb. of carbon to carbonic acid (column 4):—

Direct Combustion Furnace—Surplus Air Supply.

1. Volumes of Air in Excess of Ideal Requirements for the Combustion of Carbon to Carbonic Acid, present in every 100 Volumes of Air supplied to the Furnace.	2. Volume (under Normal Conditions) of Chimney Gases from the Furnace per Pound of Carbon Consumed.	3. Heat carried by Chimney Gases leaving the Furnace at 975° C.	4. Ratio of Heat carried by Chimney Gases leaving Furnace at 975° C. to Heat furnished by the Combustion of the Carbon.
	Cubic Feet.	B.T.U.	Per cent.
0	143·5	5,940	40·8
1	145·0	5,995	41·2
2	146·4	6,050	41·6
3	147·9	6,100	41·9
4	149·5	6,160	42·3
5	151·0	6,215	42·7
7	154·3	6,330	43·5
10	159·4	6,515	44·8
12	163·1	6,645	45·7
15	168·8	6,855	47·1
20	179·4	7,235	49·7
25	191·3	7,665	52·7
30	205·0	8,155	56·1
35	220·8	8,725	60·0
40	239·2	9,385	64·5
45	260·9	10,170	70·0
50	287·0	11,110	76·3

It will be seen from the foregoing table that even a slight excess of air increases the proportion of the heat furnished by the fuel which is carried off by the chimney gases and is wasted unless recovered by a system of recuperation. Nevertheless, owing to the difficulty of securing uniform distribution of the air supply to the fuel, it is practically impossible to ensure that only carbonic acid is formed from the combustion of the carbon unless a marked excess of air is supplied to the furnace. It is usual to supply to direct combustion retort furnaces air in such quantity that fully 20 per cent. is in excess of the quantity which forms carbonic acid and water from the fuel. This means that 50 per cent. of the heating value of the fuel is carried from the furnace by the products of combustion or chimney gases (ignoring for the time being the fact that the latter contain water), whereas if ideal conditions of air supply and combustion could be practically maintained only 41 per cent. of the heating value of the fuel would be so carried off. An increase to nearly 50 per cent. in the heat carried off is, in practice, almost unavoidable, but care should be taken by limiting the air supply to the 20 per cent. excess that the 50 per cent. loss of heat is not exceeded. How great may be the proportion of the heating value of the fuel unnecessarily carried off by the chimney gases through air being supplied too freely to the furnace may be seen from the last two or three lines in the table. For instance, when 50 per cent. of the air supplied is excess, over 76 per cent. of the heating value of the carbon is carried away in the chimney gases.

The effect of diminishing the air supply below the volume which the maintenance of ideal conditions entails may next be ascertained. The following table shows the effect both on the heat developed by the combustion of 1 lb. of carbon (column 2) and on the proportion of the heat developed which is carried off by the products of combustion or chimney gases (column 6), when the air supply is thus diminished by the amounts indicated in column 1. In considering the figures in the table, it must be borne in mind that the chimney gases, in addition to carrying as sensible heat the amounts stated in column 5, also contain carbonic oxide, which is capable, on combustion with a further supply of air, of developing heat equivalent to the difference between the corresponding percentage in column 3 and 100.

DIRECT COMBUSTION FURNACE—INADEQUATE AIR SUPPLY.

1 Volumes of Air supplied stated in Percentages of the Volume required to form Carbonic Acid only from the Carbon of the Fuel.	2 Heat developed by the Combustion of 1 lb. of Carbon with Air Supply as stated.	3 Percentage which the Values in Column 2 represent of the Heat developed by the combustion of 1 lb. of Carbon to Carbonic Acid only.	4 Volume (under normal conditions) of the Chimney Gases from the Furnace per lb. of Carbon consumed with Air Supply as stated.	5 Heat carried by the Chimney Gases leaving the Furnace at 975° C. (Sensible Heat only).	6 Percentage which the Values in Column 5 represent of the Heat developed as shown in Column 2.
	B.T.U.		Cubic Feet.	B.T.U.	
100	14,550	100	143·5	5,940	40·85
99	14,345	98·6	142·4	5,885	41·04
97	13,940	95·8	140·1	5,773	41·42
95	13,535	93·1	137·8	5,660	41·82
90	12,525	86·1	132·2	5,380	42·94
85	11,515	79·2	126·5	5,095	44·24
80	10,505	72·2	120·8	4,815	45·81
75	9,500	65·3	115·1	4,530	47·71
70	8,490	58·4	109·4	4,250	50·06
60	6,470	44·5	98·0	3,685	56·96
50	4,450	30·6	86·7	3,120	70·12

Hence, combustion of carbon, wholly or partially to carbonic oxide instead of carbonic acid, entails loss of heat in two directions (unless the carbonic oxide is subsequently utilized instead of being discharged directly to the chimney)—viz., (1) the heat of combustion of the carbonic oxide, and (2) the increased proportion of the sensible heat of the chimney gases.

Thus, when the air supplied to the furnace amounts to 80 per cent. of the requisite volume for the formation of carbonic acid only from the carbon of the fuel, the loss of heat to the furnace will amount per pound of carbon consumed to (1) 4,040 B.T.U., representing the heat of combustion of the carbonic oxide which passes unconsumed from the furnace, and (2) 4,815 B.T.U., representing the sensible heat of the chimney gases. The total loss of heat is, therefore, 8,855 B.T.U., or nearly 61 per cent. of the heat which the carbon would develop if only carbonic acid were formed from it. But, as already seen, nearly 41 per cent. loss is unavoidable (unless recovered more or less by recuperation), and consequently the loss due to only 80 per cent. of the requisite air being supplied is 20 per cent. of the heat which the carbon is capable of developing. This percentage is greater by about 11 than when 20 per cent. of the air supplied to the furnace is in excess of ideal requirements, notwithstanding that the volume of chimney gases, and hence the heat carried by them, is very much less when the air supply is inadequate than when it is in excess. Similarly, it can be seen from the data in the two tables that the loss of heat to the furnace is always greater when the air supplied to the furnace is reduced by a given percentage than when the same percentage represents air in excess. Consequently, since it is practically impossible to supply exactly the proper amount of air uniformly to the fuel throughout the furnace, it is more economical to work with a slight excess of air than with a deficiency. This rule is generally accepted, but the foregoing tables and explanation indicate why it is a sound rule, and the extent to which deviations in either direction will affect the efficiency of a furnace.

Effects of Moisture in the Air Supply.—The effect of moisture in the air supplied to the furnace has also to be considered. The amount of moisture normally present in the atmosphere would not suffice to influence the course and products of combustion in the furnace to an appreciable extent, but actually the air supplied to the fuel picks up on its way through the ashpit and fire bars much more moisture from the water which is kept in the ashpan with the primary object of cooling the fire bars. This moisture is decomposed by the heated carbon of the fuel, with which it yields carbonic oxide and hydrogen. If the furnace is supplied, as it should be, with a slight excess of air, these gases are burnt, and yield carbonic acid and water (steam) respectively. The net result, in a direct combustion furnace, of the presence of moisture in the air supplied, is that the heat required to evaporate the water, and to raise the resultant steam to the temperature of the chimney gases, or products issuing from the furnace, is taken from the heat produced by the combustion of the carbon of the fuel. But moisture or steam in the air supplied to the furnace incidentally serves to cool the fire bars, to render the clinker less difficult of removal, and to transfer the development of heat from the fuel from the lower to the upper part of the furnace, thus facilitating the heating of the retorts. It should not be forgotten that it is in virtue of these indirect benefits derived from the moisture, that the addition of steam—generally produced merely by the evaporation of water with which the ashpan is kept filled—to the air supplied to a direct combustion furnace finds its justification. The benefits are rightly held to compensate for the loss by way of the chimney gases of a greater proportion of the heat evolved by the combustion of the carbon of the fuel than would occur if the air supply were free from moisture. That the proportion of the heat evolved carried away by the furnace gases is greater when moisture is present will be seen from the consideration of one case.

The amount of water evaporated from the ashpan of an ordinary retort furnace may be taken at about $\frac{2}{7}$ of the amount of coke, or $\frac{1}{3}$ of the amount of carbon, consumed in the furnace. Hence, for every pound of carbon consumed there is evaporated $\frac{1}{3}$ lb. of water. Now the heat required to convert $\frac{1}{3}$ lb. of water at 60° F. to steam at 212° F. is very nearly 373 B.T.U., or over $2\frac{1}{2}$ per cent. of the heat which the complete combustion of 1 lb. of carbon will liberate. This $2\frac{1}{2}$ per cent. is not practically recoverable, as no system of recuperation admits of the chimney gases being cooled below 212° F. But in direct combustion retort furnaces, the products of combustion leave the setting at about 975° C. or say 1,800° F., and to raise the steam from 212° F. to this temperature entails an expenditure of about 264 B.T.U. Hence, for every pound of carbon consumed in the furnace, $373 + 264 = 637$ B.T.U. are taken to raise the aqueous vapour in the air supplied to the furnace to the temperature at which the products of combustion leave it. This heat represents nearly 4·4 per cent. of the heat liberated by the complete combustion of 1 lb. of carbon in the furnace. Practically 1·4 per cent. might be recovered by a system of recuperation, but the remaining 3 per cent. (or theoretically 2·5 per cent.) could not be recovered. The 4·4 per cent. or thereabouts in the case of the ordinary furnace, or 3·0 per cent. or thereabouts if recuperation is practised, is the proportion of the heating value of the fuel which is diverted from the primary object of heating the retorts in order that the fire bars, &c., may be kept cool. It represents the cost of cooling the bars, &c.

The fact that the steam may be decomposed when it passes through the bed of red-hot fuel, forming, by interaction with the carbon, carbonic oxide, carbonic acid, and hydrogen, does not affect the foregoing conclusions as to its effect, provided there is some excess of air supplied to the furnace. It has already been indicated that, in proper working, the furnace should always be supplied with a slight excess of air. The combustible gases resulting from the interaction of the steam and carbon—viz., carbonic oxide and hydrogen—will, in presence of excess of air, be burned as they escape from the fuel bed, and form carbonic acid and aqueous vapour. The heat liberated by their combustion will exactly balance that expended in the decomposition of the steam, so that there will be neither a gain nor a loss of heat to the furnace from the chemical reactions involved in the decomposition of the steam and the subsequent combustion of the resultant combustible gases. There will be a transposition to some extent of the zone of most intense heat to a higher plane in the furnace or setting, and this may indirectly facilitate better heating of the retorts. That the decomposition of the steam and subsequent combustion of the gases formed do not affect the ultimate composition of the chimney gases may be seen from the following equations:—

(1) Assuming that the steam is decomposed in the furnace, we have:—

Initially.	Intermediately.	Finally.
Steam, . . Carbon of fuel, Atmospheric oxygen, .	$\left.\begin{matrix}H_2O\\C\end{matrix}\right\} = \left\{\begin{matrix}H_2 & = H_2O\\CO & = CO_2\end{matrix}\right.$ $O_2 = O_2$	Steam. Carbonic acid.

Or (2) assuming that the steam passes through the furnace undecomposed, we have:—

Initially.		Finally.
Steam, ...	$H_2O = H_2O$	Steam.
Carbon of fuel, . . Atmospheric oxygen, .	$\left.\begin{matrix}C\\O_2\end{matrix}\right\} = CO_2$	Carbonic acid.

These equations show that, starting with the same quantities of steam and reacting carbon, the same ultimate products result in the same quantities, whether the steam is assumed to be decomposed or not, provided there is the same excess of atmospheric oxygen present. Therefore, it is immaterial, so far as liberation or absorption of heat in the furnace is concerned, whether the steam interacts or no with the carbon. It is a fallacy to suppose, as is sometimes done, that in a direct combustion furnace the admixture with the air supply of steam increases the amount of heat liberated, because it is conceivable that the steam yields combustible gases in passing through the bed of fuel. Whatever heat is obtainable from the combustion of those gases has been previously derived from the fuel, and might equally well have been obtained without the intervention of the steam, while the presence of the steam entails, as already pointed out, a greater loss of heat to the system by way of the chimney gases. Nevertheless, the presence of steam is unavoidable owing to the considerations already set out, but, on the other hand, it is undesirable and uneconomical in true direct combustion furnaces to admit an excessive proportion of steam to the fire.

The case in which steam is admitted, while the air supply to a furnace is deficient, stands on a somewhat different footing; but it will suffice after what has already been said to state that the addition of steam in no way reduces the loss of heat or falling off in efficiency which has been shown to ensue in the absence of steam through a deficiency in the air supply. Investigation of the point will confirm this statement. Since, therefore, a deficient air supply means, in any case, loss of efficiency, it should invariably be guarded against in direct combustion furnaces.

Control of Direct Combustion Furnaces.—There are various means of ascertaining whether a direct combustion furnace is being operated in such a manner as to afford the highest degree of efficiency practically attainable. For the most part they depend directly or indirectly on a partial analysis of the products of combustion or chimney gases. The composition which these products should have under certain ideal conditions has already been indicated, and it is only necessary to give a typical analysis of the chimney gases when the furnace is being worked with such an excess of air and such a supply of steam as is customary under good practical working conditions. The chimney gases are, of course, analysed when cold, and hence the large proportion of aqueous vapour present when they leave the setting does not appear in the analysis. Their composition, in a typical case, will be in volumes per cent.:—Nitrogen, &c.,

79·2; carbonic acid, 16·5; oxygen, 4·3. It can readily be seen from this analysis that out of 100 volumes of air supplied to the furnace, very nearly 20·7 volumes were in excess of the amount utilized in the combustion of the carbon of the fuel. Reference to the first table shows that consequently the chimney gases have carried away 50 per cent. of the heat furnished by the combustion of the fuel, in addition to the heat (say 4½ per cent.) carried away by the steam originally present in the chimney gases. It has already been stated that a loss of nearly 50 per cent. of the heat by way of the chimney gases is practically almost unavoidable in direct combustion furnaces, but that it should not be exceeded. It will, however, readily be seen that this maximum permissible loss is being exceeded if in the chimney gases the percentage of oxygen exceeds 4·3, and the percentage of carbonic acid is less than 16·5. Hence, if the chimney gases are found to contain more than 4·3 per cent. of oxygen and less than 16·5 per cent. of carbonic acid, the air supply must be reduced until these limits are reached. The limits must not, however, be overpassed to any very great extent. Theoretically, no oxygen is essential in the chimney gases, but practically, for reasons already given, a small proportion of oxygen must be present, otherwise some of the carbon will have been burnt so as to yield carbonic oxide instead of carbonic acid, and there will thus be an avoidable loss of heat. Actually 1·0 per cent. of oxygen in the chimney gases is the *least* that should be allowed, and 2·0 per cent. is a safer minimum limit to work to with direct combustion furnaces.

The rule should be, therefore, to control the air supply to the furnace so that the chimney gases contain on the average from 2·0 to 4·3 per cent. of oxygen, and from 16·5 to, say, 19·0 per cent. of carbonic acid, and do not at any time show a very large departure either way from these limits. Fluctuations are unavoidable, owing to both the feeding and the clinkering of the furnace being carried out intermittently. The state of the fire naturally varies according to whether a short or long time has elapsed since fresh fuel was added to, and clinker removed from, the furnace. In default of means of automatically controlling the air supply, according to the fluctuations in the composition of the chimney gases, considerable divergence from the limits named cannot be avoided at times in practice; but the average composition from one time of feeding to the next, and from one time of clinkering to the next, should fall within the range stated, and the intervals should not be so long as to give rise to very great fluctuations.

The composition of the chimney gases is ascertained either by direct analysis, or inferentially from their density by means of

LIBRARY
OF THE
UNIVERSITY
OF
CALIFORNIA

special apparatus designed for the purpose. With regard to the analysis of chimney gases, it usually suffices for all practical purposes to determine only carbonic acid and oxygen. If oxygen is absent, or the volume of it present is less than about 1 per cent., there will probably be some carbonic oxide in the chimney gases; but for the purpose of controlling the working of the furnace it is superfluous to determine carbonic oxide, as the knowledge that the proper excess of oxygen is not present in the chimney gases is sufficient to indicate at once that the air supply is inadequate. As soon as the air supply is made adequate, as proved by the presence of 1 to 2 per cent. of oxygen in the chimney gases, carbonic oxide will no longer be found in appreciable amount in them. Hence, any gas analysis apparatus which admits of the rapid determination of (1) carbonic acid, and (2) oxygen, with an error not exceeding 1 per cent. in the case of the former, and 0·2 per cent. in the case of the latter constituent, should serve for analysing chimney gases for the purpose of controlling the working of a furnace. The Bunte burette is very commonly used for these analyses, and if manipulated with care, so as to avoid a large error from absorption of carbonic acid in the water used, it serves the purpose very well. It is, of course, better to use a simple apparatus in which the gas is measured over mercury, but a little more care is required in the use of such apparatus. The various types of gas analysis apparatus are described, and the necessary precautions in use are stated in Volume II. The sampling of chimney gases for analysis must be carried out by means of a pipe, of which one end is thrust through a hole into the chimney, and an aspirator. The pipe, which may be $\frac{1}{2}$ or $\frac{3}{4}$ inch iron gas pipe, or aluminium tube, is usually 3 to 4 feet in length, and is plugged at the end which is thrust into the flue. For a length of about 9 inches from this end, the pipe has a number of small perforations through which the gases are drawn. The opposite end of the pipe is connected to the sampling bottle, tube, or burette, and this again is connected to an aspirator, by means of which gas is drawn from the flue through the pipe into the sampling vessel. The pipe which enters the flue may, if results of a very high degree of accuracy are desired, be lined with fused quartz or platinum tubing, correspondingly perforated.

A very valuable study of the efficiency of an ordinary direct-fired furnace for heating a setting of seven retorts has been made by Euchêne, who gave his results in the course of an exhaustive treatise on the "Heat Exchanges in Coal Distillation," presented to the International Gas Congress at Paris in 1900.* The furnace consumed coke having the following

---

* *Journ. of Gas Lighting*, lxxvi., 1080 and 1141.

average composition in percentages :—Carbon, 81·5 ; ash, 10·0 ; moisture, 6·0 ; sulphur, 1·0 ; nitrogen, 1·0 ; and hydrogen, 0·5. The chimney gases resulting consisted, in volumes per cent., of nitrogen, 79·5 ; carbonic acid, 16·0 ; and oxygen, 4·5. Their temperature at the outlet of the furnace was 975° C., or, say, 1,800° F. The water evaporated from the ashpan amounted to $\frac{2}{7}$ of the weight of the coke consumed. The chimney gases carried off 56·5 per cent. of the heat liberated by the combustion of the coke, while 15·3 per cent. represented the loss of heat by radiation from the surfaces of the furnace and setting, and 0·9 per cent. was the loss of heat in the ashes. It will be seen, therefore, that between 25 and 30 per cent. only of the heat produced by the combustion of the coke in the direct-fired furnace is the maximum available for heating the retorts, their contents and products. How this proportion of the heat of the fuel burnt in the furnace is actually disposed of ultimately will be considered when the subject of the carbonization of coal is discussed. So far as the furnace is concerned, however, it is important to note that the *excess* of air supplied entailed in this instance a loss of $9\frac{3}{4}$ per cent. of the heat of combustion of the coke by way of the chimney gases, and that the water in the ashpan required 5 per cent. of the heat to evaporate it and raise the steam formed to the temperature of the chimney gases. The $9\frac{3}{4}$ per cent. loss due to the excess of air might in practice be slightly, but not greatly, reduced ; the loss by radiation and the expenditure on the evaporation of water are practically unavoidable, and could not be appreciably reduced. The great waste of heat, amounting in the whole to over 55 per cent. of the heating value of the fuel, which results from the escape of the chimney gases at the high temperature of 975° C. or 1,800° F., can be appreciably reduced only by recourse to a system of recuperation.

Before finally passing on, however, to discuss the application of recuperative arrangements, it may be worth while to point out that a small improvement in efficiency may be secured by a slight modification of the direct-fired furnace. This consists in limiting the supply of air through the grate, so that some of the carbon of the fuel yields carbonic oxide instead of carbonic acid. This carbonic oxide, and any other remaining combustible gas, is burnt above the bed of fuel by means of air admitted through holes in the furnace door or face of the setting. This second supply of air can be regulated more narrowly than can the air supply when the whole is admitted under the grate, so that practically the ultimate excess of air in the chimney gases may be reduced by over one-half its usual amount without risk of combustible gas escaping unconsumed. Actually so-called direct-fired retort furnaces are nowadays usually of this semi-producer type, and their forms gradually emerge into the producer or generator proper.

Producer for Retort Heating.—The producer or generator, which yields so-called producer gas, will be further discussed later, but for the present it will suffice to say that, so far as retort heating is concerned, it comprises a furnace chamber charged with coke to which the air supply is so restricted that the product of combustion of the carbon of the coke consists almost wholly of carbonic oxide, with as little as may be of carbonic acid. A producer aims at accomplishing as completely as possible what should be wholly avoided in the direct-heating furnace—viz., the production and preservation of carbonic oxide. The producer is a necessary part of an installation for the heating of retorts according to any recuperative or regenerative system, but it may be used independently of any system of recuperation. The gas formed from the carbon of the fuel in a producer which has a sufficiently restricted air supply, should, in the absence of moisture, consist of 34·7 per cent. (by volume) of carbonic oxide and 65·3 per cent. of nitrogen, &c. The requisite volume of air for the production of such ideal producer gas is exactly one-half of the volume required to form the ideal products of combustion or chimney gases in a direct-fired furnace, and reference to the table on a previous page (p. 75) will indicate that the heat developed in the producer in the formation of ideal producer gas is only 30·6 per cent. of that which should be developed from the same amount of fuel in a direct-combustion furnace. Hence it follows that 30·6 per cent. of the heating value of the carbon of the fuel is expended in the producer. A portion of this is lost by radiation from the walls, &c., of the producer, and the remainder is expended in raising the gas formed (*i.e.*, the producer gas) to the temperature of about 800° C. (1,470° F.) at which it issues from the producer. The percentage of the heating value of the carbon of the fuel which would be expended in raising the ideal producer gas to 800° C. would be 17·2, or about 2,500 B.T.U. per lb. of carbon consumed in the producer. Provided the conduit which conveys the producer gas from the producer to the furnace is short, and not subjected to abnormal cooling influences, the greater part of this 17 per cent., or thereabouts, of the heating value of the carbon of the fuel will be carried by the gas (as sensible heat) into the furnace and thus utilized. If, however, the producer stands at a distance from the setting, and the producer gas has to pass through a long conduit, in which it comes under cooling influences, or if the gas is stored for a short time in a gasholder before it reaches the furnace, this 17 per cent. of the heating value of the carbon of the fuel will be more or less completely lost. Hence it follows that some adequate compensating advantage in some other direction must be gained by the erection of the producer at a distance from the setting, or by the collection of the producer gas in a gasholder, if either of these plans is to be adopted in preference to placing the producer immediately beneath or adjoining the furnace. It is claimed, with reason, that such adequate advantage can be gained by these procedures. It will be referred to again shortly.

The effect of the presence of moisture in the air supplied to the producer is, however, important, and must be taken into consideration. The moisture, whether natural atmospheric humidity or derived from water in the ashpan, is raised to the temperature of the bed of fuel in the producer, and interacts wholly or partially with the hot carbon of the fuel. Whether the final products of the interaction are wholly hydrogen and carbonic oxide, and therefore wholly combustible, or whether they contain a large proportion of carbonic acid, which is incombustible, depends, as will be explained later, on the prevailing conditions—viz., the temperature of the bed of fuel and the ratio of the mass of water evaporated in a given time to the mass of interacting carbon, which ratio is practically conditioned by the areas of the grate and ashpan and the depth and temperature of the bed of fuel. The natural atmospheric humidity may in practice be ignored.

Now, the necessity for adequate cooling of the fire bars by the evaporated water entails in practice the introduction of so much steam to the bed of fuel in the producer that the temperature of that fuel is lowered below that required for the formation, from the interacting carbon and steam, of hydrogen and carbonic oxide only. The alternative reaction, resulting in the formation of hydrogen and carbonic acid, occurs usually to a preponderating extent, so that the production of carbonic oxide from steam is in practice almost suppressed in the producers of retort settings. For instance, the following particulars obtained by actual observation of the average performance of the producer of a Siemens recuperative retort setting, taken from the communication by Euchêne, already quoted, illustrate this point. The amount of water evaporated from the ashpan was 40 per cent. of the weight of coke, or 49 per cent. of the carbon consumed in the producer. But only 67·6 per cent. of this water reacted with the carbon of the fuel; the remaining 32·4 per cent. passed out of the producer as steam. Hence, water amounting to about 33 per cent. of the weight of carbon consumed interacted with the carbon (in addition to 6 per cent. of water in the coke = 7·35 per cent. on the carbon). The whole of this interacting water would react with from 0·135 lb. to 0·270 lb. out of every pound of carbon consumed in the producer. The amount of carbon reacting with the steam would be 0·135 lb. if the products were only hydrogen and carbonic acid, and 0·270 lb. if the products were wholly hydrogen and carbonic oxide. In the one case the steam will have yielded about 8 cubic feet of hydrogen and 4 cubic feet of carbonic acid, and in the other case the same volume of hydrogen and 8 cubic feet of carbonic oxide, per pound of carbon consumed in the producer. Now, the portion of each pound of carbon which is not required for interaction with the steam would yield either about 75 or 63½ cubic feet of ideal producer gas, according as one or other reaction took place between the steam and the other portion of the pound of carbon. The composition of the gas produced would be, in volumes per cent., approximately as follows:—

	If the *Steam* yielded Hydrogen and	
	1 Carbonic Acid but no Carbonic Oxide.	2 Carbonic Oxide but no Carbonic Acid.
Nitrogen, ...	56·6	52·4
Carbonic oxide, . .	29·6	37·6
Hydrogen, . . .	9·2	10·0
Carbonic acid, . . .	4·6	...

Now, Euchêne found the composition of the producer gas, when the steam decomposed in the producer bore the proportion to the carbon which gives by calculation the foregoing figures, to be as follows:—

Nitrogen, ...	61	per cent.
Carbonic oxide, ...	25	,,
Hydrogen, ...	8	,,
Carbonic acid, ...	6	,,

Obviously, these figures more nearly agree with those in column 1 than in column 2 of the calculated proportions. If we assume that about 9 per cent. of the carbon which combines with the oxygen of the air forms therewith carbonic acid (instead of carbonic oxide, as in the case of the formation of ideal producer gas) the composition of the gas formed in the producer, working under the conditions which prevailed in Euchêne's experiments, would, by calculation, be approximately as follows:—

Nitrogen, ...	58·7	per cent.
Carbonic oxide, ...	25·7	,,
Hydrogen, ...	8·7	,,
Carbonic acid, ...	6·9	,,

These figures are as nearly concordant with those actually found by Euchêne, on analysis of the gas issuing from the producer, as could be reasonably expected when the continually varying composition of the coke and gas is taken into consideration. It would, therefore, seem that Euchêne's researches support the assumption, which theoretical considerations warrant, that when the water evaporated from the ashpan in a given time exceeds in quantity that which the bed of fuel in the producer is capable of decomposing, the undecomposed steam abstracts heat from the fuel, while the decomposed steam yields practically no carbonic oxide, but only hydrogen and carbonic acid. Moreover, there is a further proportion of carbonic acid formed from the carbon of the fuel and the atmospheric oxygen. Admittedly, the gas liberated from the producer is less valuable the more carbonic acid it contains. If the producer, under the conditions investigated, could have been manipulated so that it yielded gas containing no carbonic acid (*vide* column 2 of the foregoing table), this gas would have had a calorific power of nearly 163 B.T.U. per cubic foot, whereas the gas actually made in the producer investigated by Euchêne had a calorific power of only 113 B.T.U. It is important, therefore, to see to what extent and by what means this deficiency in the heating value of the gas made can be reduced.

All undecomposed steam passing through a retort-heating system (producer, furnace, &c.) robs that system of heat, and thereby makes the prevailing temperatures lower than they would be in the absence of undecomposed steam. The temperature at which the spent gases escape into the chimney is a measure of the *net* loss to the system as a whole, but, if the spent gases traverse regenerative passages before escaping to the chimney, the loss of heat to the producer *per se* may (if recuperation is not applied to the primary as well as the secondary air supply) be greater than the *net* loss to the system. Hence the passage of steam, in excess of that which the fuel can decompose, through the system usually should be felt far more seriously in the producer than elsewhere in the system. The escape of undecomposed steam from the producer implies that heat has been abstracted by this steam from the bed of fuel, the temperature of which is thereby lowered. But a lowering of the temperature of the bed of fuel renders it less competent to decompose steam and form carbonic oxide rather than carbonic acid. Hence the undecomposed steam injures the working of the producer indirectly as well as directly. Every endeavour should, therefore, be made to avoid more steam traversing the bed of fuel than it can decompose, unless it can be shown that some very great collateral advantage accrues from the excess of steam. Now, the only advantages which can be reasonably claimed for a large inflow of steam to the ordinary producer are cooling of the fire bars and avoidance of hard clinker. The practical question, therefore, is whether these advantages cannot be secured to an adequate extent without the steam supply exceeding that which the bed of fuel is competent to decompose? Actually, it would appear that this question has not been satisfactorily investigated, but it may be assumed that the answer would be different for different types of producers and different descriptions of coke—much depending on the area of the grate relatively to the air and steam supply and on the temperature at which the ash of the coke fluxes. Nevertheless there is no doubt that it is very rarely that steam in excess of the quantity which will be decomposed is required to keep the fire bars adequately cool, and avoid clinker being formed to an obstructive extent. As a rule, large grate area and large cross-section of the producer favour low evaporation of water from the ash-pan relatively to the volume of air entering the producer.

But, while it is eminently desirable, for the efficiency of the producer, that no undecomposed steam should leave it, it is also desirable, for the production of gas of high calorific power, that as much steam should be supplied to the producer as the bed of fuel is competent to decompose. Now, the decomposition of steam entails an absorption of heat, which, in the case of a producer, must be furnished by the combustion of carbon by air. Hence, for a particular producer, given a uniform grade of coke, there must be a particular ratio between the steam and air supply at which the heat, which the combustion of carbon by the air affords, suffices to balance exactly the heat absorbed in the decomposition of the steam and the losses of heat through the effluent gas and by radiation, &c. This ratio, however, will vary with different producers, according to the proportion of the heat evolved by the combustion of the carbon which is lost by radiation, &c. The proportional loss by radiation will be less, speaking generally, with large producers.

The particular producer studied by Euchêne showed a loss by radiation (through walls, fire bars, and exit gas-conduit) equivalent to 5·7 per cent. of the heating value of the coke consumed, while the effluent producer gas carried off 22·3 per cent. Assuming that these losses would be substantially the same if the working of the producer were modified (a by no means warrantable assumption), it should be possible to calculate the ratio of steam to the air entering the producer, which will result in the heat evolved by the combustion of the carbon balancing that absorbed in the decomposition of the water. The result of the calculation would not be trustworthy, because the data assumed are not sufficiently well established, but, nevertheless, it might prove instructive. There is, on the one side, the heat removed by the effluent gas and by radiation, amounting to $5{\cdot}7 + 22{\cdot}3 = 28$ per cent. of the calorific power of the fuel *plus* the heat absorbed in the decomposition of steam ($= x$), and, on the other side, the heat liberated by the combustion of the carbon ($= y$), which must be regarded as yielding only carbonic oxide, since the object is to form ideal producer gas. Now, 1 lb. of carbon requires 71·75 cubic feet of air for its combustion to carbonic oxide, and furnishes thereby 4,450 B.T.U.

But 1 lb. of carbon consumed in the producer combines in part with the oxygen of the air supplied, and in part with the oxygen of the steam. Let a represent that fraction of each lb. of carbon which combines with the oxygen of the steam, then the steam decomposed will be $= \frac{3a}{2}$ lbs. One lb. of water requires for its decomposition by carbon a supply of 3,930 B.T.U., hence each lb. of carbon consumed in the producer must yield up, for the decomposition of water, $\frac{3a \times 3{,}930}{2} = 5{,}895\,a$ B.T.U. Further, there is only available for combination with the oxygen of the air supplied $(1 - a)$ lb. of carbon per lb. of carbon consumed in the producer. This amount will therefore only furnish $4{,}450\,(1 - a)$ B.T.U. But 28 per cent. of the total calorific power of 1 lb. of carbon (assuming that the calorific power of the coke is derived wholly from its carbon) is removed by the effluent gas and by radiation, as already stated. This is equivalent to $28 \times 145{\cdot}50 = 4{,}070$ B.T.U. Hence the heat balance for the producer, taking 1 lb. of carbon consumed therein as the unit, is as follows :—

$$4{,}450 - 4{,}450\,a = 4{,}070 + 5{,}895\,a,$$

and therefore

$$a = \frac{380}{10{,}345} = 0{\cdot}0367 \text{ lb.}$$

Hence the water decomposed

$$= \frac{3 \times 0{\cdot}0367}{2} = 0{\cdot}0551 \text{ lb.}$$

The volume of air admitted to the generator per lb. of carbon consumed will be—

$$71{\cdot}75\,(1 - a) = 71{\cdot}75 \times 0{\cdot}9633 = 69{\cdot}1 \text{ cubic feet.}$$

Consequently, for the particular producer under consideration, the ideal ratio of steam to air supplied to the fuel would be that for each lb. of water evaporated 1,250 cubic feet of air should be admitted to the producer. But since neither the air admitted nor the gas made can, in practice, be measured with any approach to precision, it is more convenient to state simply that the ideal ratio is represented by an evaporation of 0·055 lb. of water per lb. of carbon consumed, or a consumption of 18·15 lbs. of carbon per lb. of water evaporated. Actually, however, Euchêne found that, in practice, the water in the coke and that evaporated from the ashpan of his Siemens producer amounted to over 56 per cent. of the weight of carbon consumed in the producer. In other words, it was ten times more than the ideal amount required by the producer.

This conclusion, as already pointed out, must not be accepted as of general application or even as trustworthy for the particular case. But it indicates that the common practice is to evaporate an excessively large proportion of water in producer furnaces. So far as cooling the fire bars is concerned, the water in the coke itself is of very little service, yet it has to be evaporated by the expenditure of a part of the heating value of the fuel. It is more advantageous to evaporate water from the ashpan than from the coke itself, because the water in the first case is in a better position to exercise a cooling influence on the fire bars. Consequently, the coke used in producer furnaces should be as nearly free as possible from moisture.

Recuperation of Waste Heat.—It was pointed out in connection with the direct-fired retort furnace that, with a typical example of the same, as much as 41 per cent. of the heat evolved by the combustion of the fuel was carried out of the furnace by the products of combustion or chimney gases. In direct-fired furnaces, this large proportion of the total heat is usually wholly wasted, and it is the object of systems of recuperation to retrieve as much as may be of it. This object may be attained in two ways, which may be distinguished as the alternating and the continuous. By the alternating system the products of combustion from the furnace are led, before they pass into the chimney, alternately into one or other of two chambers or system of passages, usually packed with firebrick. The packing and linings absorb heat from the passing gases, which thus enter the chimney at a lower temperature than if no heat-absorption chamber is interposed between furnace and chimney. After the gases have passed through one chamber for a given period, the duration of which is such that the packing and lining are raised to a temperature not far short of that of the entering gases, a valve is moved, and the gases are thus diverted and caused to pass through the second heat-absorption chamber. At the same time another valve is opened, which allows air to pass through the heated chamber to the furnace. The air absorbs heat from the packings and linings of the chamber, and thus acquires a high temperature before it enters the furnace. After the lapse of the proper time, the functions of the two chambers are reversed by a shifting of the valves, so that, at given intervals, one chamber is alternately engaged in absorbing heat from the products of combustion and in giving up its absorbed heat to the air supplied to the furnace, while the other chamber is always engaged in performing whichever of these two functions is not being carried out in the first.

The continuous system of recuperation involves the use of an arrangement of two series of parallel or contiguous flues or conduits, separated only by a thin, but gas-tight, firebrick wall or partition. Through one set of flues the hot products of combustion pass on their way from the furnace to the chimney, while through the other set passes, usually in the reverse direction to the stream of hot gases, air on its way to the furnace for supporting the combustion of the fuel. The air acquires heat, through the partition or dividing wall, from the products of combustion, and reaches a high temperature before it enters the furnace, while the temperature of the products falls to a corresponding extent before they enter the chimney.

By either system, heat is transferred from the spent gases, as they are about to enter the chimney, to the air which is supplied to the furnace for supporting the combustion of the fuel, and is thus brought back to the furnace. The gain to the furnace may be very considerable, for the air supply must sooner or later be raised to the temperature of the furnace; and, if it is cold when it enters the latter, the whole of the heat required to bring it to the furnace-temperature must be derived from the combustion of fresh fuel. But, if it is hot when it enters the furnace—having been previously raised in temperature by absorption of heat from the products of combustion of fuel, of which the directly utilizable heat has already been exhausted—it follows that so much less fuel needs to be consumed in the furnace to raise it to the furnace-temperature. Exactly how much less depends broadly on the ratio of the difference between the temperature of the cold and hot air to the difference between the temperature of the cold air and of the furnace.

Now, observations by Euchêne on furnaces provided with a system of alternating recuperation indicate that, when the difference between the temperature of the cold air and of the outlet of the furnace is about 1,035° C., the difference between the temperature of the cold air and of the hot air may be (with this system of recuperators) about 540° C. Hence, about

$\frac{540}{1,035} = \frac{12}{23}$ of the total heat required to raise the air to the heat of the furnace is obtained or recovered from the chimney gases. On the other hand, the difference between the temperature of the cold air and the temperature at the outlet of a direct-fired furnace supplied with it was about 960° C., and the heat required to raise the air to this temperature must be wholly derived from the combustion of fresh fuel. The saving of fuel effected by the recuperative system is thus not only large, but there is a substantial rise in the average temperature of the furnace.

With regard to the different forms of setting for applying the recuperative principle to the heating of retorts and to the questions involved therein, it will be convenient to discuss the conditions of heating the retorts which should be aimed at. There are a number—usually from six to ten—of retorts disposed in two to four horizontal rows within the arch of the setting. Obviously the same work has to be carried out in all—the case, which sometimes occurs, of cannel being carbonized in one or two and common coal in the remaining retorts may for the moment be ignored—and hence any difference in the conditions of heating the several retorts indicates that they are not equally well fitted for performing their function. Broadly speaking, the aim is to have the retorts heated to as high a temperature as possible, but attempts to achieve this aim must be subordinated to the even more important object of securing a reasonably uniform (while high) temperature for all the retorts. Many troubles ensue when the retorts in a setting are heated to widely different temperatures, or when one portion of a retort is more highly heated than the rest. One of the great advantages of gaseous, as compared with direct, firing of a bed of retorts is that it affords facilities for more uniform heating of the retorts, especially if it is combined with preheating of the secondary air supply by means of recuperative arrangements. It is possible with direct firing to secure a high temperature locally, and so to heat one retort in the bed very highly, but there will almost invariably be a difference of nearly 400° C. between different parts of the retorts in the bed. On the other hand, a well-designed bed heated by gaseous fuel with hot air supply will not show more than 200° C. difference of temperature between such parts in the bed. But, if the design of the setting is bad, there may occur, with gaseous firing, even greater differences of temperature between different parts of the bed, and the work of carbonization will be injuriously affected, while the retorts will be rapidly destroyed through local overheating. Euchêne found that, in a direct-fired retort furnace, the temperature in the hottest part was about 1,375° C. and the products of combustion left the furnace at 975° C. Hence the heating duty of the furnace, as indicated by this drop in temperature, was about 24 per cent. In a regenerative setting, the highest temperature in the furnace was 1,250° C., and the products of combustion escaped at 1,050° C., showing a heating duty for the furnace of only 13·1 per cent. From the purely thermic standpoint, therefore, the direct-fired furnace shows a higher efficiency than the regenerative furnace, considered apart from its recuperative adjuncts, because a greater drop of temperature occurs in it. That is to say, a larger proportion of the heat liberated is directly taken out of the products of combustion and directly utilized in the direct-fired furnace. But this is a bad rather than a good feature when its effect on gas making is concerned, because it is achieved only by a great want of uniformity in the temperature in different parts of the setting. The smaller range of temperature observed by Euchêne in the furnace of the regenerative setting is far better for gas making, because, if the retorts in the setting are charged uniformly, as should be the case in ordinary working, the whole of each charge and all the charges will be equally well carbonized in a given time. The uniformity of temperature throughout the furnace observed by Euchêne is not necessarily found in all gaseous-fired settings, as a badly-designed regenerative setting may show a greater difference of temperature than a direct-fired one, but such uniformity cannot practically be attained in the case of the latter, and, if attained, it would be at an enormously increased expenditure of fuel, owing to the reduced thermic efficiency of the furnace *per se*. In the case of regenerative settings, the low thermic efficiency of the furnace is so counterbalanced by the recovery and return of heat in the recuperators that the thermic efficiency of the whole system—*i.e.*, generator, furnace, and recuperators—becomes considerably superior to that of a direct-fired setting, always assuming that the regenerative system is fundamentally well designed. It is the capacity of systems of regenerative firing to afford more uniform heating of the retorts, together with a reduced consumption of fuel, which justifies their adoption, and individual systems should be compared on the basis of their attainments in these directions and their initial cost and durability.

Euchêne showed that the Siemens alternating recuperative setting had a very high thermic efficiency as a whole, though, as already seen, the thermic efficiency of the furnace *per se* was considerably lower than that of a direct-fired setting. The products of combustion in traversing the recuperator fell from a temperature of 1,050° C. at the outlet of the furnace to an average of 600° C. at the outlet of the recuperator. Hence the total drop in temperature in furnace and recuperator was 1,250° - 600° = 650°, and the heating duty of the setting as a whole, as indicated by this drop in temperature, was 43·3 per cent. Hence the heating efficiency of the regenerative setting becomes nearly double that of the direct-fired setting.

Spent Gases.—The waste gases or products of combustion from the furnaces, after passing through the flues to impart a portion of their heat to the air supply, where the regenerative system is in use, pass into a main flue running throughout the length of the stack, and thence up a shaft terminating a short distance above the roof of the house. When complete combustion is not taking place in the furnaces, the carbonic oxide burns on coming in contact with the air at the top of the shaft, producing the flame too often observed there. This is a sure indication of improper working of the furnaces, and the supply of secondary air should be increased to ensure combustion of the whole of the carbonic oxide produced in the generator under the retorts.

It has been assumed that coke is the fuel used for heating the retorts, but in some works where direct firing is in vogue tar has partially replaced solid fuel for the purpose. It is either allowed to burn on an inclined plate on to the upper part of which it is dropped slowly, or it is injected through specially-constructed nozzles with air or steam. In most systems of burning liquid fuel used in this country, a small amount of inferior solid fuel, such as breeze, is burnt with it and forms a fuel bed. Where the state of the market favours the use of tar as fuel on the works, it is more often consumed under the boilers than in the retort furnaces. The lid of the generator is frequently so placed that the coke may be fed directly into it as the retorts are drawn, thus saving the loss of heat on quenching.

The **retort stack** is constructed of firebricks set in fireclay, or fire-resisting cement, in all parts adjacent to the furnace or hot-gas flues. Stourbridge and Dinas firebricks are in common use, but gas engineers are by no means united in opinion as to the best variety of brick for the purpose. The cements used differ considerably also in composition; some are intended for use alone, others require the addition of a certain proportion of lime before use.

The Welsh fireclays contain a much higher percentage of silica than those of Stourbridge and Newcastle; in the former it is from 93 to 97, in the latter two about 65·0.

Furnace-Bar Cooling.—A pan of water is always placed under the furnace bars, as already explained. The heat from the fire and from the falling cinders vaporizes the water, the steam passes up into the furnaces and is decomposed by the incandescent carbon, yielding the hydrogen found in the producer gas. The effect on the heating value of the gas, and on the efficiency of the furnace, has already been referred to. The steam passing through the furnace bars serves to keep the latter cool, and to moderate the effects the intense heat of the fire would otherwise have upon them. The water in the ashpan is renewed at the rate at which it vaporizes.

Charging and Drawing Horizontal Retorts.—The working or charging stage is situated about a foot below the level of the lower tier of retorts, and generally above the top door of the generator, which is then charged from the basement, though sometimes the lid of the generator is on the level of the stage and carried forward to admit of charging direct with the glowing coke from the retorts. Space is commonly left between the stage and the settings for the dropping of the coke, as it is drawn from the retorts, to the basement, where it is quenched and loaded into waggons. The stage is left clear for a width of 12 or 15 feet where the charging of the retorts is done by hand, and the space from that point to the walls of the house serves for the storage of coal. From this store of coal, running the whole length of the house on each side of it, the scoops and shovels for charging are filled. The coal is often shot in the house from hopper waggons traversing an elevated railroad. In charging by hand a scoop of semi-circular section, and in length half that of the through retort, is used. It is fitted with a T-handle, as shown in Fig. 11, and a piece of bar iron known as the saddle, shaped as in Fig. 12, is used for raising the opposite end of the scoop. The scoop is laid lengthwise on the stage and filled from the adjacent coal heap, the handle end is then raised by one stoker, the saddle is next placed under the opposite end of the scoop by two other stokers, who, one on each side, raise it to the mouth of the retort, when the saddle is withdrawn and the scoop is thrust in and overturned by the stoker in charge of the handle. It is then withdrawn, refilled, and again carried to the retort, being overturned on the opposite side of the retort to the former scoopful. Three or four shovelfuls of coal are then usually added and the retort closed. It will be seen by this description that three

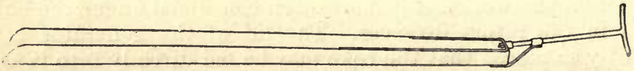


Fig. 11.—Scoop for hand-charging of retorts.

Fig. 12.—Saddle for raising scoop.

stokers are required to charge a mouthpiece with the scoop. The chief stoker who holds the handle and manipulates the scoop is known as the scoop-driver. Through retorts must be charged at both ends simultaneously, therefore they cannot be conveniently used with fewer than six stokers. The scoop holds about 1¼ or 1½ cwts. of coal, consequently about 3 cwts. constitute the charge per mouthpiece. The lid or lids of the retort are closed immediately the full charge is in it, and a period of from four to six hours elapses before the coke is drawn out. The time occupied in burning off the charge varies with the description of coal, the heat of the retort, and the quality of gas required. Five hours is a common allowance, though six is very general in the London gas works, where Durham coal is carbonized. With the latter time, and with high heats, practically no gas remains in the coke; but the average quality of the gas made is poor, and if ordinary bituminous coal is used the candle power is only 12 to 14. The gas thus made from Durham coal, when burnt at the rate of 5 cubic feet per hour in the London Argand burner, develops a light of about 14 candle power. Consequently enrichment must be cheap, or the regulations as to "illuminating power" not exacting, to make the thorough carbonization, which prolonged exposure to a high heat affords, remunerative. The amount of the difference between the pressure within the retort and the barometric pressure also exercises an important influence on the quality and quantity of the gas made from a given quantity of coal, mainly by reason of the effect produced on the interchange which occurs by diffusion between the coal gas within, and the fuel gas and air without, the retort. The difference of pressure usually depends on the depth to which the dip-pipe is sealed by the liquor in the hydraulic main, and the crude gas is more or less severely washed by the liquor according to the depth of this seal. The washing which the gas thus receives has a more marked direct effect on its composition and quality than has the pressure *per se* within the retort. At the expiration of the allotted time for the working off of the charge, one stoker loosens the lever on the lid of the retort, while a second holds with a pair of tongs a piece of red-hot coke to the edge of the lid to ignite the gas remaining in the retort as the lid opens. The gas then burns away quietly, whereas if the lid is thrown open suddenly cold air rushes in, and combines with the contained gas with explosive violence, thereby shaking the settings. The noise of the explosion renders carelessness in opening the retorts easy of detection. The coke is withdrawn from the retort by means of a long-handled rake; in the case of through retorts half is drawn from each end. A piece of sheet-iron called a "fender," fixed to a suitable framing, is placed at the edge of the charging stage to prevent the coke scattering on to the latter, and to direct it downwards, either to the basement of the house, where it is quenched as rapidly as possible by directing water from a hose on to it, or to a conveying trough containing water for quenching, and traversing the stage longitudinally a short distance in front of the bench of retorts. It is kept in the basement for firing the generators, or loaded into waggons or on to a conveyor for conveyance to the coke store. In some few instances the lids of the generators are on the level of the charging stage, and the firing is done with the hot coke as it is drawn from the retort. The retorts should be charged again as soon as possible after drawing.

Exit Pipes.—The upper part of the mouthpiece has a socket for the reception of the lower end of the ascension pipe, which forms the means of exit for the gas from the retort. The ascension pipe is usually 5 inches in diameter internally, and is straight or bent, according to the position of the retort in the setting. At its upper end it joins the bridge pipe, which is of the same diameter, and runs horizontally for about 2 feet towards the middle of the stack. Here it joins the dip pipe, running vertically downwards into the hydraulic main, which runs the whole length of the stack. The bridge pipe often is in the shape of an inverted V, and the tops of the ascension and dip pipes project above the junctions with the bridge pipes, and have the ends closed by plugs, which can be removed for cleaning purposes should the pipes become badly blocked. The ascension pipe, the bridge and dip pipes, and the hydraulic main, in section, are shown in Fig. 13.

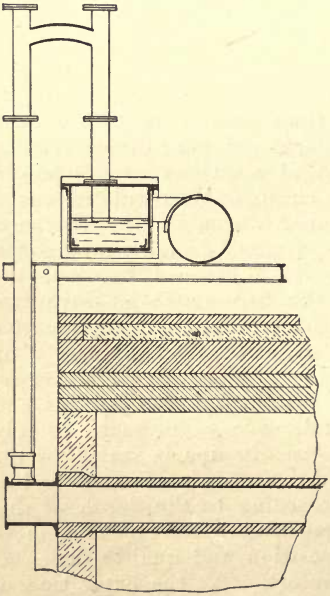


Fig. 13.—Sectional view of ascension pipe, bridge and dip pipes, and hydraulic main.

Hydraulic Main.—The hydraulic main is usually square or oblong in cross-section, and is now generally constructed of mild-steel plates. Cast-iron hydraulic mains were at one time common, but they were extremely heavy, and liable to crack on sudden changes in temperature. The main runs along the top of the retort bench, and receives the dip pipes, which are sealed by the liquid in the bottom of the main. This consists of tar and ammoniacal liquor deposited from gas that has previously passed through. The depth of seal commonly adopted is about ¾ inch, though frequently it is greater. The layer of liquor floating above the tar should be sufficiently deep to maintain the requisite seal, as contact of the gas with tar is deleterious to the quality of the former. Several ingenious devices for drawing off the tar to a uniform level, and maintaining a constant depth of liquor seal, are in use. In this country it is very common to divide the hydraulic main into several sections, each with an outlet for the gas, which passes into a large main running the whole length of the house, at the back of the hydraulic main, known as the foul main. This arrangement presents considerable advantages when some sections only of the house are at work, or when repairs are necessary to some portion of the hydraulic main. Many mechanical devices, known as "anti-dips," for taking the place of the water seal of the hydraulic main have been proposed, and some have been extensively adopted.

Condensers.—From the foul main the gas passes to the condensing plant, which is often a system of pipes situated outside the retort house. In some cases, however, the pipes have been carried round the walls of the house, so as to avoid a sudden lowering in temperature of the gas. In the more common plan the condensers are placed at a short distance from the retort house, though, even in this matter, instances may be adduced in which the gas traverses several hundred yards of main between the house and the condenser. The main is usually laid beneath the ground, so that no large amount of condensation takes place in it. A form of condenser much favoured in this country is a system of nearly horizontal pipes, exposed to the air, and in hot weather cooled by water sprayed on to them. The main bringing the gas from the retort house enters a short cross main, to which from two to twelve condensing pipes of 6 to 12 inches diameter (the number and size being proportioned to the make of gas) are connected. These pipes run side by side, slightly inclined to the horizontal, and are commonly from 50 to 80 feet in length. The gas passes along these pipes, and thence along a similar series of pipes ranged beneath the former. From these it passes along another similar series beneath the last; an ordinary condenser will have from eight to twelve rows of pipes so arranged—one beneath the other. A slight inclination is given to all the pipes, so that the condensed matters may run to the outlet at the lower end of the condensing pipes. All the pipes in the bottom row lead into a cross main, the outlet of which goes to the exhauster or washers. The gas entering the condenser passes the whole length of it as many times as there are pipes in each vertical row; the number of pipes side by side being so fixed as to enable them to pass the whole of the gas at a slow rate in sufficiently small streams to expose it freely to the inner surfaces of the pipes, the outer surfaces of which are in contact with the air. A view of this type of condenser is given in Fig. 14.

It is evident that this and indeed all atmospheric condensers are efficient in proportion to the superficies of the pipes, and, consequently, these should be of as small diameter as is consistent with working with freedom from stoppages from accumulations of tar. About 6 inches internal diameter has been found to answer this requirement in large works. The total length of pipe through which each stream of gas should pass is largely determined by its rate of flow. At the temperatures prevailing in this country, and with water sprayed on to the condenser in summer, from 150 to 200 square feet of condensing surface will usually be allowed for each thousand cubic feet of gas passing per hour. The calculations should be based on the maximum make of gas. The hot gas entering the top pipes first, and gradually becoming cooler as it descends, induces currents of air to pass

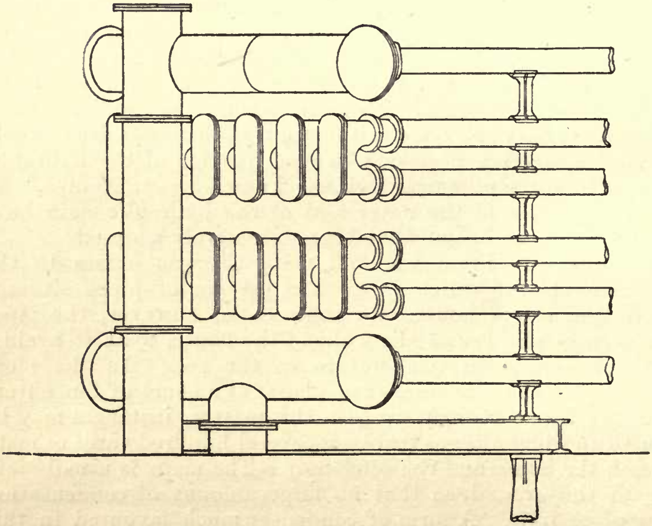


Fig. 14.—End view of horizontal condenser.

upwards among the condensing pipes, and the lower pipes which the gas enters after parting with much of its heat are continually surrounded by air at the atmospheric temperature. Strangely enough, a recently erected condenser in a large works has the course of the gas reversed—*i.e.*, the gas enters the lowest tier of pipes first. Some other instances of this arrangement may also be found. In old works vertical atmospheric condensers are frequently still found, but they are less efficient than the horizontal form. They consist of a number of pipes, 20 to 30 feet long, placed vertically side by side. The gas passes up one pipe and down the next throughout the series. The condensed matters pass out at the lower ends of the pipes into a cistern, small partitions sealed by the liquor directing the course of the gas in the cistern, unless a separate cistern is attached to each pair of pipes. Some forms of vertical condensers have a sprinkler at the top, by means of which water or weak gas liquor is sprayed into the gas space, which may be more or less filled with a cellular packing in order to favour intimate contact of the gas and liquid. This attempt to combine the functions of the condenser and the scrubber in one apparatus usually gives very unsatisfactory results. The liquor produced cannot attain a high ammoniacal strength because it leaves the apparatus at a comparatively high temperature, while the gas at the exit is supersaturated with naphthalene and other constituents of tar, which either do not condense at all to liquids, or only with difficulty. These "condensers" in which the gas is brought in direct contact, while hot, with water or weak liquor, stand on quite a different footing from those in which water, either partially or wholly, replaces the air in an atmospheric condenser as the condensing medium. The latter type of condenser depends on the application of sound principles, and it is only inferior to the horizontal atmospheric condenser of ample size in cases where the object is to prevent any greater loss of "illuminating power" than is absolutely unavoidable. Where it is of no moment whether the gas is one-tenth or thereabouts of a candle-power lower than it might be with good atmospheric condensers, the use of water-cooled condensers will be advantageous. There are various patterns; for instance, a horizontal condenser has been immersed in water, which is withdrawn and replaced continuously; or, as in Cutler's pattern, small tubes pass throughout the interior of the condensing chambers, and convey a stream of water in the opposite direction to that of the current of gas. These devices are growing in favour, especially where space is limited. It must be borne in mind, however, that coal gas condensers have not generally been designed to effect as rapid a cooling of the gas as possible, but rather to bring the gas to the atmospheric temperature by easy gradations. The chief reason for this at first sight unscientific and uneconomical procedure is to favour the retention in the gas of minute quantities of highly volatile hydrocarbons, which contribute to the "illuminating power" of the gas to a perceptible extent.

Exhausters.—In most works the gas passes from the condenser to the inlet of an exhauster. The exhauster is designed to draw the gas from the hydraulic main and condensers, and so to reduce the pressure both within these and also in the retorts. It also serves as a pump to force the gas through the washing and purifying apparatus to the holder. Several types of exhauster have been proposed, but those in most general use at the present day are based on Beale's design, which is similar to that of a rotary engine produced by Ramella in 1588. This has undergone many modifications to adapt it especially for use as a gas exhauster. As now usually made, it consists of a cylinder with closed ends set with its axis horizontal, and having inlet and outlet gas ports on the opposite sides of its lower half. Within this is a smaller cylinder set eccentrically to the outer one, and with its outer surface in contact with the interior surface of the larger cylinder at its lowest point. On a pivot fixed in the axis of the outer cylinder revolves a block, sliding within guides attached to two blades which extend to the inner surface of the outer cylinder. A steam engine, generally horizontal, is commonly used to turn the exhauster; the slides forcing the gas from one side, where the inlet is, to the other side of the cylinder, where the outlet port is situated. The axle bearings are outside the cylinder. A section of this pattern of exhauster, as made by

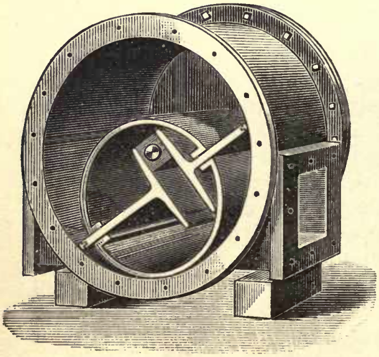


Fig. 15.—Beale's gas exhauster, patented in 1877.

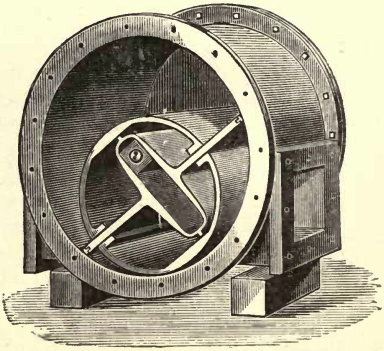


Fig. 16.—Donkin's improved Beale's gas exhauster, patented in 1892.

Messrs. Bryan Donkin & Co., in accordance with Beale's 1877 patent, is given in Fig. 15. An improved form, in which the capacity of the inner cylinder is also utilized for pumping, was patented in 1892, and described by E. Bryan Donkin in his paper, read before the Incorporated Gas Institute in 1893. He claims for this that, in addition to possessing increased capacity, it steadies the flow of gas, and does away with the pulsations of the ordinary exhauster. The pulsating action of the common pattern may be neutralized by using two exhausters, revolving with the slides at right angles to one another, or by passing back some of the gas from the outlet to the inlet pipe to equalize the pressure, but the uneconomical nature of the latter plan is condemnatory. For most purposes on a gas works the pulsating action of the exhauster is not of great importance. Donkin's improved form of Beale's exhauster, patented in 1892, and made by Messrs. Bryan Donkin & Co., Ltd., is shown in Fig. 16. In other forms of the rotary exhauster there are two slides partially overlapping, and guided, to maintain contact with the surface of the outer cylinder, by segments running in grooves in the end plates of the exhauster. Exhausters in which toothed wheels geared together revolve on parallel axes in a casing have been used, as also have fans, for pumping gas, but practically these have been superseded by Beale's pattern. The lubrication of exhausters working immediately after the condensers is almost sufficiently effected by the tar deposited from the gas, but this may be supplemented by the introduction of tar oil when necessary. Exhausters pumping clean gas are best lubricated by a good machine oil free from sulphur impurities and perfectly fluid at low temperatures. Rotary exhausters are sometimes driven by a gas engine instead of the more usual steam engine.

An exhauster has been devised by Cleland, in which high-pressure steam is projected through a series of inverted truncated cones increasing in size progressively, and slightly overlapping. The gas is drawn in at the spaces left between the segments, and is carried on by the steam. The latter is afterwards removed by condensation. This pattern, as made by Körting Brothers, has been used on the Continent. Reciprocating exhausters, of which many have been devised, are less steady in action than rotary, and have given place to the latter except in a few instances.

Inclined Retorts.—The carbonization of coal for the production of gas has hitherto been considered to take place in retorts set horizontally in a furnace and charged and drawn by manual labour. This method of carbonizing was until comparatively recently the only one in vogue, and even now is probably the most common. But mechanical means for charging and drawing horizontal retorts have come into common use during the past twenty years, and the plan of setting the retorts at an angle of 30° to 36° to the horizontal has also been very largely followed. The last-named plan may be said to date in this country from the application of M. Coze, of Rheims, for letters patent, which were granted to him in 1885, for a retort setting in which the retorts were set at such an angle that the coal entering at the upper end would naturally rest in an even layer on the bottom of each retort. The coke which remained in the retort when the charge had been worked off was removed through the lower end of the retort with comparative ease owing to the inclination of the bottom on which it rested. The original arrangement of M. Coze has since undergone considerable modification, and has been supplemented by various mechanical devices for bringing the coal to the mouths of the retorts and for facilitating the withdrawal and removal of the coke. Thus modified and improved in the light of the practical experience of M. Coze and many other gas engineers who adopted the system in the first instance experimentally, settings of inclined retorts are now in very extensive use in many gas works in this country, and almost to the exclusion of settings of horizontal retorts in several large Austrian and other continental works. It will therefore be appropriate to refer briefly to the principal characteristics of the arrangement as now commonly carried out. Usually in this country the retorts are about 15 feet in length and ⌓-shaped, and are set at angles varying from 29° to 36° to the horizontal. They are generally arranged in two benches about 30 feet apart, the retorts sloping downwards to the stage between the benches. They are charged from elevated stages at the sides of the house, the coal being allowed to run into the retort from a hopper. Various mechanical contrivances for conveying the coal to the hoppers and transferring it thence to the retorts have been tried with more or less success. The difficulties of charging are not great if the retorts are set at the correct angle for the particular coal in use. The angle of repose of coal in a fireclay retort varies somewhat with the nature and degree of fineness of the coal. The smaller the pieces of coal the greater the angle of inclination to the horizontal at which they will rest. The actual angle of repose of coal on fireclay is not generally greater than 29°, but since the coal is stopped at the lower mouthpiece of the retort, it will bank up and form an even layer on the bottom of a retort at as great an angle as 36° Practically, it is advantageous to set inclined retorts at about 32°, as most descriptions of coal can be satisfactorily charged into the retort at that angle, and the coke falls out with readiness. At a less angle the coke does not automatically fall out when the lower lid of the retort is opened, and the layer is gently pulled with a rake. The proper angle at which inclined retorts should be set has been vigorously discussed, but the consensus of opinion now favours one of about 32°. In some settings the retorts of the lower tier are set at a smaller angle than those of the upper. A levelling-plate has been used for spreading the coal evenly in the retort, but the heat to which it is subjected quickly renders it pliable and useless, until cooled, and it has been generally discarded.

In the arrangement of benches mentioned above, the charging stages running alongside the outer walls of the retort house should be about 15 feet in width. This scheme does not greatly reduce the dimensions of a retort house as hitherto designed for horizontal retorts, except in so far as mechanical coal-conveying devices, readily applicable to the inclined retort system, permit the abolition of extensive bays for the storage of coal at the back of the charging stage. The scheme also demands a retort house with lofty outer walls. It has, therefore, been found convenient in many cases to reverse the position of the benches of retorts, and to make one central charging stage 25 to 30 feet in width, and two drawing stages alongside the walls, each about 20 feet in width. This arrangement is economical in that it reduces the necessary height of the retort house, as it is merely essential that the roof should be about 8 feet clear of the bridge pipes, and there will be ample room for the conveying machinery and coal hoppers above the charging stage. Where the available land and capital are limited, a light roof may be supported on iron columns set against the outer faces of the benches, and the customary close brick walls then become unnecessary. The coke from the retorts then falls outside the house. This plan of construction, which has been adopted at one of the Imperial Continental Gas Association's works at Vienna, is very economical. It is advisable to provide on the central charging stage screens which the stokers may shift as required, to protect themselves from the intense heat radiated from the benches. The flues in the settings should be arranged so that the lower ends of the retorts are somewhat hotter than the upper. It is necessary that the coal be stopped before it reaches the lid of the lower mouthpiece, and various stops have been tried. A pattern which has given satisfaction consists of a flat bar or sheet of iron, held in position by a stay which fits in a hollow in the lower mouthpiece. Many other stops are, however, in use. Retorts increasing in width gradually towards the lower end have been used to facilitate the discharge of the coke. Where the retorts slope towards the middle of the house, the coke can readily be run into trucks or to a conveyor passing through it, and the same means of removing the coke can be adopted though less advantageously when the retorts are otherwise disposed. The furnaces are generally charged from the front of the bench, and may be merely modifications of ordinary regenerative or simple settings. The original Coze setting has been largely used on the Continent and has given satisfaction. The ascension pipe to inclined retorts is usually from the lower mouthpiece, and is less subject to stoppages than with horizontal retorts. It is asserted that the make of tar is somewhat lower than with horizontal retorts, and this points to a greater production of gas. When the retorts are properly heated no accumulation of tar should take place at the lower mouthpiece. The cost of erecting inclined settings is considerably greater than that of erecting settings for horizontal retorts; but comparatively simple charging machinery for sloping retorts enables them to be worked with greatly diminished labour compared with the hand charging of the horizontal variety. The settings occupy less ground space than those for horizontal retorts for the same make of gas. The most palpable disadvantages of the system are the liability of the retorts to drop in the middle, and subsequently to crack, unless the supporting walls are more numerous and substantial than are customary for the same length of horizontal retort, and the need for a very thick front to the setting to withstand the thrust of the retorts. The heat on the charging stages is most oppressive unless the house is very liberally ventilated, and this is still more noticeable when the arrangement first mentioned is reversed, and the charging stage is in the middle of the house and serves for the two benches of retorts, which slope downwards towards the walls of the house. Of course further difficulties supervene if the retorts are not at the angle most suitable for the description of coal carbonized, and if the charging appliances are not operating satisfactorily. Among the largest and most successful installations of inclined retorts may be mentioned those at the works of the Brentford Gas Company in England, at the Municipal Gas Works at Vienna, and at the Mariendorf Works of the Imperial Continental Gas Association at Berlin.

Mechanical Stokers.—Inclined retorts lend themselves more readily to the use of mechanical appliances for charging and drawing than horizontal, but the latter being, to many minds, superior in other respects, many machine stokers have been invented for them. Of these a few only have survived the ordeal of extended trial under ordinary working conditions. As the tendency at the present time is to free a gas works, as far as possible, from the trammels imposed by the generalissimi of labour cliques, these machines, which diminish the number of workers in the retort house, and do not require the skill or physique of the ordinary gas stoker, must be briefly mentioned.

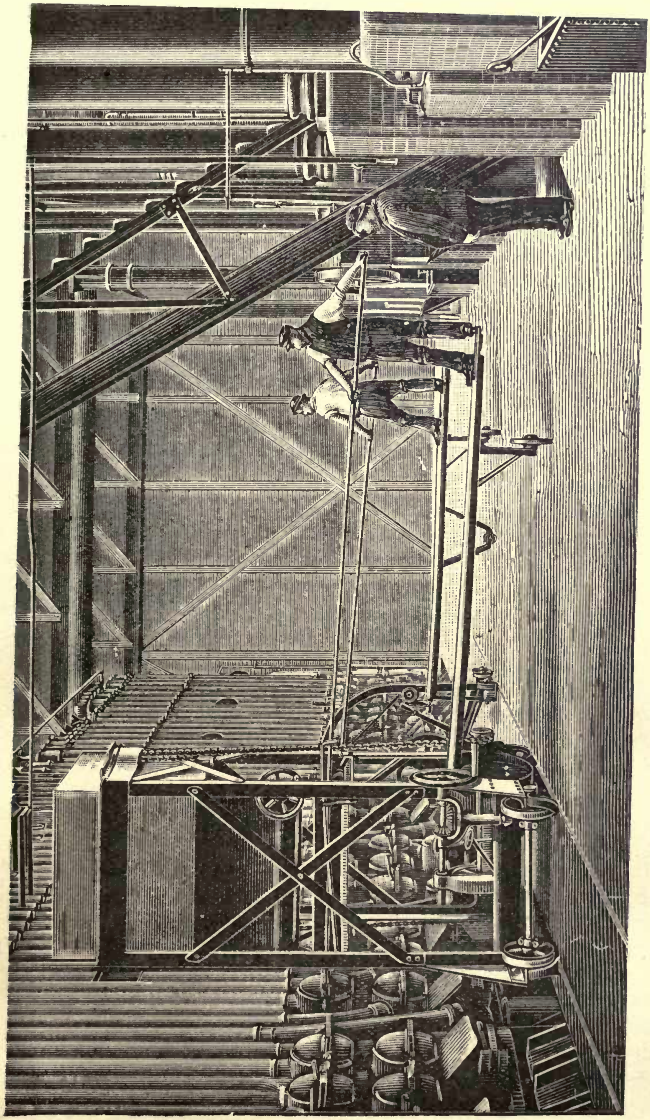


Fig. 17.—West's manual charging and drawing machinery.

They have the further advantages of doing away with the very arduous work of manual charging, and of improving the hygienic conditions for the retort house staff. The simplest substitute for the ordinary manual charging, as described above, is perhaps **Wests' Manual charging machine**, which consists of a light trolley, which is pushed into the retort to charge it. It is worked in conjunction with a machine for breaking the coal moderately small, and an elevator or conveyor for transferring the broken coal to a hopper, whence it falls, as required, into the charging trolley. Two men only are required to charge retorts by this method, in place of the gang of six required for the ordinary scoop charging of through retorts. It is, therefore, especially adapted for use in small works. The coal-breaking machine, conveyor and hopper, introduced into gas works by John West for stoking machinery, are, in slightly different forms, adjuncts of nearly all modern systems of mechanically charging retorts. An efficient hand-drawing machine, which permits of the use of a large, wide rake head, is supplied for use in conjunction with the West manual charging machine. The manual charging and drawing machinery, as now made by West's Gas Improvement Co., Ltd., is shown in Fig. 17. Another manual charging machine which is widely used, is the "Rapid," made by Biggs, Wall & Co. West, the inventor of the manual trolley, has given much attention to designing and perfecting retort-charging and drawing machinery, and his plant has probably been more extensively tried than any other. The original designs, and the successive improvements introduced by him, have been protected under the following patents:—No. 789 of 1881, No. 1,226 of 1886, No. 723 of 1888, No. 5,806 of 1893, and Nos. 5,036 and 5,037 of 1895; for full details, the specifications should be consulted. The compressed air system of conveying power to the machines is that generally recommended by West's Gas Improvement Co. for use in large works, and has been brought by them to a high state of efficiency, productive of great economy. The **drawing apparatus** consists essentially of a rake projected into and withdrawn from the retorts by a bar held in channel guides on the machine. This bar can be raised or depressed by a rocking lever, and so kept above or lowered into the coke at will. The bar is propelled forwards and backwards through chains working round a drum connected to the piston-rod, the movements of which are controlled by a hand-lever actuating a slide valve, which admits compressed air to either side of the piston. The rod is cooled each time it is withdrawn from the retort, by a spray of water from a tank carried overhead. A winch worked by a hand-wheel hoists or lowers the frame holding the rake bar to the heights required by the different levels of the retorts. The machine is propelled on rails running the length of the retort house, by means of a hand-wheel actuating bevel gearing connected to one of the supporting wheels, or by means of gearing driven by a compressed air motor. This drawing machine does its work rapidly and well, and, when worked with ordinary care, without injury to the retorts and mouthpieces.

The **charging machine** is likewise supported on rails, and is propelled by a motor, to enable it to travel along the rails in either direction as required. The charge of coal is put into the retort by means of a scoop, which is half the length of a through retort. The scoop is charged from a coal hopper in the upper part of the framework of the machine. The frame supporting the scoop and the hopper can be raised or lowered, according to the level of the retorts, by means of the motor. The scoop is directly supported by a carrier running in horizontal guides, a chain passing to each end of the carrier and then round a drum. The drum is revolved by a pinion operated by a rack attached to the piston-rod of a cylinder into which compressed air is admitted by movement of a hand-lever. The end of the cylinder to which the air is admitted determines the direction of revolution of the drum and, thereby, the driving forward or backward of the scoop carrier. The scoop is pushed fully into the retort twice to make a complete charge; the first time it enters it is emptied to one side, then withdrawn, refilled, and sent in a second time, when it is emptied on the opposite side to the former charge, and withdrawn; in both operations, the scoop moves several inches from the centre of the retort to the side where the coal is to be deposited. The scoop has a blade running throughout its length to further the even distribution of the charge on the bottom of the retort, and the lateral movement given to the scoop, previous to emptying, has the same object in view. The whole cycle of operations is readily performed by one man, but another must follow the machine to close the retort lids. The hopper attached to the machine is replenished from fixed hoppers placed at intervals above the stage, and filled by elevators. The machine works well, and the average time occupied in charging each retort is forty seconds. The West machines can also be driven by hydraulic pressure and by wire or cotton rope, and many specimens so driven are at work, but the compressed air system is that generally preferred. Fig. 18 shows the latest form of West's charging machine.

Fig. 19 shows the compressed air drawing and charging machines, being a view on the stage of the Bradford Road Works at Manchester. The whole of West's charging and drawing machinery is made by West's Gas Improvement Co., Ltd., Manchester.

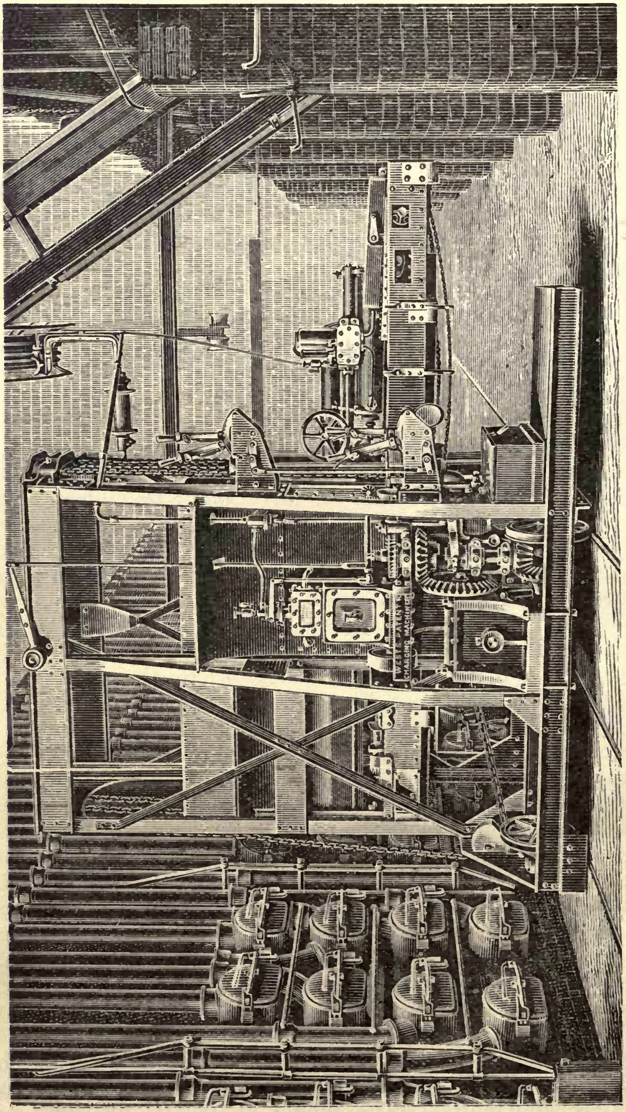


Fig. 18.—West's compressed air charging machine.

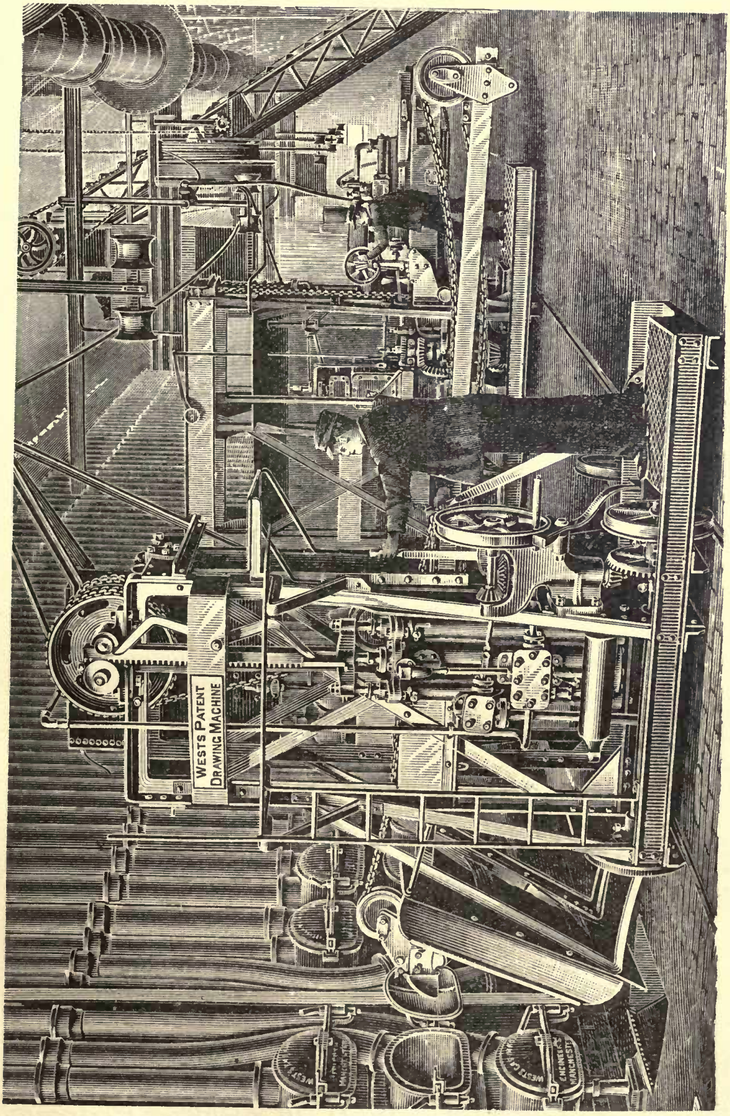


Fig. 19.—West's compressed air drawing and charging machinery.

Ruscoe's charging machine, as made under patents No. 18,108 of 1889, No. 14,720 of 1890, No. 8,479 of 1891, and No. 864 of 1892, puts the charge into the retort at one operation by means of two scoops carried side by side and overturned in opposite directions. Where desired, the scoops can be drawn slightly apart, as soon as they have entered the retort to their full extent, so that some of the charge is dropped directly on to the middle of the retort floor, and the remainder afterwards distributed to the sides by the tipping of the scoops in the usual manner. The scoops are moved into and out of the retort in somewhat the same manner as that adopted in the West machine. The machine is designed for a charge of 3 cwts. of coal, which it distributes very evenly in the retort.

The **Woodward and Crossley charging machinery** (see patent, No. 4,246, 1892) had a gas engine attached to provide the requisite power. The machine travelled on rails in front of the retorts, gas being supplied to the engine by means of a flexible pipe, or from a water-sealed trough traversing the house. In the latter case the water was taken from the trough for cooling the cylinder, being afterwards returned to it. The scoop was filled from a hopper travelling on the machine, having a shoot the same length as the scoop, thus filling it at once. In a later patent of J. Woodward, two scoops were described of such section that, when overturned in the manner shown, the coal was very evenly distributed in the retort. The machine contained mechanism for raising and lowering the scoop to suit the heights of the retorts, and could be moved along the rail by gear on one of the axles worked by the gas engine. A gas engine hardly appears at first sight suited for working within the retort-house, but these machines to a great extent dispelled any doubts arising on that head. An alternative method was to use one large gas engine outside the house in place of small ones on the travelling machines, the power being conveyed to the latter by friction pulleys. Woodward and Crossley's patents also covered a design for a drawing machine, which was likewise driven by a gas engine supplied with gas in the same manner as that on the charging machine. The arrangement of the rake was not very dissimilar to that of the West machine, and the supporting rod was likewise cooled by water each time it was withdrawn from the retort. There is considerable similarity in design in most of the machines for discharging the coke, and the West may broadly be taken as typical of them all.

The **Foulis-Arrol charging machine** acts in a totally different manner to those previously described. Details of it will be found in patent specifications No. 14,440 of 1891 and No. 16,749 of 1893. The coal is discharged in measured portions, generally one-sixth of the total charge, on to a shoot placed in the mouthpiece, and is then pushed along the bed of the retort by a pusher-head. The first portion is pushed to the end of the (single) retort; the stroke of the pusher diminishes automatically with each successive portion until the retort is fully charged. The amount of coal delivered each time can be regulated to suit the number of strokes made by the pusher. The coal being put in in portions banks up slightly, but appears, nevertheless, to carbonize perfectly. The machine is considerably lighter than most of the power chargers on the market, and can be propelled along the stage by two men. The pusher is driven by hydraulic power, which is also used for raising the charging frame to the upper tiers of retorts. A very light hydraulic power drawing machine has also been designed, and may be used with advantage where hand charging is retained, as well as where the charging machine is used.

An ingenious charging machine has been patented (No. 16,750, 1892) by F. Grein. A funnel-shaped tank discharges coal on to an endless metal band traversing a long metal frame which is thrust into the retort. The band distributes the coal on the floor of the retort as the trolley carrying its frame and the coal hopper is drawn backwards from the setting. The trolley either runs on the stage of the house or is supported by a frame running on beams above.

Recently, charging and drawing machinery driven by electric power has been adopted in several gas works. One type of charging machine thus driven is the De Brouwer, which projects coal into the retort from a rapidly travelling band. The band presses against the outer edges of a large grooved pulley for rather more than a fourth of its circumference, being kept in position by three smaller pulleys over which it runs, as shown in the illustration (Fig. 20). The coal is dropped into the groove of the pulley, against which it is held by the running band. As the latter takes the horizontal direction and leaves the pulley at its lowest point, the coal is carried on it at the velocity with which it is running, and when the band turns down to run over the small lowest and foremost pulley, the coal continues to fly forward in a horizontal line. Hence, if the machine is properly placed in front of the open mouth of a retort, the coal will thus be projected into the retort, and if it leaves the band with sufficient velocity it will first be arrested by the bottom of the retort at its far end, and will afterwards pile up against the coal already in the retort. Thus an even layer of coal on the floor of the retort is secured. If the machine is run at a sufficiently high velocity, it is quite possible thus to charge retorts 20 feet in length, entirely from one end. In actual working, three or four retorts have been charged per minute by this machine. It can, of course, if preferred, be driven by other power than electricity which, however, has been used in existing installations because of its great convenience. The arrangements for bringing the coal

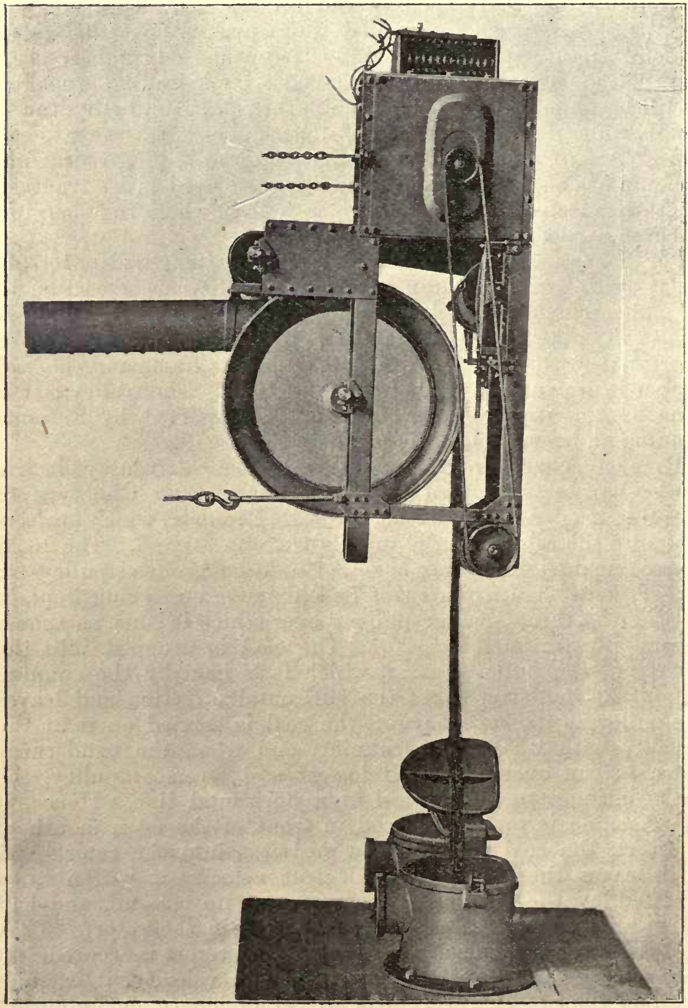


Fig. 20.—The De Brouwer charging machine.

into the shoot of the machine evidently may be varied to suit the conditions and situation of the retort house and benches, without materially modifying the machine itself. The machine is usually suspended above the stage of the retort house, from a trolley running on rails, placed parallel to the benches of retorts, and is moved along in front of the retorts, and raised or lowered as required, either by hand or by means of a motor. The delivery end of the band is about 5 feet in front of the mouthpiece of the retort which is being charged. When the machine is in this position, and is properly worked, no coal falls short of the retort.

Another type of machine, which likewise projects the coal into the retorts, and is driven by electric power, is in use at La Villette Works of the Paris Gas Company. The coal drops from a hopper into a shoot, from which a turbine, which in the present machines is 28 inches in diameter and has five blades, blows it into a horizontal shoot which is levelled so that the projected coal flies directly into the retort. This machine will charge a 20-foot retort from one end only. The speed of the turbine is reduced while each charge is being delivered, so that the coal falls in the proper place on the floor of the retort until it reaches the near mouthpiece and the retort is fully charged. A certain amount of combustion of the blown coal naturally takes place before the retort is closed, but it is not much more serious than the combustion which always occurs while a retort is being charged.

At La Villette Works a discharging machine for expelling the coke from the retorts is used, which is likewise driven by electric power, and acts on quite different lines from the ordinary drawing machines. It comprises a ram, which for long retorts is telescopic, by means of which the coke is pushed from the retort through the far mouthpiece. Clearly, it can only be used with through retorts. It presents the advantages of expelling the coke rapidly and without pulverizing it so much as the drawing rakes do. This form of ram discharging machine might advantageously be adopted in many cases where the type of charging machines used at La Villette Works is not employed.

Drawing and charging machines, especially the latter, have been described here mainly because the manner in which they act has considerable influence on the products. A charging machine which deposits the coal in ridges or an uneven layer, on the bottom of the retort, cannot be considered to satisfy reasonable requirements, because the coal so deposited will not be uniformly carbonized and completely worked off in a given time. It is essential to good carbonization, and rapid and thorough working off of the charge, that it should be placed in the retort in a uniformly distributed layer, and, moreover, not compressed or compacted to any considerable extent. The action of charging machines, in these respects, differs very much, and at the time of writing it does not appear to be established that the quite recently introduced projecting machines deposit the coal in the retort under as favourable conditions for good carbonization as does the charging scoop. It is not enough that the coal should lie in an even layer; it ought not to be compressed into a close mass into which the heat cannot readily penetrate through the multitude of channels which naturally occur in coal which has been lightly shovelled or dropped into position. A closely compacted mass of coal offers resistance to the swelling which ensues as soon as the heat begins to penetrate it, and thus becomes yet more closely compacted, so that the free escape of aqueous vapour and gas from it is obstructed. The gas suffers thereby. It is a fact that the quantity of gas produced by the carbonization of a given quantity of coal varies considerably according to the manner in which it is deposited in the retort, and it is not therefore merely a question of the "illuminating power" of the gas being affected by the mode of charging. The question is one of practical importance even where a large make of gas, irrespective of slight fluctuations in "illuminating power," is the primary consideration. It is not possible to foretell, without practical trial, whether a particular mode of charging is likely to prove productive of a high yield of gas of good quality, but, generally speaking, it seems essential that the coal should be lightly laid in a layer of uniform thickness on the bottom of the retort, for choice banking up slightly against the side walls. Any method which leaves the coal heaped up along the axis of the retort is certainly bad, and compression also appears harmful. Bearing these conditions in mind, the relative advantages of different modes of charging must be ultimately settled from a comparison of the results of practical trials of them. In such a comparison, however, it must be ensured that the conditions are otherwise strictly comparable—the same type of settings, the same variety of coal, &c., must have been used in all cases. Otherwise differences in the results may be attributed to the mode of charging which, in reality, are wholly accountable for by other differences in the conditions.

Continuous Carbonizers.—The principal machine stokers have been now enumerated, but before passing on to consider the phenomena of carbonization in general, brief reference may be made to continuous carbonizers. For years schemes for distilling coal and oil continuously have been propounded, but have not proved workable. One of the most promising inventions of the kind was the **Yeadon & Adgie revolving retort**, which met with some measure of success. The patent for the original invention was No. 19,183 of 1889, but various modifications have been since protected. A conical cast-iron retort is set with its axis horizontal, and is revolved on suitable bearing rollers. The middle portion of the retort passes through a furnace, which heats it to a bright cherry-red heat. The coal enters at the small end, being carried through a small cylinder by a shaft fitted spirally with blades which make a gas-tight packing to the cylinder. The gas passes out by a fixed ascension pipe at the large end, while the coke drops into a channel from which it is removed by a similar spiral conveyor to that used for supplying the coal. The joints between the stationary and revolving parts are made gas-tight with asbestos packing. The carbonization of coal is effected in this retort in less than a quarter of an hour, and a great part of the tar obtained in the ordinary process of gas making appears to be converted in the revolving retort to gas, increasing both the quantity and quality of the latter from a given amount of coal. The coke obtained is small and comparatively valueless. The system seemed well worth consideration for use as an auxiliary to ordinary retorts, and generally for intermittent use, but no experiments with it on a large scale appear to have been made. This invention, however, shows an appreciation of one direction in which an improvement in carbonizing methods may be sought, and on this account the Yeadon & Adgie retort should not be ignored. It has been adapted with slight modification for the destructive distillation of tar and other hydrocarbon liquids.

Vertical Retorts.—Recently several forms of vertical retorts for the carbonization of coal have been proposed for use in gas works, and some have proved fairly successful in working trials. One of the best known types of vertical retort and setting is that designed by Settle and Padfield, which has been erected at the Exeter Gas Works. The system presents the advantage over settings of horizontal retorts of requiring considerably less ground area and less cubic space of retort per ton of coal carbonized. The Exeter trials so far indicate that it is possible by the Settle and Padfield retort to obtain a make of about 13,000 cubic feet of gas, of which the "illuminating power" is stated to be 14½ candles, from a ton of Somerset slack coal, which, when carbonized in horizontal retorts, would yield only about 10,500 cubic feet per ton. The coal is fed into the retort in portions of 6 to 7 lbs. every 1½ or 2 minutes, and must necessarily be free from large lumps in order to traverse the feeding cylinder.

The frequent feed of small quantities of coal shows that the system embodies one of the most highly commendable features of the earlier continuous carbonizers. The retort widens at its lower end to facilitate the withdrawal of the coke at intervals from the mouthpiece in which the inclined lower portion of the retort terminates. Other types of vertical retort have been devised by Bueb and by Isbell, and they are being tried in Continental gas works at the time of writing. It is worthy of note that some types of coke ovens, designed primarily for the production of coke for metallurgical uses, are in effect large vertical retorts, and that they furnish a large yield of gas of tolerably high average quality. In these ovens, however, the charge of coal is very large, and the period of carbonization is very prolonged. In this respect they differ from the Settle and Padfield vertical retort, as well as in the fact that the working is intermittent instead of continuous.

Carbonization Products of Coal and Hydrocarbons.—The above brief description and discussion of the appliances and mechanical devices used for obtaining gas from coal lead up to the consideration of the most essential conditions governing its production and determining the nature and proportions of its several constituents. The majority of the schemes for producing coal gas are so nearly allied that gas almost identical in composition may be obtained by all of them, and, consequently we may assume that its evolution is governed by the same general principles, notwithstanding differences in form and working of the apparatus employed in the production. These general principles are less perfectly understood than is commonly supposed.

The elucidation of the phenomena of coal gas manufacture would be far easier were the raw material a less heterogeneous aggregation of carbon compounds. Some light may be thrown on the subject by the close study of the dry distillation at various temperatures of pure hydrocarbons, such as cellulose, and members of the paraffin and other series of carbon compounds. Coal is so complex a body, and its elementary constituents are grouped together in compounds, the natures even of few of which are known, that the ultimate analysis of a sample gives very little indication of its behaviour on carbonization. In 1880 and the two following years Cross and Bevan, in the course of researches on cellulose, incidentally examined several coals. Balzer had previously put forward the theory that coal was made up of a series of compounds of carbon, oxygen, nitrogen, and hydrogen genetically, if not homologously, related. Cross and Bevan stated, at the York meeting of the British Association in 1881, that they had found a cannel react vigorously with chlorine, bromine, and nitric acid, with each of which it formed soluble substitution products. These facts, and the formation of similar coal-like bodies from cellulose by the action of sulphuric acid, were said by them to "make it at least probable that cellulose, lignin, peat, lignite, cannel coal, and anthracite are terms of a vast series of compounds differentiated under natural conditions difficult of elucidation and impossible to reproduce." This view of the constitution of coal has been supported by the report of a committee presented to the Liverpool meeting of the British Association in 1896. The experiments undertaken by J. A. Smythe at the instigation of this committee showed that the substance of Durham coal, cannel, and brown coal from Brühl, near Cologne, was attacked freely by the powerful oxidizing medium of a mixture of dilute hydrochloric acid and potassium chlorate. The action was rather slow, but thorough. The residue remaining after removal of the oxidation products by extraction with acetone, if treated again with the oxidant, was further attacked. By successive oxidation and removal by extraction of the products of oxidation, nearly the whole of the substance of the coal was attacked. The products of the oxidation were, however, chiefly complex bodies, which afforded very little information as to the nature of the material from which they were formed. In the case of Durham coal and cannel, the dried products of oxidation weighed more than the coal, but strangely enough in the case of the brown coal, they weighed less than the coal. The products in all cases were chlorinated compounds of an acid nature, but as already indicated, the attempts made to investigate their constitution led to no satisfactory results. There is, therefore, still doubt as to the actual composition of the coal substance and of the series of compounds which constitute it. But in addition to the series of compounds referred to, which constitute the coal substance proper, coal contains a small percentage of resinous bodies, which may be extracted more or less completely by various organic solvents. These resinous bodies have been classified by Muck in his *Chemie der Steinkohle.* Very rarely do they amount to more than 4 per cent. of the coal. Nevertheless, the illuminants of coal gas are undoubtedly chiefly derived from these resinous hydrocarbon constituents of the coal, though the cellulose-like coal substance yields methane, and perhaps traces of olefines, in addition to the more strictly diluent gases. Present knowledge of the actual constituent substances of coal does not, therefore, throw very much light on the phenomena of its destructive distillation. The rules by which gas is made at the present day are for the most part empirical, and the large profits that the industry has yielded ungrudgingly even in recent years have tended to repress attempts to establish it on a more scientific basis. Nevertheless, something in this direction has been accomplished, and under the stress due to the competition of other lighting and heating agents much more may be anticipated in the near future.

The carbonization of coal, as it takes place in gas works, is conducted under such conditions that the stages in the formation of the permanent gas, which is the chief object of the process, cannot readily be observed. To a limited extent the actions that occur in the gas retort may be deduced on *a priori* grounds, and inferred from analogous cases. Thus, supposing an ordinary horizontal retort heated to 900° C. is ready for charging, and a charge of coal is put in covering the bottom of the retort evenly to a depth of, say, 3 inches. The temperature of the coal rapidly rises from the normal, the exterior of the layer being first affected. The points of volatilization of the water and of the light hydrocarbons of the coal are rapidly reached; in the case of the coal in direct contact with the retort, or fully exposed to the heat radiated from it, almost instantaneously. The vapour of water and of hydrocarbons so expelled seeks the outlet of the retort, but before reaching it is exposed to the intense radiation from the sides of the retort, even if it does not actually come in contact with them. The nature of the vapour first expelled from the coal must determine the result of the action of heat on it, and as it may vary with the kind of coal, and in any case is not certainly known, we cannot theorize much further in this direction. But since the general tendency of hydrocarbons on exposure to high temperatures in a state of vapour is to break down to carbon compounds of less complex molecular structure, it may be assumed that this happens in the retort, the steam perhaps being decomposed and reacting to a limited extent also. This process of the breaking down of the hydrocarbons as soon as they are liberated in the form of vapour from the coal, doubtless goes on throughout the period of gasification, and is sufficient to explain the presence of the hydrocarbons found in coal gas. At the same time as the retort is imparting heat to the coal the temperature of the retort is, in accordance with the theory of exchanges, sensibly lowered. Thus the temperature of a charge of coal, observed in the middle of the retort half-an-hour after charging, is only about 500° C., or, say, 900° to 950° F. Hence the temperature at which the first part of the distillate is given off is considerably lower than that of the retort before the admission of the charge. But that the distillation temperature may not be below that at which the bulk of the hydrocarbon vapours evolved are converted to simpler bodies which are gaseous at ordinary atmospheric temperature and pressure, a considerable excess of heat must have been imparted to the retort, as fireclay is too feeble a conductor to permit the heat from the furnace to pass through it sufficiently rapidly to compensate for the sudden abstraction of heat by the cold charge. Hence it is the custom to raise the retorts to a temperature considerably above that at which the constituents of coal gas are actually formed from the vapours of the hydrocarbons contained in coal. This is especially necessary where the mass of coal inserted at each operation is large in proportion to the heating surface—*i.e.*, where large charges which form a thick layer in the retort are used. The heating proceeds from the outside of the layer of coal inwards, and gradually causes the volatilization of the moisture and of the hydrocarbons of the coal in the interior of the charge. Moisture in the coal especially tends to lower the temperature of the retort on account of the large amount of heat absorbed in converting it to vapour, that is to say, on account of the high latent heat of steam. Hence coal for carbonization should contain as little moisture as possible. As soon as the moisture is driven off the temperature rises rapidly, and the heavier hydrocarbons volatilize. But owing to the thickness of the layer of coal usually carbonized, the heat passes to the interior of the mass very slowly, and the process of volatilization extends gradually only. Also, at each moment, hydrocarbons of very different boiling points are given off from different parts of the charge, according to the varying temperatures. Nevertheless all are submitted to nearly the same temperature before they pass from the retort. The amount of heat rendered latent, and the slow passage of the heat through the coal, render the process of gas making under the usual system a slow one, and the charge usually remains in the retort from four to six hours. This prolonged heating is not necessary for the perfect gasification of coal, but it is inherent to the system of charging relatively large masses of coal at a time, and to the use of retorts of feebly-conducting material. The rapidity with which coal may be carbonized is proved in the working of small experimental iron retorts, and of the revolving gas retort, where the mass in the retort is small enough to favour rapid diffusion of heat throughout it. In these two cases, also, it is not necessary to keep the heat far above that of the conversion of the hydrocarbons of the coal to stable gases, as no sudden and exhausting call is made on the heating arrangements by the insertion of a large mass of cold solid material at one time. Hence small retorts, and the revolving retort, may advantageously be of iron, which will withstand the heat they require, while its good-conducting powers are secured. But large retorts holding charges in a layer 3 to 6 or more inches in thickness must necessarily be of a more refractory material.

Little is known of the nature of the constituent hydrocarbons of ordinary gas coal. In certain rich coals hydrocarbons of the paraffin and olefine series are undoubtedly present, and their behaviour under the treatment to which coal is subjected in gas manufacture may be considered with advantage, being doubtless analogous to that of the constituents of ordinary gas coal.

The higher members of the paraffin series of hydrocarbons (C_nH_{2n+2}) break down even at temperatures below their boiling points under normal pressure, to lower hydrocarbons of the same series, and hydrocarbons of the olefine series (C_nH_{2n}). Thus—

$$C_N H_{2N+2} = C_n H_{2n+2} + C_n H_{2n}. \quad \text{Where } 2n = N.$$

A somewhat similar action occurs on the application of a high temperature to the lower members as well as the upper, and hence the higher paraffins should be resolved chiefly into ethane and ethylene. At a red heat ethane yields methane, carbon, and hydrogen, thus—

$$C_2H_6 = CH_4 + C + H_2.$$

From paraffin hydrocarbons we should therefore expect to obtain the gases methane, ethylene, and hydrogen, and a deposition of carbon. Haber, working in conjunction with Samoylowicz at first and Oechelhaeuser later,* has investigated the nature of the products resulting from hexane when it is exposed to a high temperature. Hexane is the sixth member of the paraffin series of hydrocarbons, and constitutes a good subject for investigating the general question of the behaviour of these hydrocarbons on exposure to high temperatures. It has the formula C_6H_{14}, and it is conceivable, therefore, that benzene, having the formula C_6H_6, might be formed from it by direct splitting off of the redundant hydrogen atoms. As benzene is invariably a product of the decomposition of paraffin hydrocarbons at high temperatures, the manner in which it is produced from them becomes a question of practical importance in connection with gas manufacture. This question could be studied best, in the first instance, on a single member of the series of hydrocarbons, rather than on the mixtures which occur naturally in oils and coals, as the remaining constituents of these bodies yield products which would confuse the results. Hence, hexane was selected by Haber as a typical paraffin for the study of the fundamental products of the decomposition of paraffin hydrocarbons on exposure to high temperatures. The products changed as the temperature was increased, doubtless owing mainly to the effect of secondary reactions. The following table shows the average

---

* *Journ. für Gasbeleuchtung*, 1896, 377 and 799; *Journ. of Gas Lighting*, lxviii., 369, and lxix., 349, *et seq.*

composition, in volumes per cent., of the gas obtained from hexane at the temperatures named :—

Temperature, ...	606° C.	820° C.	940° C.	1,200° C.
Olefines, chiefly ethylene, .	50·10	51·08	19·33	4·40
Paraffins, chiefly methane, .	37·20	35·27	46·33	22·60
Hydrogen, ...	10·60	10·42	32·42	65·20
Carbonic oxide, ...	...	1·23	0·22	6·00
,, acid, ...	0·46	0·43	0·57	0·70
Nitrogen, ...	1·64	1·57	1·12	1·10

The benzene and the readily condensible olefines had been condensed or absorbed prior to the collection of the gas for the analyses. It is evident that, at the lower temperatures, a simple loosening of the hexane chain has been the chief reaction, resulting in the formation of the paraffin, methane, and olefines, among which ethylene predominates, probably owing to secondary decompositions. There was but little benzene or liquid olefines formed at the lower temperatures, and the splitting off of hydrogen and separation of carbon took place only to a small extent. At the higher temperature of 940° C., however, a serious falling off in the proportion of ethylene is noticeable, the methane has increased in quantity, and, what is especially noteworthy, hydrogen has become an important constituent. At the same time, appreciable amounts of acetylene and benzene have been formed, and carbon has been separated in large quantity. The decomposition of the hexane has no longer followed a simple course, and secondary products are predominant. The temperature at which the hexane gives the best gas has been passed, and the benzene and acetylene produced do not equal in illuminating value the ethylene destroyed by the secondary reactions. It is better to preserve the ethylene as far as may be, and avoid the production of benzene. The manner of formation of benzene and other aromatic hydrocarbons from paraffins was shown to be by a building up of the molecule from the ultimate products of decomposition of the hexane. Benzene was proved not to result by a simple splitting off of hydrogen from the hexane molecule. Neither did it result to an appreciable extent from the polymerization of acetylene, which was proved by direct experiment to yield very little benzene even at high temperatures, provided oxygen was absent. Similarly, naphthalene was shown not to result directly from benzene, but to be formed along with it. Thus the final products of the decomposition of paraffin hydrocarbons would appear to be, at temperatures not exceeding 600° C., essentially ethylene and methane, with higher olefines; at about 900° C., methane, hydrogen, and carbon, with only a moderate amount of ethylene; and at over 1,100° C., hydrogen, a moderate proportion of methane, and very little ethylene, but a considerable quantity of benzene and other aromatic hydrocarbons.

The hydrocarbons of the olefine series break up at a red heat to lower members of the same series, to members of the acetylene series, to methane and other paraffins in small quantity. Thus from ethylene are obtained methane, acetylene, and smaller amounts of ethane and other hydrocarbons. Now, at a red heat these bodies yield benzene, and thus a new series of hydrocarbons is introduced. Therefore, from the higher hydrocarbons of both the paraffin and the olefine series are obtained directly or indirectly the following gases, or easily vaporized bodies:—Hydrogen, methane, ethylene, acetylene, and benzene, besides homologues of the last four in small quantities. None of the reactions alluded to above occur completely, but according to the well-known theory of reversible chemical changes, an equilibrium is established at the reacting temperature, and both the original bodies and the products are present in certain proportions dependent on the temperature and pressure in the reacting mixture. Secondary actions occur freely also.

The influence of the oxygenated bodies which are present in coal must also be considered. As a general rule, organic bodies containing oxygen, on heating, decompose, through the splitting off of the oxygen in conjunction with hydrogen as water, or with carbon as the monoxide or dioxide. The hydrocarbon residues unite to form hydrocarbons, which may then undergo a further change according to their nature. This decomposition of oxygenated compounds would suffice to explain the presence of the oxides of carbon among the products of the destructive distillation of coal. The gases produced by the destructive distillation of cellulose (see p. 5) are rich in the oxides of carbon, and, therefore, we should expect to find the latter in coal gas also.

But to account for the presence of certain other products of coal carbonization the secondary actions that take place in the retort must be regarded. It has been seen that benzene is formed, either indirectly or directly, at a red heat from the vapours of most methane derivatives. Together with it are formed some of its homologues, also diphenyl, naphthalene, anthracene, phenanthrene, and other products containing either the benzene nucleus or condensed benzene nuclei. Herein lies the explanation of the presence of benzene vapour in coal gas, and of benzene and other aromatic hydrocarbons in the liquid products of the destructive distillation of hydrocarbon bodies. It is a commonly observed fact that the yield of benzene and other aromatic hydrocarbons is greatest when the heat is intense, or its application to the vaporized hydrocarbons prolonged, and this is in accordance with the principle that benzene is formed at a higher temperature than the gaseous aliphatic compounds, and that it is probably the result of a secondary action. In the formation of aromatic hydrocarbons from paraffins and olefines hydrogen would be liberated, hence the preponderance of that gas in coal gas, especially when the latter is made at a high heat.

It is not pretended that the above reactions completely, or even to any considerable extent, explain the formation of the products of the carbonization of coal, but they offer a partial and possible explanation, and for lack of more definite knowledge may serve to show the general course of the process. When our knowledge of the constituent hydrocarbons of coal is approximately exact, the true transformations occurring during carbonization can be learned from experiments on the effects of different degrees of heat on these hydrocarbons singly and in groups of a few, but at present no such knowledge is available. Hence the inadequacy and defectiveness of the explanations hitherto offered.

Mills' Theory.—E. J. Mills has attempted to show that in the destructive distillation of coal a very simple relation subsists between the fixed carbon and the carbon in the gas and tar. He concludes that C_3 appears to be the fundamental unit in all cases, and by using collocations of symbols to represent coal and gas and tar, he gives instances of the concordance of his theory with the results found in practice. Thus excluding the minor constituents, he finds that the organic matter of a coal is nearly represented by the collocation of symbols, $C_{24}H_{18}O$. Its destructive distillation may be thus represented :—

$$\underset{\text{(Coal.)}}{2C_{24}H_{18}O} = \underset{\text{(Fixed carbon.)}}{33C} + \underset{\text{(Gas and tar.)}}{C_{15}H_{34}O} + \underset{\text{(Organic water.)}}{H_2O}$$

According to this, 100 parts of the organic matter of the coal should yield 61·5 parts of carbon, 35·7 parts gas and tar, and 2·8 parts water. In practice 61·5 parts fixed carbon and 38·5 parts volatile matter were actually obtained after eliminating the effect of the minor constituents of the organic matter of the coal by calculation. The results from other coals are given by Mills, and are in accordance with his theory, which will, however, be generally regarded as too elastic, and is certainly at present incomplete. As an attempt to throw light on the phenomena of destructive distillation it may well find favour, and perhaps furnish a basis for further generalizations.

Distribution of Nitrogen in Distillation Products.—Before studying the influence of temperature on the production of gas from coal, and the composition of the different fractions yielded on the distillation of coal, it may be advantageous to see what becomes of the minor constituents of coal during carbonization. Those of most interest to the gas maker are nitrogen and sulphur. William Foster studied the distribution of the nitrogen of coal among the several products of destructive distillation.* He concluded that in ordinary gas manufacture, of the total nitrogen in the coal, 14·5 per cent. is evolved as ammonia, 1·56 per cent. as cyanogen, while 46·68 per cent. remains in the coke. There is still 35·26 per cent. as free nitrogen in the gas, or contained in the tar, but the amount in the latter is considered to be relatively small. Apart, however, from basic bodies containing nitrogen which are yielded on the distillation of coal tar, the pitch on cooling evolves a considerable amount of nitrogen, which may be increased by the passage of moist air or steam. According to Watson Smith,† coal tar contains 1·667 per cent. of nitrogen, or a very small proportion of the nitrogen in the coal. Yet some of this nitrogen must be combined in a very stable form, as it remains in the coke from pitch, and is evolved as ammonia during cooling.‡ The coal on which Foster conducted his experiments contained 1·73 per cent. of nitrogen. Generally the amount of nitrogen in gas coals lies between 1 and 2 per cent. E. Schilling has observed that the amount of ammonia produced rises and falls with the amount of nitrogen in the coal, and he finds that 14·0 per cent. of the total nitrogen is the average yield as ammonia, and 20 per cent. the maximum in a number of experiments.§ According to Lewis T. Wright,‖ the yield of ammonia from a coal is greater at a medium than at high or low heats, and he instances this by a typical example of the distillation of a coal from the borders of Yorkshire and Derbyshire containing 1·28 per cent. of nitrogen. At a high heat, when 11,620 cubic feet of gas were made per ton of coal, 0·331 ammonia per cent. of coal was obtained, at a lower heat with a make of 10,162 cubic feet, 0·352 ammonia per cent. of coal, and at a still lower temperature with a make of 9,431 cubic feet, 0·335 ammonia per cent. of coal. Thus the medium heat gave the highest yield of ammonia. It will be observed that these figures show a higher percentage of the nitrogen of the coal as ammonia than was found by Foster—viz., 22·3, 23·6, and 22·6 respectively, against the 14·5 of the latter. According to G. Beilby, 17 per cent. of the nitrogen in shale is obtained as ammonia on destructive distillation, and some figures given by

---

* *Journ. Chem. Soc.* for February, 1883, 105.

† *Journ. Chem. Soc.* for April, 1884.

‡ Watson Smith, *Journ. Soc. Chem. Ind.*, 1892, 119.

§ *Dingler's polyt. Journ.*, cclxv., 218.

‖ *Journ. Soc. Chem. Ind.*, 1888, 59.

C. Winckler* point to nearly 20 per cent. of the nitrogen of coal being obtainable as ammonia on distilling it in coke ovens. Accurate figures as to the disposition of the nitrogen of coal cannot readily be obtained from the ordinary working on a large scale in a gas works. The percentage of nitrogen recovered as ammonia may be increased in various ways. By the admixture of 2·5 per cent. of lime with the coal before carbonization the production of ammonia is sensibly increased, and further additions of lime up to 10 per cent. cause still further increase in the ammonia produced. The admixture of lime with coal before carbonization under Cooper's process will be considered later; but one of the chief advantages claimed for it is increased yield of ammonia. In one instance where the same description of coal was carbonized with and without lime, the nitrogen recovered as ammonia was 0·19 per cent. of the coal when lime was not used, against 0·27 per cent. when lime was used. The admixture of silica with coal does not appreciably affect the yield of ammonia. Were the chief object of the destructive distillation of coal the recovery of as much as possible of its nitrogen as ammonia, several means not adopted in gas works might be resorted to.

For instance, the passage of steam or certain gases over the coal during carbonization increases the yield of ammonia. Hydrogen is specially effective, causing no less than 35 per cent. of the nitrogen in the coal to be evolved as ammonia under favourable conditions. Carbonic oxide slightly improves the yield; coal gas appears to hinder the formation of ammonia through deposition of finely-divided carbon on the hot material.† The temperature at which ammonia is decomposed is below that at which carbon decomposes steam, with formation of carbonic oxide, consequently we do not find a large yield of ammonia from water-gas generators, although hydrogen is present in the upper part of the fuel bed. Ramsay states that ammonia may, under favourable conditions, decompose under 500° C., hence its dilution with a large volume of neutral gas suggests itself as a means of preserving it during its passage through the retorts. This probably explains the action of steam in increasing the yield of ammonia. Either alone or admixed with air, steam passed over coal at an ordinary carbonizing temperature, or, more certainly, at a somewhat lower heat, will convert 60 per cent. of the nitrogen of the coal into ammonia.‡ Practically this yield is nearly attained in the Mond gas producers, in which 1 ton of slack coal, from the Nottingham and Lancashire districts chiefly, is made to yield 23 to 24 lbs. of ammonia, equivalent

---

* *Chemiker Zeitung*, 1884, 691.

† See a paper by R. Tervet, *Journ. Soc. Chem. Ind.*, 1883, 445.

‡ See a paper by George Beilby, *Journ. Soc. Chem. Ind.*, 1884, 216.

to, say, 50 per cent. of the nitrogen present, on the average, in such coal. This large yield is secured by passing a large volume of steam through the coal, and by this and other means preventing the temperature of the producer rising above that at which ammonia is decomposed. The large yield of ammonia in this instance is attained at the expense of the gas, which contains upwards of 16 per cent. of carbonic acid and only 11 to 13 per cent. of carbonic oxide. It will be apparent, therefore, that in the Mond gas producers the production of an ideal power or semi-water gas is entirely subordinated to the production of ammonia from the coal, and its recovery from the gas. The large excess of steam admitted to, and the low temperature prevailing in, the Mond gas producer are conditions which preclude the formation of gas containing the maximum proportion of carbonic oxide relatively to the proportions of hydrogen and nitrogen present. The large proportion of the incombustible gas, carbonic acid, representing so much combustible carbonic oxide already burnt, is a measure of the price paid—in spent gas—for the recovery of so large a proportion of the nitrogen of the fuel in the form of ammonia. The gas, regarded as a fuel gas, is greatly impoverished for the sake of the ammonia recovered, which amounts to about four times as much as is obtained from the carbonization of the same weight of coal in ordinary gas retorts. As ammoniacal liquor is generally worked up into ammonium sulphate—a readily marketable product—the yield of ammonia from coal is often stated in its equivalent amount of ammonium sulphate per ton of coal. This can readily be approximately converted into percentage of nitrogen in the coal by means of the following factor:—105 lbs. ammonium sulphate (pure) per ton of coal is equivalent to 1 per cent. of nitrogen in the coal.

Distribution of Sulphur in Distillation Products.—The behaviour of the sulphur contained in coal, when the latter is submitted to destructive distillation, may now be considered. The methods of estimating sulphur in coal have been given in Chapter i., and it must have been apparent from the information given there that the form in which the sulphur is combined influences the amount and nature of the sulphur compounds it yields to gas. The sulphur present in coal as sulphate, generally of calcium, remains as such in the coke remaining on destructive distillation, and its amount may be estimated in the ash. The remainder of the sulphur exists in the coal either as organic sulphur compounds or as pyrites. The roasting of these in a reducing atmosphere gives rise chiefly to hydrogen sulphide, but also to carbon disulphide. The latter compound was originally discovered by its formation when pyrites and charcoal were heated together, conditions almost analogous to those obtaining when pyritic coal is being carbonized. Small amounts of other sulphur compounds also pass into the gas. Some of the volatile sulphur is condensed in the tarry products, but this is probably only a small percentage of the whole. No exhaustive experiments on the behaviour of the sulphur of coal during destructive distillation have yet been carried out, and further information on the subject is much needed. Difficulties arise at the outset of an investigation of the matter, owing to the difficulty of differentiating between the sulphur combined organically, and as pyrites in the coal. It appears from experiments conducted by I. S. Drown,* that the whole of the iron present in coal does not exist as pyrites. However, both the organic and pyritic sulphur are partly eliminated in the gas, though some of the organic sulphur almost invariably remains in the coke, and appears in the products of its combustion. The exact distribution of the organic and pyritic sulphur of coal among the gas, tar, and the coke has not been satisfactorily determined for given samples. The general experience is that the destructive distillation of good caking coal produces gas containing about 1·6 per cent. of its volume of sulphuretted hydrogen, and, in addition, about 0·03 per cent. by volume of carbon disulphide and other vaporized sulphur compounds. The author has found from experiments that the crude gas, taken from the hydraulic main, contained, on an average, 1·2 per cent. of its volume of sulphuretted hydrogen, when coal containing 1·1 per cent. of sulphur was being carbonized.

The proportion of the total amount of sulphur in the coal which passes into the gas on carbonization, increases with the temperature of distillation, especially that portion which is not evolved as sulphuretted hydrogen. This even increases at a greater rate than the volume of gas made, so that high heats mean not only a greater amount of sulphur in the total gas from a given weight of coal, but even a greater amount per volume of gas made. For the results of a number of experiments on this point, a paper entitled "Studies in Coal Distillation," by Lewis T. Wright, may be consulted.† The admixture of a small amount of lime with the coal, prior to distillation, diminishes the quantity of sulphur passing into the gas; in some cases, by as much as one-half its weight under the ordinary conditions.

Quality and Quantity of Gas Produced.—The carbonization of coal may now be considered in relation to the quality and quantity of gas produced. The gas evolved shortly after coal is placed in a retort at an ordinary carbonizing temperature,

---

* *Amer. Chem. Journ.*, iv., 1.

† *Journ. Soc. Chem. Ind.*, 1888, 59.

contains the gases occluded in the coal. These are mainly nitrogen and methane, with small quantities of oxygen, carbonic acid, and other gases; consequently, the "illuminating power" of the gas coming from the retort during the first half hour after charging is very low. Then it rises rapidly, and the gas evolved during the next hour is the best obtained from the charge. If the heat of the retort is low, this period is prolonged, and the gas is even richer. But, from the middle or end of the second hour to the end of the third hour, it may be taken that the gas will be considerably poorer, and thence to the end of the distillation that it will be very poor indeed. The period at which the richest gas is produced is also that of the most rapid production, though the rate of evolution does not fall off markedly in the ensuing period.

In the manufacture of gas from ordinary good gas coal, when about 11,000 cubic feet of gas, having an average "illuminating power" of about 14 standard candles when the gas is consumed at the rate of 5 cubic feet per hour in the London Argand burner, is made, the fraction produced during the first half hour, amounting to about a seventh of the total volume, will be only about 10 candle gas. During the next hour and a-half, the candle power of the gas made will be 17 to 18, and the production nearly one-half of the total. During the next hour, the make will be nearly a fifth of the total, but the candle power only about 14. The remainder of the gas will be only 8 to 10 candle. These figures are, of course, only rough approximations, and the description of coal, the heat, and, indirectly, the pressure in the retort, may cause great variations from them. They are applicable only to a high heat, and consequent rapid working off of the charge.

The temperature of retorts in gas works is seldom determined with accuracy. It probably averages about 950° C. or 1,750° F. For ordinary working, the eye is relied on to determine if the retorts are sufficiently hot, and experience in observation renders it a very reliable guide. The condition of the coke at the time of drawing also serves as an indicator of the temperature, as, if this is low, the charge will not be completely burnt off in the allotted time. Gas engineers are not unanimous in opinion as to the most economical carbonizing temperature, and, doubtless, a decision is liable to considerable modification if the local conditions are in any way altered. It is the custom, however, in most large gas works in this country, to work at a heat which gives a yield of about 11,000 cubic feet of gas per ton of coal, allowing six hours for the working off of each charge. This is generally termed a bright cherry-red heat, and represents a temperature of about 1,100° C. The actual temperature at which the distillation takes place is, however, lower than this, averaging about 800° C., but before the charge is completely burnt off, it is raised to the higher temperature of 900° to 1,000° C., or in some works even still higher.

The product of the volume of gas per ton of coal and its "illuminating power" tends to increase with the first factor, hence high heats, which mean large volume, are apparently more economical. But where gas of a certain fixed "illuminating power" above that of common coal gas has to be supplied, the economy of very high heats is nullified by the increased cost of enriching the poor gas so obtained. The shortened life of retorts and increased cost of firing also tell against the adoption of very high heats, and most works are content to carbonize at about the temperature named above. Where enriching material is expensive, it pays to work at still lower temperatures, and so obtain a better gas at the sacrifice of quantity. Except in very exceptional instances, the economy of working to a make of less than 10,000 feet per ton of good caking gas coal is more than questionable. The quantity and quality of gas from a given weight of coal, though mainly determined by the temperature of distillation, are also affected by the pressure within the retort. This is controlled by the exhauster, and is usually gauged by the pressure in the hydraulic main. This is generally maintained slightly below that of the atmosphere, the difference being represented by the pressure exerted by a column of water from 0·5 to 1·0 inch in height. Where rich gas is required, however, the pressure in the hydraulic main is that of the atmosphere. The ultimate effect of increasing the pressure on coal during its destructive distillation is to diminish the volume of the gas, while enhancing its quality. Where the pressure in the retorts is equal to, or above, the atmospheric, gas escapes at cracks and imperfect joints. On the other hand, a considerable vacuum within the retorts is accompanied by the ingress of appreciable quantities of air and furnace gases, unless the retorts are quite sound, and the lids hermetically sealed. The greater transference outwards in the one case, and inwards in the other, account mainly for the differences in the quality and quantity of gas obtained when the pressure at which it is evolved is different, but the increased production of tar when the pressure is increased shows that the products of the distillation are also directly affected.

The best way of ensuring a high yield of gas from the coal undergoing distillation, and at the same time avoiding the breaking down of gaseous olefines and other illuminating hydrocarbons, is to introduce into the retort a stream of inert gas, which has the effect, *cœteris paribus*, of reducing the partial pressure of the coal gas, or, rather, of its more important constituents, within the retort. The gas which has so far been used for this purpose with the best results is simple water gas, which acts in the same manner on the gas evolved from the coal in the retort as it acts in carburetted water gas plant on the gas evolved from the oil. In both cases it has the effect of improving the quality of the gas liberated while maintaining or even increasing the quantity. In 1862 Thénius had passed highly superheated steam over the coal undergoing carbonization in the retorts, and in 1883 Guéguen spoke well of this procedure, and referred to the advantage of passing any gas which was inert, or at least exercised no harmful influence, through the retorts. Jouanne, in 1893, reported that he had obtained a largely increased yield of gas from the coal by thus injecting highly superheated steam into the coal gas retorts. V. B. Lewes has lately reported favourably on the passage of simple water gas into the retorts while the carbonization of coal is in progress, and this procedure has been followed at several gas works on an extensive scale. The results obtained with it at Remscheid have been exhaustively reported on by Lecomte,* and may be referred to here. The mixture of coal gas and water gas, obtained when water gas was passed into the coal-gas retorts, contained on the average 28·65 per cent. by volume of water gas, of which the average composition by volume was:—Carbonic acid, 4 per cent.; carbonic oxide, 38 per cent.; and nitrogen and hydrogen, 58 per cent. The mean calorific power of this gas was 283 B.T.U. per cubic foot. The yield of coal gas per ton of coal carbonized averaged 9,527 cubic feet, having an "illuminating power" of 11·2 candles when burnt at the rate of 5·3 cubic feet per hour in the Elster Argand burner, and a calorific power of 596 B.T.U. per cubic foot. The mixed gas containing 28·65 per cent. of water gas had an "illuminating power," when tested in the same manner, of 9·7 candles, and a calorific power of 541 B.T.U. per cubic foot. Assuming that the water gas had neither any "illuminating power" of its own, nor any natural deteriorating influence on the "illuminating power" of the coal gas, the illuminating power of the mixed gas would, according to the proportions of the constituent gases, be calculated to be only 8·0 candles. Therefore the mixed gas appears to have had its "illuminating power" increased by 1·7 candles in virtue of the admixture having taken place in the retorts. Similarly it appears to have had its calorific power increased by 35 B.T.U. per cubic foot. Representing both the "illuminating power" and the calorific power of the mixed gas by 100, the proportion of this value due to the admixture being effected in the retorts would be 17·6 in the case of "illuminating power" and 7·0 in the

---

* *Journ. of Gas Lighting*, lxxxii., 447, 668.

case of calorific power. These are substantial gains in the quality of the mixed gas, and they indicate that certain components of the coal gas as evolved from the retorts are retained, owing to the reduction in their partial pressure and in the duration of their exposure to the heat radiated from the walls of the retorts in the mixed gas which would be broken up or deposited if the water gas were not passed through the retort. It does not appear to have been established directly what is the nature of these components which are thus preserved and retained, but it may be surmised that ethylene is prominent among them. Lecomte does not appear to have observed any considerable gain in the volume of gas evolved from a ton of coal under these conditions, and it is conceivable that the volume is, in fact, less than when the coal is carbonized under conditions similar in all respects except that the admission of water gas is omitted. Results even more favourable to the process of passing water gas into the coal-gas retorts than those observed by Lecomte have been found by others who have investigated the process.

Croissant has made trials of the process of introducing water gas into retorts in which coal is undergoing carbonization, with a view especially to ascertaining the effect of the process on the volume and calorific power of the gas obtained.* He varied the proportion of water gas admitted from 25 to 51½ volumes per 100 volumes of coal gas evolved, and ultimately arrived at conclusions which may be summarized as follows:—The most favourable results, judged from the calorific value of the gas secured, are obtained when from 40 to 50 cubic feet of water gas are introduced into the retorts, for the first forty-five to seventy-five minutes after charging, per 100 cubic feet of coal gas evolved during the complete working off of the charges. The proportion of water gas and the time during which it is introduced should both be varied within the limits stated, according to the quality of the coal undergoing carbonization. There is an increase both in the total yield of hydrocarbons in the gas, and in the calorific value of the total production of gas, with an increase in the heat of the coal gas retorts. The calorific power of the mixed gas produced, when 40 to 50 volumes of water gas are admitted per 100 volumes of coal gas, can be raised to very nearly that of the coal gas, ordinarily obtainable from the same description of coal, by adding as many ounces of benzol per 1,000 cubic feet of water gas used as there are volumes of water gas added per 100 volumes of coal gas.

The Calorific Balance of the Carbonization of Coal.—It may be interesting to refer briefly to the distribution of the

---

* *Journ. für Gasbeleuchtung*, 1903, p. 1068; *Journ. of Gas Lighting*, 1904, lxxxv., 337 and 404.

energy of the coal among the products of its carbonization. Comparatively little exhaustive work on this subject has been done, and only two series of researches need be referred to here —viz., those reported by Euchêne in 1900, and some earlier ones by P. Mahler on Commentry coal.* In the latter the products were obtained by the distillation on a large scale of this coal by the Paris Gas Company, and the calorimetric tests were made with the calorimetric bomb. One ton of the coal had a heating value of 7,542,032 calories. The coke produced had a heating value of 7,132,040 calories per ton, and the heating value of the tar from all sources was, on the average, 8,941,214 calories per ton. The dry gas had a heating value of 11,289,300 calories per ton. The specific gravity of the gas was 0·404, and, therefore, the heating value of one thousand cubic feet of gas at 0° C. and 760 mm. was 164,342 calories. The products and their heats of combustion are shown in the following table:—

Products.	Percentage of the Coal.	Heat of Combustion	
		Of the Amount of each Product yielded by 1 ton of the Coal.	In Percentage of the Heat of Combustion of the Coal.
		Calories.	
Coke, ...	65·66	4,682,683	62·09
Gas (dry), . . .	17·09	1,929,252	25·58
Tar, ...	7·81	671,231	8·90
Ammoniacal liquor, .	9·36	...	...

The total amount of heat yielded by the products from 1 ton of coal is, therefore, 7,283,166 calories, and on deducting this from the heat of combustion of 1 ton of coal—viz., 7,542,032 calories, we find a difference of 258,866 calories.

The total loss of heat during carbonization, therefore, amounts to 258,866 calories per ton of coal, or 3·43 per cent. of the calorific value of the coal. If the carbon deposited in the retorts and the naphthalene separated in mains were included in the account, the loss shown would be somewhat reduced. The actual loss of the energy of the coal by the process of carbonization is, therefore, according to Mahler's investigation, very small.

The difference observed by Mahler—viz., 258,866 calories per ton of coal carbonized, may be taken to represent heat liberated by the process of carbonization. Euchêne's researches similarly indicate that a small quantity of heat is liberated during the carbonization of coal. He found that the same description of coal as that on which Mahler's investigation had been carried out

---

* *Comptes Rendus*, cxiii., 862.

liberated 64,530 calories per ton on carbonization. The difference between Euchêne's and Mahler's results is small, having regard to the difficulty of obtaining precise figures for the heat radiated and dispersed under the ordinary working conditions of carbonization, and the fact that the matter was attacked in a different manner by the two investigators. It is important to note, however, that both found a liberation and not an absorption of heat when coal undergoes carbonization. Though the observed absorption in both cases is barely greater than the possible errors of observation, &c., it seems, from the fact that the results already quoted and others obtained by Euchêne all indicate liberation rather than absorption of heat by coal undergoing carbonization, that the process of carbonization is, in fact, endothermic, though the quantity of heat liberated is quite small. This observation is of great significance, for it points to the possibility of carbonizing coal without expenditure of extraneous heat, provided all sources of loss of heat from the sphere of the operation could be avoided. The realization of this possibility in gas works' practice is, of course, out of the question, but it affords a definite ideal on which to set attention in improving carbonizing methods. The endothermic character of the carbonization process also explains the difficulty of arresting the progress of "fires" in coal mines and other stores of coal in which combustion is prevented by stopping the access of air.

Euchêne investigated the heat balance of the destructive distillation of two other descriptions of coal of a less highly bituminous character than the one already dealt with. These coals, on carbonization under ordinary gas works' conditions, were found to have a slight negative heat of decomposition. The one liberated 36,560 calories, the other 12,590 calories, per ton of coal carbonized.* A liberation of so small an amount of heat, relatively to the heat of combustion of the coal or coke, is negligible, as the amount is well within the range of probable errors of observation. Nevertheless, the figures indicate, like those previously quoted, that heat is liberated rather than absorbed during the carbonization process. It is highly desirable that further investigations should be made in the same direction, and with equal care, as the results cannot fail to be of great service to the gas industry. It is essential that they should be conducted on full size gas-works plant, as experiments of this nature on mere experimental plant or on a laboratory scale would not give results of any practical utility. Euchêne's work may well serve as a pattern for such investigations, as it was conducted with extraordinary care and thoroughness.

Retort Carbon.—A curious phenomenon of the destructive

---

* *Journ. of Gas Lighting*, lxxvi., 1080, 1141.

distillation of coal is the deposition of carbon on the sides of the retort. The breaking down of hydrocarbon vapours with the liberation of hydrogen, and hydrocarbons containing fewer carbon atoms to the molecule, is accompanied by liberation of carbon, and as this process is favoured by a high temperature, the deposit of carbon in retorts might be expected to be greatest where high heats are used. As a matter of fact, this is *cœteris paribus*, found to be the case in gas works. Where a slight vacuum is maintained in the retorts, the gas is removed from them very quickly after its evolution, and in such cases few hydrocarbon vapours are completely broken up, and the deposition of carbon is slight. Similarly the reduction in the partial pressure of the hydrocarbons in the retort by the introduction of some diluent gas, such as water gas, tends to lessen the amount of carbon deposited in the retort. A pressure within the retorts above that of the atmosphere favours the deposition of carbon. The deposit is very hard and close in texture, and is removed with difficulty. It is generally allowed to accumulate until it forms a layer from 1 to 2 inches in thickness, when it is chipped off with a chisel. The thick layer diminishes the capacity of the retort, and hinders the rapid transference of heat to the charge. In large works, with the retorts in continuous work, the carbon deposit or scurf is removed at intervals of about six months. Some methods designed to supersede the old method of removing the carbon with chisel bars have been proposed, but have not found general acceptance in this country, though they have been extensively adopted in Continental gas-works. The retort carbon is a marketable article (see the part of this work treating of Bye-Products.)

Composition of Crude Coal Gas.—The composition of crude coal gas may be roughly indicated with advantage at this point. As it leaves the dip pipes it contains a quantity of tarry matter in suspension, some of which is deposited in the hydraulic main, and the remainder in the condenser and the purifying plant. The bulk of the gas is hydrogen and methane, but it also contains carbon monoxide, nitrogen, carbon dioxide, hydrogen sulphide, a variable amount of gaseous hydrocarbons, ammonia, and certain other nitrogen and sulphur compounds. Of these hydrogen, methane, carbon monoxide, and the hydrocarbons which do not condense at ordinary temperatures are desirable constituents, while it is impossible to remove the nitrogen. The other constituents are either completely removed or appreciably diminished in amount by the processes to which the gas is subsequently subjected. The hydrocarbons are also affected by the subsequent treatment. The gas leaves the hydraulic main at a temperature of 50° to 60° C., and enters the condenser at a slightly lower temperature. If the condenser is efficient, the gas should leave it at about 15·5° C., or, in hot weather, very little above the atmospheric temperature. Its constitution is somewhat altered by condensation. Aqueous vapour is condensed until the gas leaves the condenser with only the normal quantity which saturates it at its temperature. Tarry vapours also are condensed, and carry down with them small quantities of lighter hydrocarbons, which would otherwise remain in the gas at the normal temperature. This washing out and solution of some of the illuminating hydrocarbons of gas by the tar is especially prevalent when the condensation is rapidly effected. On the other hand, rapid condensation tends to leave the gas supersaturated with naphthalene vapour, or loaded with suspended solid naphthalene in a state of very fine subdivision. Until recently the system of condensation was expected to be capable of reducing the quantity of naphthalene in the gas to not more than the amount which would saturate the gas at ordinary temperatures. Now, however, other special means are commonly adopted for reducing the proportion of naphthalene in cool gas. The aqueous vapour in condensing carries with it some of the ammonia, carbonic acid, and sulphuretted hydrogen of the crude gas, but the ammonia is in excess of the amount required to neutralize the acid radicles, as far as the liquor condensed in the hydraulic main is concerned, while the acids are in excess in the liquor thrown down in the condensers. It is, therefore, evident that the gas at the outlet of the condenser is somewhat altered in composition from what it was on entering the hydraulic main. It has lost a considerable quantity of aqueous vapour and of heavy tarry hydrocarbons, also small quantities of light hydrocarbons, ammonia, hydrogen sulphide, carbon dioxide, and very small amounts of other matters. The percentage by volume of the various constituents of gas from common gas coals, as it leaves the condensers, will lie between the figures given below:—

Composition of Gas from Common Coal after Condensation, but prior to Washing.

Hydrogen, ...	from 42	to 53	per cent. by volume.
Methane, ...	,, 32	,, 39	,, ,,
Carbon monoxide, ...	,, 3	,, 10	,, ,,
Hydrocarbons—			
Gaseous, ...	,, 2·5	,, 4·5	,, ,,
Light, condensable vapours,	,, 0·5	,, 1·2	,, ,,
Carbon dioxide, ...	,, 1·1	,, 1·8	,, ,,
Nitrogen, ...	,, 1·0	,, 5·0	,, ,,
Hydrogen sulphide, . . .	,, 1·0	,, 2·0	,, ,,
Ammonia, ...	,, 0·5	,, 0·95	,, ,,
Cyanogen, ...	,, 0·05	,, 0·12	,, ,,
Carbon disulphide, . . .	,, 0·020	,, 0·035	,, ,,
Naphthalene, ...	,, 0·005	,, 0·015	,, ,,

The gas also contains very small amounts of sulphur compounds not enumerated above, the nature of which is somewhat doubtful; some heavy tarry vapours, amounting, when condensed, to from 2 to 4 lbs. per 1,000 cubic feet of gas, and frequently a small quantity of oxygen. It is, moreover, saturated with aqueous vapour. Actually, naphthalene in a state of vapour and of finely-divided solid is usually present in quantity more than sufficient to saturate the gas with naphthalene vapour at the prevailing temperature. Some of the minor constituents enumerated above do not exist in the gas as such, but are, partially at least, in combination. For most purposes it is not misleading to regard them as free. The light condensable hydrocarbon vapours are such as are removed by alcohol according to Bunsen's method,* or by exposure to low temperature according to Claire-Deville's method,† and consist almost entirely of benzene and small quantities of its homologues. The nature of the gaseous hydrocarbons will be considered later.

The hydrogen will approach the highest figure given for it when high heats and low pressure prevail in the retorts. The quantity of methane is more nearly constant; high heats slightly diminishing it. Carbonic oxide varies somewhat unaccountably; probably the amount of moisture in the coal affects its formation. Also, some varieties of coal are known to yield it more freely than others. The gaseous hydrocarbons are highest with low heats, while vapours of aromatic hydrocarbons result more freely from high heats. The amount of hydrocarbons depends primarily on the nature of the coal, but their character chiefly on the heat and pressure in the retort. At the outlet of the condensers ordinary coal gas contains about 1·25 per cent. of carbonic acid. When the nitrogen exceeds 3 per cent. leakage may be suspected. The sulphuretted hydrogen, other sulphur compounds, ammonia, and cyanogen are chiefly dependent in quantity on the proportion of their elements in the coal carbonized. Special treatment of the coal during carbonization is, however, effective in altering the yield of ammonia to a very great extent. Tar is formed more freely at low heats, but the quantity in the gas at the outlet of the condenser should not be greatly affected by the heat of the retorts.

In gas from cannel, there are larger percentages of methane and hydrocarbons than in coal gas, and the hydrogen is proportionately less. Thus cannel gas contains 40 to 47 per cent. of methane, 35 to 43 per cent. of hydrogen, and from 9 to 15 per cent. total hydrocarbons, of which there is an appreciable diminu-

---

* Bunsen, *Gasometrische Methoden*, 144.

† *Journ. des Usines à Gaz*, 1889, 13.

tion in the course of the purification of the gas. The remaining constituents are present in very similar proportions to those in which they occur in common coal gas, though in recent years the bad quality of much of the cannel on the market has caused sulphur impurities to be in general higher than in gas from ordinary bituminous coal. The quality of cannel gas is affected in the same manner by the heat and pressure at which the cannel is distilled as that of gas from common coal, and need not be separately discussed. Cannel gives an increasing value for the product of volume of gas and "illuminating power" as the volume increases; consequently high heats are generally favoured in producing cannel gas. The practice is perfectly sound, for the larger volume of volatile matter driven off in a short time from cannel undergoing carbonization withdraws a larger quantity of heat in a given time from the retort, which must therefore be more highly heated in order to meet this greater call upon it. The coke from cannel is in general in small pieces, and being heavily loaded with ash, is of very little value. The tar from cannel contains a larger amount of "paraffins," or non-aromatic hydrocarbons than common coal tar, and does not yield pure products so readily in the hands of the tar distiller. The yield of tar is rather greater than that from ordinary bituminous coal. A ton of good cannel should yield at least 11,000 cubic feet of gas having an "illuminating power" of not less than 28 candles.

CHAPTER III.

COAL GAS—(*Continued*).

Impurities in Coal Gas.—Those constituents of crude coal gas which are harmful to it either by reason of their presence having a deleterious effect on its illuminating value, or by reason of the products of their combustion being noxious, are conveniently classed together as impurities. Those of the first order, which the gas engineer prefers, on the score of economy, not to have present in the gas distributed, since they lower its "illuminating power," calorific power, and the temperature of its flame in a marked degree, are carbon dioxide and nitrogen. Of these the first, very commonly known as carbonic acid, is the most harmful, and is present in the crude gas as a direct product of the destructive distillation of coal. The nitrogen, less harmful, is in part derived from the breaking up of the nitrogenous constituents of the coal, in part from the air occluded in the coal, and in part from air which has diffused through the retorts or has gained admission through cracks and imperfect joints in the apparatus. The specific heat of carbonic acid is greater than that of nitrogen, consequently a given proportion of the former in gas withdraws more heat from the flame produced on the combustion of the gas than the same proportion of nitrogen in it would do. As will be shown later, loss of heat to the flame implies decreased "illuminating power" and diminished capacity for raising a mantle to incandescence, and hence carbonic acid, volume for volume, depreciates the lighting value of the gas more than nitrogen does. The specific heats of equal volumes of carbonic acid and nitrogen, according to Regnault's determinations, are as 0·3307 to 0·2368, but the specific heat of the former increases with the temperature, and, therefore, at the flame temperature the effect of carbonic acid in depressing "illuminating power" and mantle luminosity will be greater, compared with that of nitrogen, than the above ratio would indicate.* This conclusion, based on theoretical considerations, is confirmed by empirical results. P. Frankland found that 60 per cent. of carbonic acid rendered ethylene non-luminous, whereas 70 to 80 per cent. of nitrogen was required to produce the same effect.† V. B. Lewes states that 1·26 volume of carbonic acid or 2·30 volumes of nitrogen mixed with 1 volume of coal gas rendered it non-luminous.‡ The diminution of "illuminating power," if uniform, would therefore, according to these observations, be at the rate of 0·3 or 0·23 candle for every 1 per cent. of carbonic acid or nitrogen in a mixture of one of these gases with coal gas. The diminution is not, however, uniform, and it also varies with the nature of the burner. The values quoted are for a Bunsen burner. If the carbonic acid does not exceed 2·5 per cent., the diminution in "illuminating power" is at the rate of about 0·5 and 0·8 candle for every 1 per cent. of carbonic acid for Argand and flat flame burners respectively. The precisely analogous values for small percentages of nitrogen are about 0·4 and 0·6 candle. These figures indicate the importance of restricting the quantities of carbonic acid and nitrogen in gas in all cases where high "illuminating power" is a primary consideration. The diminution of mantle illumination by reason of the presence of a small proportion of carbonic acid or nitrogen is far less marked, though quite appreciable. There is usually no attempt made to diminish the amount of carbonic acid formed

---

* The formula $W = 8{\cdot}272 + 0{\cdot}013112\,t + 0{\cdot}0000023628\,t^2$, where W is the specific heat of the molecular quantity (44 parts by weight) of carbonic acid at constant pressure, is commonly accepted.

† *Journ. Soc. Chem. Ind.*, iii., 271.

‡ *Journ. Chem. Soc.*, lxi. 334.

in the process of carbonization; the amount of nitrogen in the crude gas is kept as low as possible by the use of sound retorts and apparatus, and by the maintenance of a pressure slightly higher than the atmospheric within them. The removal of nitrogen from gas is impracticable, consequently nothing further can be done to diminish the amount present. The removal of carbonic acid is comparatively easy, and is more or less perfectly carried out in all works. Whether its removal is less costly than enrichment of the gas to the extent to which the carbonic acid depreciates its "illuminating power" depends on the relative costs of purification and enrichment, and may, on the basis of the above figures for the depreciation by carbonic acid, be computed for any particular case. Generally speaking, removal of carbonic acid is less costly than enrichment to compensate for its retention in the gas. But where, as is now commonly the case, gas for lighting purposes is consumed mainly in incandescent burners, the removal of carbonic acid from coal gas is hardly required, and enrichment to compensate for its retention in the gas will seldom be warranted by results.

Noxious Constituents.—The chief noxious constituents of crude coal gas are ammonia, hydrogen sulphide, and carbon disulphide. Other nitrogen and sulphur compounds are present in small amount, but do not generally form the subject of any special treatment of the gas. Ammonia, derived from the nitrogenous constituents of the coal, is removed from the gas on account of its marketable value, even where legislative enactments do not render its presence in more than a small (practically negligible) amount a penal offence. Hydrogen sulphide, or sulphuretted hydrogen, formed from the sulphurous constituents of the coal, is almost universally "wholly" removed from gas before its distribution to consumers. This complete removal of sulphuretted hydrogen is generally demanded by law even where no other restrictions as to purity are imposed on the gas works. Carbon disulphide, likewise a direct product of the destructive distillation of sulphurous coal, is partially removed from gas in most large gas works, the regulations imposed on gas companies generally limiting the amount of sulphur that may be present in the gas as carbon disulphide and sulphur compounds other than sulphuretted hydrogen to a certain small quantity. Mechanically carried forward with the gas there is also some tar which has escaped condensation in the condensers, and a small quantity of cyanogen, free and combined, will also require consideration.

The process of removing these impurities varies according to the approximation to perfection demanded of it, but the comprehensive scheme carried out where the highest degree of purification is enforced on the manufacturer—as in London—covers all essential points of the partial purification methods, and need alone be given detailed consideration here. It does not involve the removal of each impurity in strict sequence by a separate process, for fortunately some of the impurities aid the removal of others. Thus ammonia is a strong base, while carbonic acid, sulphuretted hydrogen, and cyanogen are of an acid nature. Hence ammonia removed from gas will serve to take up one or more of the acid bodies until it is fully saturated.

The amounts of the impurities in the gas as it leaves the condensers will, with Durham coal worked at a moderately high heat, be about as follows :—

						Grains per 100 cubic feet.		
Ammonia, . . .	0·65	to	0·95	%	by vol. or	200	to	300
Carbonic acid, . . .	1·20	,,	1·80	,,	,,	980	,,	1470
Sulphuretted hydrogen, .	0·90	,,	1·50	,,	,,	570	,,	950
Carbon disulphide, . .	0·020	,,	0·035	,,	,,	28	,,	50
Other sulphur compounds,	...		...			5	,,	8
Cyanogen, . . .	0·05	,,	0·10	,,	,,	50	,,	100
Naphthalene, . . .	0·005	,,	0·015	,,	,,	12	,,	35

GAS PURIFICATION.

Washing or Scrubbing the Gas.—The first stage in the removal of gaseous impurities is invariably the washing or scrubbing of the gas with water, or, in practice, with the liquors condensed in the hydraulic main and condenser. These liquors, though containing ammonia, sulphuretted hydrogen, and carbonic acid, are not fully saturated, and are capable of absorbing much more of each of these impurities. With them is generally mixed the liquor or washing-water of the last stage of the washing process, which likewise contains a small quantity of each of these impurities. It is desirable to perform the whole of the washing of the gas with as small a bulk of water as possible, so that the resultant liquor may contain a high percentage of ammonia, and that the subsequent recovery of the latter may be rendered as economical a process as possible, through the avoidance of handling a large quantity of water per unit of ammonia. The ammonia taken up by the liquor enters into combination with the carbonic acid and the sulphuretted hydrogen in varying proportions, and also with the cyanogen absorbed, so that the liquor will contain both the acid and neutral carbonates, the acid and neutral sulphides, thiocarbonate, cyanide, thiocyanate, and ferrocyanide. The liquor generally also contains sulphate, thiosulphate, sulphite, chloride, and traces of acetate. Many of these salts are, however, present in only small quantities, and the most important factors to the gas engineer in the composition of gas liquor are the quantities of carbonic acid and sulphuretted hydrogen combined in it, and their proportion to the quantity of ammonia present. As neither acid radicle exists in the liquor combined in only one proportion with the ammonia, there is no precise theoretical limit (the maximum theoretical limit, where the whole of the carbonic acid or sulphuretted hydrogen would be present as the acid ammonium salt, is never approached) to the amount of carbonic acid and sulphuretted hydrogen which a given quantity of ammonia in the liquor can absorb, but in practice it is found that the saturated liquor from washer-scrubbers contains somewhat more of the acid radicles than would suffice to form the neutral salts with the ammonia with which they are combined. One combining equivalent of ammonia may be expected to absorb carbonic acid or sulphuretted hydrogen to the extent of $1\frac{1}{6}$ to $1\frac{1}{4}$ combining equivalent of one or both of these acid bodies. In other words, ammonia will take up sufficient sulphuretted hydrogen and carbonic acid to be wholly converted to the neutral salts, and will then continue to absorb them, until at least one-sixth of the amounts absorbed to form the neutral salts has been in addition absorbed. The absorption would, doubtless, continue further, but the practice of gas works is to remove the liquor from further contact with the gas at this stage. The approximate amount of work done by the ammonia of the gas towards the removal of the acid impurities is now evident. The most important consideration is to effect the removal of the ammonia by means of as small a volume of water as possible, and at an expenditure of as little power as practicable. Towards these ends, innumerable mechanical devices have been brought forward, but space is not available for their detailed description.

Tar Extractors.—To prevent the clogging of the scrubbers proper with tar that has escaped deposition in the condenser, the gas is very commonly passed through a small scrubbing apparatus, known as a tar extractor, before it enters those vessels. The principle involved in this apparatus is the subjecting of the gas to friction by causing it to pass through a large number of small perforations in metal plates, which are arranged to offer more or less resistance and obstruction to the direct passage of the gas, according to the quantity of tar to be removed, the situation of the apparatus, and the pressure at which it is designed to work. In some designs, the number of perforations presented to the gas is regulated automatically by the quantity of gas passing into the apparatus in a given time, so that the scrubbing effect of the plant is the same whatever the rate of flow (within fixed, but tolerably wide, limits) of the gas. One of the most popular tar extractors in this country is made by

C. & W. Walker. A tar extractor which has been used for many years in Continental gas works has lately come into favour in this country also. It is named after its inventors, Pelouze and Audouin, but is very commonly referred to as the "Pelouze" or "P. & A." condenser or tar extractor. It consists of a double-walled balanced bell contained in an outer casing, and rising or falling in a seal as the pressure of the inflowing gas increases or diminishes. The outer wall has a number of narrow slits, the inner wall a number of holes. The gas passes through these openings, which are interjoggled in the two walls of the bell, so that it is compelled to take an indirect course. The number of openings exposed for the passage of the gas is automatically regulated by the rise and fall of the bell with the pressure to correspond with the volume of gas to be dealt with. Thus, within the comparatively wide range of the capacity of a particular example of this apparatus, the gas invariably obtains the same treatment; the number of openings through which it can pass varying precisely with the quantity. The gas thus passes through an opening at very nearly the same rate of flow whatever the output of gas. Both the outer and inner walls of the bell often consist of two or more parallel or concentric plates. Sometimes these tar extractors receive the gas direct from the hydraulic main, and, therefore, at a high temperature, but this plan of working, though it offers some advantages, is open to serious objection unless the gas passes at once from the Pelouze apparatus to an oil-charged washer for the extraction of naphthalene. A tar extractor separates some ammoniacal liquor as well as tar from the gas. An efficient tar extractor reduces the amount of tar passing forward with the gas to an inappreciable quantity, and saves clogging in the scrubbers.

Tower Scrubbers.—Gas engineers are by no means unanimous as to the best washer and scrubber to be used. The tall tower scrubbers, packed with coke or wooden chequer work, down which water or weak liquor trickles, and meets the gas passing up the spaces left by the packing material, form a prominent feature in most old gas works, but are now generally discarded in favour of the more compact "washer-scrubbers," of which there are several efficient varieties on the market. In the tower scrubbers the water or weak liquor is generally distributed on to the upper layer of coke, or other filling material, by a revolving distributor or sprinkler driven mechanically. Two at least of these scrubbers must be used in series, the one up which the gas first passes being fed with the weak liquor from the hydraulic main, condenser, and last scrubber. The ammonia already taken up in the weak liquor is, therefore, able to take out carbonic acid and sulphuretted hydrogen from the gas, while a further quantity of ammonia is absorbed. The second scrubber, when two only are worked in series, is fed with clean water, and must reduce the amount of ammonia in the gas to within the prescribed limits. The efficiency of tower scrubbers depends on their height, or more correctly, on the sum of the heights of the scrubbers worked in series, and also on the extent to which the gas is split up in its passage through the vessels, and the regular distribution of the water throughout the filling material. Unless the gas is thoroughly freed from tar coke-filled scrubbers choke readily, and the gas passes up by a few large channels only. Washers are very generally used before the old type of scrubbers. In them the gas is passed in finely-divided streams through a number of water seals. The friction and contact with the water remove tar and a quantity of ammonia. They are not generally filled with clean water, but with the overflow liquor from the scrubbers. The depth of water seal varies, but the simple washer should never throw more than 3 inches water pressure. The washer was often placed at the bottom of the tower scrubber, and the gas passed out of it direct into the latter piece of apparatus. The old types of washers were accused of greatly deteriorating the "illuminating power" of the gas passing through them, and doubtless in the winter months the accusation was often well founded.

C. Carpenter has lately adopted tower scrubbers, packed with metal bundles similar to those used in the "Standard" washer-scrubber (*vide infra*), and has thus succeeded in effecting a great economy in the size of tower required for dealing with a given make of gas. He compares the areas and wetted surfaces in the different types, and the following figures, taken from his comparisons, are instructive:—

SCRUBBERS TO DEAL WITH A MAXIMUM (WINTER) MAKE OF 5 MILLION CUBIC FEET PER DIEM, DIMINISHING TO A MINIMUM (SUMMER) MAKE OF 2 MILLIONS.

	Square Feet per Million.					
	Total Area.		Area of Gas Way.		Area of Wetted Surfaces.	
Millions passing per diem, .	5	2	5	2	5	2
1. Two tower scrubbers, 70 feet high 20 feet diameter, working in series, packed with ¼-inch boards ¾ inch apart, .	63	157	47	118	105,557	263,894
2. "Standard" washer-scrubber, discs 8 feet in diameter, . . .	8·6	21·5	2·7	6·8	4,934	12,336

Similar figures for a pair of Carpenter's tower scrubbers, which for a maximum (winter) make of 2 million cubic feet per diem are 26 feet high and 2½ feet square, are as follows:—

	Square Feet per Million.					
	Total Area.		Area of Gas Way.		Area of Wetted Surfaces.	
Millions passing per diem, .	2	1	2	1	2	1
Carpenter's towers, packed with iron bundles, . .	3·1	6·2	2·6	5·1	6,075	12,150

It will be seen from these figures that Carpenter has succeeded in making the tower scrubber practically as compact an apparatus, for the removal of ammonia from a given quantity of gas, as the highly compact and efficient washer-scrubbers about to be referred to. He further divides his towers, by means of vertical partitions, into several chambers, of which the number worked in parallel is proportioned to the quantity of gas to be dealt with, so that at all times practically the same relation is maintained between the area of scrubbing surface and the volume of gas treated, instead of following the usual plan of maintaining a constant area of scrubbing surface irrespective of fluctuations in the volume of gas passing.

The "Standard" Washer-Scrubber.—Of the modern washer-scrubbers, the "Standard," made by Kirkham, Hulett & Chandler, is one of the best known and most efficient, and may be described as typical. It is shown in Fig. 21, in end elevation in B, and in side elevation and part section in A. C and C′ are the gas inlet and outlet pipes. The spur wheel, D, on the shaft, E, is revolved slowly by an engine, thereby causing the bundles, F, of wood and metal attached to the shaft to be carried round with it. The bundles in the lower segment of their circular course pass through the water or weak liquor in the bottom of the washer, and rise up thoroughly wetted by it. By the careful packing of the apparatus the only passage for the gas through it is from the central passage outwards through the interstices in the wetted bundles, and back towards the central line through the narrower open space shown in each section of the washer. The gas takes a similar course through each section, and is, therefore, brought into very thorough contact with the wetted surfaces. The weak liquor or water with which the apparatus is fed passes

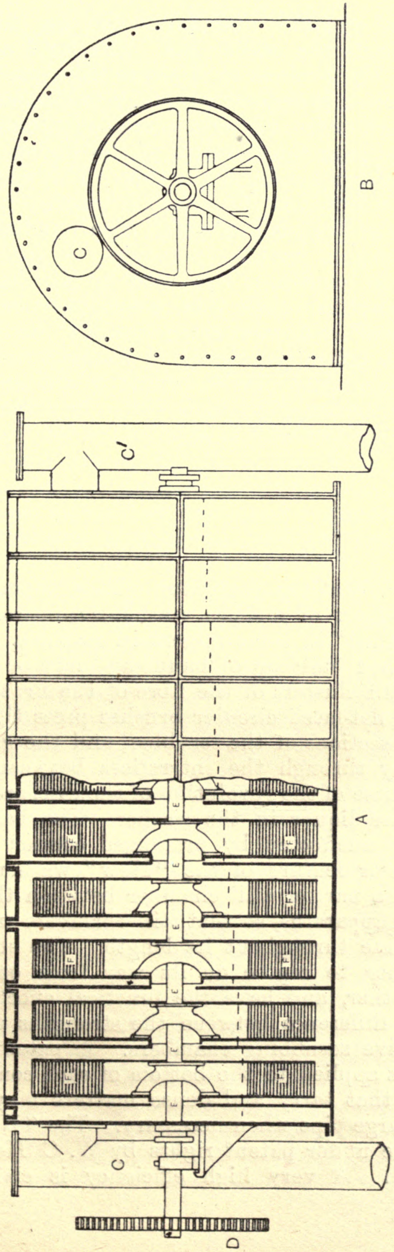


Fig. 21.—"Standard" gas washer scrubber.

B, end elevation; A, side elevation and part section; C, gas inlet pipe; C′, gas outlet pipe; D, spur wheel; E, shaft; F, bundles.

through it in the opposite direction to the gas, thus becoming stronger as it meets the cruder gas. The level of the liquor naturally falls in the sections as it passes from one to the other. From the last section it siphons out and is led to the liquor tank. In the liquor overflow there is often placed a hydrometer covered by a bell glass, so that the strength of the liquor passed away may be read off approximately at any time. This washer requires little power to drive it, and throws little pressure in comparison with the amount of work it performs. The bundles do not clog if the tar extractor is working properly. A special patented pattern of wooden bundles is now used by Kirkham, Hulett & Chandler in place of the older iron or composite bundles. Two of these "Standard" washers working in series, the last being fed with clean water, suffice practically to free gas from ammonia. They are made in various sizes according to the amount of gas passing per hour. Roughly, each cubic foot content of the "Standard" washer-scrubber is as effective for the removal of ammonia as 20 cubic feet in the old tower scrubbers, consequently the scrubbing apparatus on a gas works is now far more compact than formerly. Scrubbers working on nearly the same lines are in almost universal use in this country and on the Continent.

The "New" Washer-Scrubber.—This apparatus is one of the most efficient of modern washer-scrubbers. It differs from the "Standard" in some important respects. In place of revolving cylinders built up of bundles of iron or wood, it has discs studded with clusters of the fibre of the Brazilian bass or piaçaba. These flat-faced circular brushes press tightly against the faces of the sections of the scrubber, and the gas is obliged to work its way through the interstices between the fibres, which, in the course of the revolution of the disc, are continually moistened by the liquor in the washer. The bass fibres are very tough and unaffected by prolonged contact with liquor and gas. Another feature of the "New" washer-scrubber is the insertion of a narrow still chamber between the scrubbing chambers of the apparatus, so that still chambers and scrubbing chambers alternate throughout its length. The still chambers permit the liquor to repose on its way from one scrubbing chamber to another, and have the practical effect of creating a more marked difference between the strengths of the liquor in the consecutive scrubbing chambers. A patented catch or settling-vessel is applied to the bottom of each compartment of the washer, so that tarry and dense matters may be run off through a discharge pipe when necessary. The "New" washer-scrubber is made under patent rights by W. C. Holmes & Co., of Huddersfield. A very high efficiency is claimed for it,

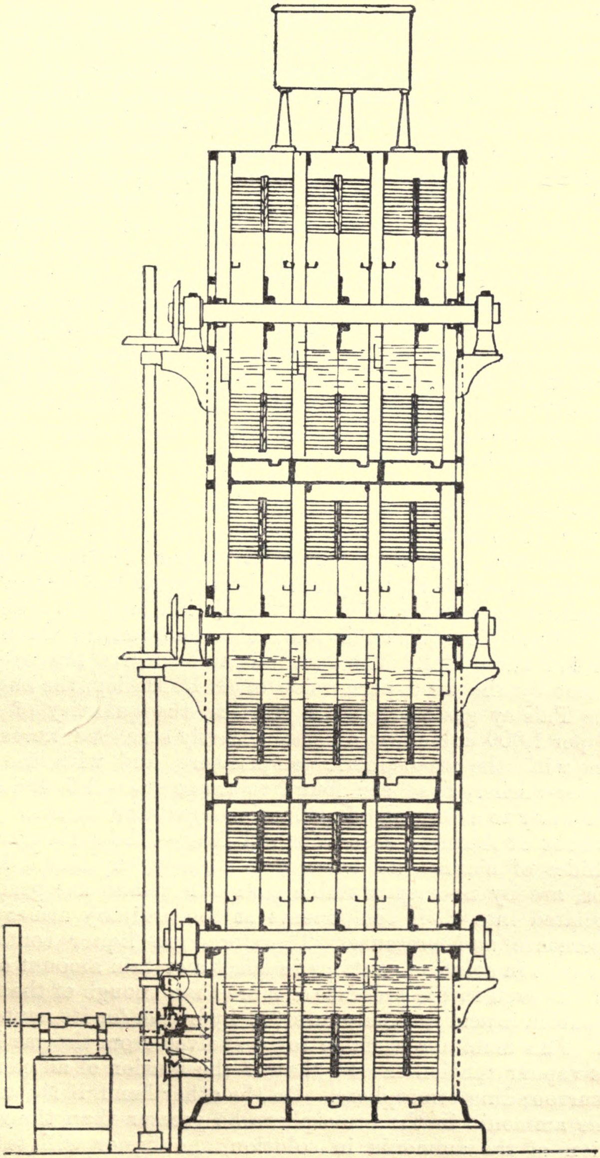


Fig. 22.—"New" washer-scrubber (vertical type).

especially in respect of the large volume of gas which it is able to cleanse with a given quantity of water. In a trial of a six-chamber apparatus of the customary horizontal type at the Kendal gas works, Lewis T. Wright found that previously unscrubbed gas passing at the rate of 200,000 cubic feet per diem was completely freed from ammonia, and that the liquor produced showed the exceptionally high strength of 29 ounces by the distillation test. He found in the same trial that 860 cubic feet of gas were completely scrubbed per diem for every cubic foot of gross volume of the washer-scrubber, but this figure is low compared with results obtained with larger washers of the same type. The customary pattern of this washer-scrubber is the horizontal, with from six to twelve or more scrubbing compartments and discs, and it is withal the most economical for general use. For special cases where ground area is limited, the washer is, however, ingeniously built up in vertical form as shown in vertical section in Fig. 22. Such an apparatus has been erected at the Paisley gas works. During a two days' test, this washer passed an average of 1,682,500 cubic feet of gas per 24 hours—though constructed to deal with only 1,500,000 cubic feet per 24 hours—and completely removed the ammonia at an expenditure of 1·02 gallons of water per 1,000 cubic feet of gas cleansed. The liquor produced averaged 8·5° Twaddel in strength, or say 20½ ounces by the distillation test. The gas scrubbed per diem per cubic foot cubical content of the washer was 1,412 cubic feet. The author is able to give the results of this test by the kind permission of G. R. Hislop, the engineer of the Paisley gas works. In practice, the quantity of water used per 1,000 cubic feet of gas, perfectly scrubbed, necessarily varies with the atmospheric temperature, and with the New scrubber-washer, has been found to range from 1·5 gallons in the summer to as low as 0·5 gallon in the winter months.

Traces of Ammonia in Washed Gas.—The carbonates and sulphides of ammonium formed, as already explained, in gas liquor, are by no means stable compounds, and are gradually dissociated into their components at the ordinary atmospheric temperature and pressure. Therefore, gas liquor containing these salts in solution contains in effect a certain amount of free ammonia even in the presence of more than enough of the feebly acid carbonic acid and sulphuretted hydrogen for its neutralization. This ammonia is liable to be evolved from the gas liquor if its vapour tension exceed that of the tension of ammonia in the surrounding atmosphere. On the other hand, if the tension of the ammonia in the atmosphere be greater than the vapour tension of the ammonia in solution, the liquor will take up ammonia from the atmosphere until an equilibrium is established and the tension of ammonia in the liquor is balanced by its tension in the atmosphere. In scrubbers, therefore, such an equilibrium soon becomes established, and liquor containing a certain amount of ammonia will remove no ammonia from gas containing less than a certain amount of it, but, on the other hand, may give off ammonia to the gas. The difficulty of removing very small amounts of ammonia from gas by means of water is, therefore, very great. Water free from ammonia will take up traces of ammonia from gas, but no sooner has it taken up a small amount than it becomes a solution of ammonia, and is prepared to give up ammonia to gas, which is quite free from it. Therefore, only an approximation to freedom from ammonia can be secured in washers, but such an approximation may become more and more nearly perfect provided sufficient clean water is used. The practical limit is probably attained when the gas contains no more than 0·5 grain of ammonia per 100 cubic feet. Scrubbed gas containing as much as 1·5 to 2·0 grains of ammonia per 100 cubic feet will appear neutral to test paper, owing to the effect of the acid impurities in the gas in masking the alkalinity of the ammonia, and this is the degree of perfection to which the removal of ammonia by washer-scrubbers is usually pushed. Such gas is commonly said to be "free" from ammonia.

Removal of Carbonic Acid.—The gas after passing the scrubbers is, or should be, quite free from ammonia, as indicated by the most delicate turmeric paper, and contains about 500 to 800 grains of sulphuretted hydrogen, and 700 to 1,100 grains of carbonic acid per 100 cubic feet. It also contains about 30 to 45 grains of sulphur compounds other than sulphuretted hydrogen per 100 cubic feet, and, unless special materials have been used for washing as well as gas liquor and clean water, also some cyanogen compounds. These impurities are removed, or diminished in quantity, by means of materials in the solid state in most gas works, though schemes have been propounded for the complete purification of gas by washing with solutions of various substances. These schemes may be dismissed for the present as outside the ordinary routine of gas-works purification. The carbonic acid is the first impurity to be removed completely from the gas, after the scrubbing process, in works where no restrictions are imposed to prevent the adoption of the most economical scheme of gas purification. The reagent invariably employed for the removal of carbonic acid is slaked lime. Lime also removes sulphuretted hydrogen, but it is not generally economical to use it for the purpose, as the sulphur is not readily recoverable. The materials actually in use at the present day for the removal of sulphuretted hydrogen from gas are hydrated ferric oxide, either alone or mixed with alkaline materials, and Weldon mud, the active constituent of the latter being the manganese dioxide. The material by which carbon disulphide is removed or reduced in amount is a compound of lime prepared by acting on hydrated lime with gas containing sulphuretted hydrogen. This material is prepared *in situ* from lime, consequently the only raw materials used in purification which need be considered are lime, ferric oxide, and manganese dioxide. Of these, lime acts also as an absorbent of the cyanogen compounds in gas, but the cyanogen so absorbed cannot be subsequently recovered on a commercial scale from the lime. Ferric oxide, however, absorbs the bulk of the cyanogen compounds likely to be present in crude coal gas, and in the absence of ammonia, retains them in a form in which they can be subsequently recovered on a commercial scale. Hence if cyanogen compounds are not removed from the gas by a prior washing treatment, and it is desired to recover them by the agency of the oxide, it is essential that the gas should enter the purifiers charged with oxide before it is admitted to a purifier charged with lime.

Mode of preparing and using Lime.—Lime in its fresh caustic state should consist wholly of oxide of calcium (CaO). It is prepared by heating limestone or chalk to a red heat in an atmosphere renewed as frequently as possible, since the carbonic acid evolved by the decomposition of the limestone hinders further decomposition if it remains in the kiln or burning chamber. In some gas works the lime is burnt in kilns fed continuously at the top with a mixture of 2 to 3 volumes of limestone and 1 volume of coke. The product is drawn off at short intervals from the bottom of the kiln, which is thus kept in continuous work. The size of the kiln and the rate of feed are such that the material takes from two to three days in passing through the kiln. Much of the ash of the fuel cannot be removed from the lime produced, consequently the coke must be as free from ash as possible, but, on the other hand, must be slow burning, or it will be consumed before the chalk has been thoroughly converted to lime. In this connection it is necessary to recall the fact that silica and alumina combine with lime to form di- and tri-calcium silicates and aluminates, and if the temperature of the kiln is at all high, the silica and alumina of the coke ash will unite with lime to form the tolerably stable tri-calcium compounds. Hence the silica and alumina of the ash must be considered to render 2·8 and 1·65 times their respective weights of lime inert, as their compounds with calcium are not decomposed on slaking. It is evident, therefore, that the presence of the coke ash not only entails the cumbering of the lime with the weight of the ash, but also the rendering valueless of a considerable quantity of the lime itself. Doubtless some of the clinker and inert material can readily be removed from the lime by hand picking, but the importance of using a coke of low content of ash for lime burning cannot be over estimated if economy is to be attained. To the deleterious effect of ash is to be traced the immense superiority of lime made from limestone or chalk by the aid of gaseous fuel. If ordinary kiln lime is used for purification, care should be taken to see that it is not loaded with siliceous compounds; with flare lime the quality is only affected by the quality of the limestone from which it is burnt, and the degree of perfection of the burning.

A cubic yard of good kiln lime weighs about 11 cwts. Slaking on the large scale, to the degree of moistness suited to gas purification, requires about 135 gallons of water per cubic yard of unslaked lime, and nearly 2¼ yards of slaked lime are formed from each yard of the unslaked material. A yard of lime slaked with the above-quoted amount of water weighs about 11 cwts. Owing to the expansion and heating of quicklime on access of moisture, its storage is attended with some risk. On a gas works the lime is usually slaked in bulk as soon as possible after burning, but it should not even then be stored for any length of time before use, as it rapidly deteriorates in quality by absorbing carbonic acid from the air. When it becomes necessary to store lime after slaking, it should be piled in large heaps, presenting as small a surface as possible. The lime will not then greatly deteriorate on keeping, except for some 12 inches below the surface of the heap.

The spent lime from the vessels in which the carbonic acid is removed from gas consists chiefly of calcium carbonate, and is sometimes reburnt to lime on the gas works. This reburning of spent lime is economical only where new lime is somewhat costly, as the spent material is with more difficulty converted to lime than the natural chalks. The difficulty of reburning spent lime lies partly in the large amount of moisture it contains, and partly in the presence of calcium salts other than the carbonate, especially the sulphate. Hence, where chalk is plentiful and fresh lime can be made at a cheap rate, the reburning of lime will hardly be undertaken; but at works situated far from good chalk supplies it should certainly be adopted. Reburning is always carried out by the aid of gaseous fuel. The waste heat from the burning chambers is generally utilized to drive off the greater part of the moisture from the lime. Only two systems for reburning spent lime have been extensively used. The oldest is Hislop's patent process, by which the gas from a producer is used to heat several small kilns set in one bench. The upper part of the bench is used as a drying chamber, and the spent lime remains in it about eight hours. It is then raked down and spread in layers 3 or 4 inches deep on the shelves in the kiln. This is heated by the producer gas burning within it, the shelves being arranged so that the burning gas passes over the lime on each shelf. Great stress is laid on the scrubbing action of the producer flame traversing the spaces between the shelves. The lime on each shelf is carefully turned once every half hour by means of a rake introduced at the doors forming the front of the kiln. The burning is finished in from four to eight hours, the charge of lime is withdrawn, and, unless the original lime was free from clinker, slaked while still hot. The process involves the frequent manipulation of the lime, but in careful hands will yield consistently a product containing not more than 8 per cent. of calcium carbonate. The second process, under Stokes' patents, is designed to avoid as far as possible the handling of the lime during burning, and the labour required is very little. The plant consists of a cylinder about 50 feet in length and 5 feet internal diameter, lined with firebrick, and set at a slight inclination to the horizontal on rollers, on which it revolves at the rate of about 1 revolution per minute. The gas from a producer passes in at the lower end of the cylinder, and is there supplied with the air for its combustion. The spent lime is raised by an elevator to the upper end of the cylinder, and is fed into it automatically. The upper 8 feet of the cylinder is larger in diameter than the remainder, and forms a chamber in which the lime is retained until it has parted with the bulk of its moisture. As the cylinder revolves the lime passes automatically out of the chamber and down to the lower end of the cylinder, meeting the flame of the producer gas, which by radiant heat raises it and the exposed parts of the cylinder lining to a high temperature. The passage of the lime down the cylinder takes from half an hour to an hour, according to the rate of the revolution, which must be proportioned to the rate of feed and the character of the spent lime. The lime drops from the burning cylinder into the upper end of a second similar inclined cylinder, up which the secondary air for the combustion of the producer gas passes. This lower cylinder also revolves and serves the purpose of cooling the lime, which gives up its heat to the air passing up for the combustion of the gas in the upper cylinder. The lime passes out of the cooling cylinder into trucks, in which it is conveyed to the slaking floor. A small engine is required to turn the cylinders and work the elevator; the supervision needed is small, and the labour is reduced to a minimum. As the labour required does not rise in proportion to the size of the plant, it is especially suitable for large works, where spent lime can be supplied to produce 1 to 2 tons of burnt lime per hour. The process is continuous, and the plant is equally adapted for the burning of chalk. The spent lime or chalk passes through a crusher, in which it is reduced to a rough powder before it enters the cylinder. In its passage down the burning cylinder every particle becomes exposed to the flame of the gas. Other schemes have been proposed for the reburning of gas lime, among which the application of the Yeadon revolving retort (see p. 115) may be mentioned. In any plan for burning lime, arrangements must be made for the removal of the carbon dioxide evolved by the decomposition of the calcium carbonate from the vicinity of the material, or the whole of the carbonate will not be decomposed whatever the temperature employed. Practically, this removal of the carbon dioxide from the atmosphere surrounding the material is generally effected by a stream of furnace gas passing over it.

Testing Chalk.—The testing of chalk and lime on a gas works is not usually very exhaustive. The chalk should be as nearly as possible pure calcium carbonate, in a slightly moist condition. It should not contain much magnesium, and must on no account contain more than 5 per cent. of silicon, aluminium, and iron. The less of these ingredients the better will be the lime produced. The lime is seldom tested except for the amount of calcium carbonate present. If the nature of the chalk and fuel from which it is produced is unknown, it should also be tested occasionally for silicon, aluminium, and iron. The amount of carbonate present in lime may be ascertained by the ordinary methods for the estimation of carbonic acid as given in Fresenius' *Quantitative Chemical Analysis.* Where an accurate determination is required, the method of absorption tubes should invariably be used. These tubes may be filled and used precisely in the manner described by Fresenius, but special care must be taken that the calcium chloride used is free from alkalinity, and that the soda-lime tube is large enough. The author is in the habit of using an apparatus arranged as follows:—Following the evolution flask is a train of bulbs, containing a little concentrated sulphuric acid, then a U-tube containing pumice saturated with sulphuric acid, then a tube containing pumice impregnated with sulphate of copper dehydrated at 150° C., then a small U-tube containing sulphuric-acid pumice, then Liebig's bulbs containing a strong solution of potash, followed by a calcium-chloride U-tube, and that by another U-tube filled with calcium chloride, and this by bulbs or a bubbling tube containing strong potash solution. The potash bulbs and the calcium-chloride tube following are weighed together, before and after the evolution of the gas, with the usual precautions. To connect up to the inlet of the evolution flask whilst air is being drawn through the apparatus, are two bubbling tubes charged with potash solution. Of chalk or spent lime half a gramme is a convenient quantity to take for the estimation; of well-burnt lime 2 grammes. The weighed potash bulbs and U-tube will generally serve for two or three estimations before they need recharging. When spent lime or reburnt spent lime is being tested, the sulphate of copper tube must be of great capacity, and the sulphuretted hydrogen must be retained by it, as well as the hydrochloric acid vapours. A rough approximation to the amount of sulphide in the lime may be obtained by weighing the copper sulphate tube before and after the experiment, but it must be remembered that the figure so obtained is too high. The sulphuretted hydrogen may be oxidised in the evolution flask by adding solution of potassium chromate with the hydrochloric acid. The copper sulphate tube will then only be needed to catch the hydrochloric acid carried forward. For an accurate estimation of sulphide as well as carbonate in spent or reburnt lime, bulbs containing solution of arsenious acid or acidified solution of cadmium chloride must be placed at the beginning of the train of apparatus, and the sulphide obtained weighed as such, or oxidized to sulphate, and the latter precipitated with a barium salt. The use of sulphuric acid drying tubes avoids any risk of absorption of carbonic acid by alkaline calcium chloride. Many operators prefer potash bulbs to soda-lime tubes for the absorption of carbonic acid, and they certainly are easier of preparation. The U-tubes should be the variety with hollow glass stoppers ground in, which will be found to weigh true after being laid aside for some days while charged. Geissler's bulbs and drying tube may advantageously be substituted for the Liebig bulbs and U-tube.

A very convenient and trustworthy form of double absorption tube has been devised by J. S. Haldane for the estimation of small proportions of moisture and carbonic acid in air, &c. It may be used in place of the potash bulbs and ordinary U-tubes in the train of apparatus just described; it simplifies the analytical work and increases its accuracy. It is shown in the annexed illustration (Fig. 23). For removing moisture from a stream of air or inert gas and, if required, estimating its amount, both limbs of the tube are packed with pumice saturated with concentrated sulphuric acid, while in the tubes intended for the estimation of carbonic acid fresh soda lime is used in the first limb and pumice saturated with concentrated sulphuric acid in the second. The tubes in their original form were closed by well-fitting shallow corks, on top of which paraffin wax was run, but the stoppered form has recently been devised. For very accurate work the tubes should be weighed against a companion tube, similarly charged and similarly treated in all respects, except that it is not actually put in the train of apparatus used for the absorptions. The complete train of apparatus for the estimation of carbonic acid in chalk, &c., if made up wholly of Haldane's absorption tubes, would comprise four of them in the following sequence, starting from the evolution flask:—(1) Both limbs charged with sulphuric acid pumice; (2) first limb charged with sulphate of copper pumice (*vide supra*), second limb with sulphuric acid pumice; (3) first limb charged with soda lime, second limb with sulphuric acid pumice; (4) similar to (3). Only (3) and (4) would be weighed; and (4) should serve merely as a guard tube.

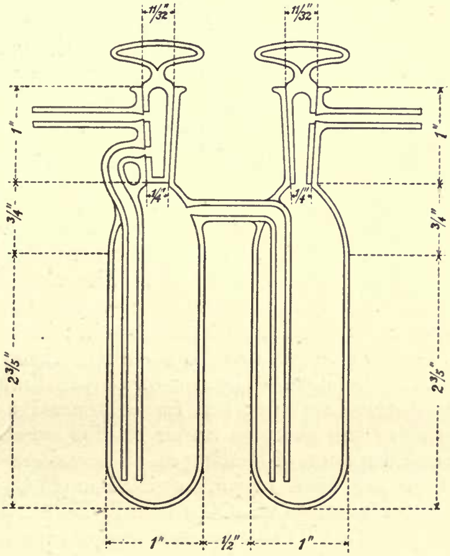


Fig. 23.—Haldane's double absorption tube, as modified by Blount.

The methods for the estimation of carbonic acid in a carbonate, which depend on the loss of weight through evolution of the gas, are only accurate when tolerably pure chalk or lime is under examination. For spent lime or reburnt gas lime they give utterly fallacious results. In all cases, where a number of estimations have to be made, the method of absorption bulbs or tubes will be found little less rapid of execution, and its accuracy is indisputable.

An instrument largely used for the approximate determination of carbonate in lime is Scheibler's calcimeter. This instrument measures the volume of gas evolved in the decomposition by hydrochloric acid of the carbonate contained in a given weight of lime, and from the volume of carbonic acid evolved the percentage of carbonate in the lime is calculated. The calcimeter is illustrated, and the method of using it described in Fresenius' and most other text-books on quantitative analysis.

The author's experience of the calcimeter leads him to the conclusion that it cannot be relied upon for the determination of small percentages of carbonate; but with care in working it is sufficiently correct for most technical purposes when the amount of carbonate is not less than 5 per cent. of the material. Estimations of carbonate by the measurement of the volume of gas evolved on decomposition can be carried out in many of the ordinary forms of gas analysis apparatus.

Testing Lime.—Lime may be tested either as such or as the hydrate. It is perhaps best, for technical purposes, always to carry out the tests on the hydrated or slaked material, as it is not easy to obtain lime for testing in the anhydrous state owing to its great affinity for water. The slaked lime must be brought to the definite hydrate—*i.e.*, freed from uncombined water, by heating it at about 200° C. for an hour. The air that comes in contact with lime during drying or other preparation for testing should, if possible, be freed from carbonic acid; if this cannot be done the lime should be exposed to the air as little as possible. It is evident that the state of hydration of the lime affects the results of the determinations; but for comparative purposes it is sufficient to dry the samples under similar conditions as to temperature and duration of heating on all occasions. A sample, consisting of 90 per cent. of pure quicklime (CaO) and 10 per cent. of calcium carbonate ($CaCO_3$) would, if exactly slaked to the hydroxide [$Ca(OH)_2$], show a percentage of calcium carbonate on the slaked sample of about 8·4 per cent. With samples containing higher percentages of carbonate the difference is less marked, nevertheless all analyses should be calculated to the same basis for comparative purposes if the samples cannot be tested in the same state of hydration. Unfortunately, neglect of this simple precaution often causes confusion in analyses made for technical purposes. The analysis of lime for other ingredients than carbonic acid is carried out according to the ordinary methods of quantitative analysis, for which the general text-books on the subject must be consulted.

Removal of Sulphuretted Hydrogen—Action of Ferric Oxide.—The next purifying material to be considered is ferric oxide, which serves for the absorption of sulphuretted hydrogen, and incidentally of hydrocyanic acid. The anhydrous ferric oxide appears to be quite unfitted for gas purification, and the suitability of hydrated oxide is determined more by its physical condition than by its chemical composition. The reaction on which the removal of sulphuretted hydrogen from gas by ferric hydrate chiefly depends is expressed by the following equation :—

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

But, besides this reaction, the following also occurs :—

$$Fe_2O_3,H_2O + 3H_2S = 2FeS + S + 4H_2O.$$

Lewis T. Wright has investigated the action of sulphuretted hydrogen on hydrated ferric oxide,* and concludes that from 17 to 30 per cent. of the sulphuretted hydrogen absorbed by oxide is taken up in accordance with the second equation, and the remainder in accordance with the first. The proportion in which the two reactions occur is approximately afforded by fouling oxide and removing the sulphur thrown down by washing with carbon disulphide, the air being carefully excluded throughout to prevent the oxidation of the iron sulphide and consequent deposition of sulphur. On evaporating the carbon disulphide, the sulphur dissolved by it remains, and is the quantity of sulphur thrown down in accordance with the second equation, and is a measure of the extent to which that reaction took place. The iron sulphides are very unstable in an atmosphere containing oxygen, being readily oxidized with the liberation of water and sulphur. Consequently there is no simple method for the determination of their relative amounts in a mixture.

The most active form of ferric oxide to sulphuretted hydrogen is the freshly precipitated hydrate in suspension in water. Under favourable conditions the whole of this may be converted to sulphide, and, consequently, we may suppose that the hydroxide, $Fe_2(OH)_6$, would form a very good purifying material. Unfortunately, this body is very unstable, though with care it may be obtained in a dry state. On heating, however, at 100°, it loses water and gradually approximates to the composition Fe_2O_3,H_2O. The amorphous compound represented by this formula may be obtained artificially in a pure state in other ways. Artificially prepared oxides for gas purification of which the active ingredient has approximately this composition are now in common use, and answer well. On continued heating at 100° C. the precipitated oxide is said to lose more water, and become $2Fe_2O_3 + H_2O$, a modification soluble with difficulty in acids. On ignition, hydrated ferric oxide passes into the

---

* *Journ. Chem. Soc.*, 1883, 156.

anhydrous oxide. The receptivity of oxide of iron for sulphuretted hydrogen appears to diminish approximately with the amount of combined water, and we find the anhydrous oxide is almost useless for gas purification. Attempts have often been made to bring the anhydrous oxide into a suitable state of porosity and division for the ready absorption of sulphuretted hydrogen; but though many operators have claimed good results for the material after some preparation, such oxide has never been extensively adopted for gas purification.

Testing Bog Ore.—The variety of oxide most in favour with gas managers is the natural bog ore, of which extensive deposits exist in the peat bogs of the north of Ireland and in Holland. This ore contains about 30 per cent. of ferric oxide, and 55 per cent. of moisture driven off at 100° C., combined water approximately equal to that required to form a monohydrate with the iron oxide, and a residue, chiefly of organic matter, in the form of roots and decayed vegetable fibre. In analyses of this oxide it is usually assumed that the whole of the soluble iron exists as the monohydrated oxide (Fe_2O_3,H_2O), and the results are stated in percentages of that body. The determinations of the iron and water in the ore are, generally, the only ones made, the decision as to the quality of the oxide, from the gas managers' point of view, chiefly resting on the results empirically obtained on submitting a small quantity of the material to the action of a stream of foul gas. The determination of the iron in oxide of iron is generally carried out by the following method:—The oxide is roughly pulverized, and about 2 grammes carefully weighed out. This amount is boiled for two or three hours with 50 c.c. concentrated hydrochloric acid and 50 c.c. water, in a flask fitted with an inverted condenser. At the end of that period the condenser tube is washed into the flask, and the contents of the flask diluted to about 200 c.c., filtered, the filter paper thoroughly washed with hot water, and the filtrate and washings made up to 500 c.c. at 60° F. with distilled water. From this solution 125 c.c. is taken by a pipette, magnesium, or zinc free from iron, added, until the change in colour indicates that the iron is completely reduced to the ferrous state, and the excess of magnesium or zinc has completely dissolved. Some operators prefer other reducing agents—such as sodium thiosulphate or stannous chloride. Care must be taken not to use an excess of the latter agent. If the exact point at which the reduction is complete is not very clear, a few drops of potassium thiocyanate may be added to the liquid, and the disappearance of the red colour produced by that salt with ferric iron will show that the whole of the iron is reduced. A little experience will, however, generally suffice to enable the operator to say exactly when the yellow colour indicating the presence of ferric salt is discharged, and the use of an indicator will then become unnecessary. When zinc or magnesium is used, an excess of the reducing agent is harmless, provided all is dissolved before commencing to titrate the solution. The standard solution generally used for the titration is decinormal bichromate of potash. Pure potassium bichromate in crystals is tolerably easily obtained, and, if roughly powdered and dried in the hot-water bath, will serve for making up the standard solution with exactitude. 4·913 grammes of the dry salt are dissolved in a litre of water to give the decinormal solution. If any doubt exists as to the purity of the potassium bichromate, the strength of the standard solution should be checked by titration against a weighed quantity of pure iron wire. The point at which a ferrous solution is completely oxidized by bichromate can only be ascertained by the use of an external indicator. This indicator is a freshly prepared solution of potassium ferricyanide, which gives a blue colour with ferrous salts. Drops of the ferricyanide solution are scattered on a glazed, white tile, and a drop of the iron solution undergoing titration is brought, on the end of a glass rod, into contact with one of the drops of ferricyanide solution, from time to time, as the bichromate is added to the iron solution. A blue coloration is formed in the drop of ferricyanide as long as the oxidation is incomplete, but when ferrous salt is no longer present, only a brown tint is formed in the ferricyanide. To find the exact point of complete oxidation when the amount of iron in solution is not approximately known, it is best to make a rough preliminary titration, and then, with a second portion of the iron solution, to titrate cautiously, as the point of oxidation is approached, testing a drop of the solution in a drop of ferricyanide solution after each addition of 0·2 c.c. of standard bichromate. By this means the exact point of complete oxidation may be found with ease and certainty. If the method of titrating with bichromate, using ferricyanide as an indicator, is new to the operator, he should proceed first on iron solutions of known strength until the results show that he has acquired sufficient familiarity with the method to use it with accuracy. The calculations requisite for finding the percentage of iron from the amount of bichromate used are readily explained. 56 grammes of iron require 8 grammes of oxygen for conversion from the ferrous to the ferric state. 1 c.c. of decinormal bichromate solution yields $\frac{8}{10{,}000}$ gramme of oxygen, or sufficient to convert $\frac{56}{10{,}000}$ gramme of iron from the ferrous to the ferric state. $\frac{56}{10,000} = 0·0056$. Therefore, the number of cubic centimetres of decinormal bichromate solution used in converting completely an iron solution from the ferrous to the ferric state, multiplied by 0·0056, will give the amount of iron present in grammes. If it is wished to know at once the equivalent amount of ferrous oxide, the multiplier is 0·0072 instead of 0·0056; if the amount of ferric oxide, the multiplier is 0·0080. Analyses of bog ore are frequently stated in percentage of hydrated ferric oxide (Fe_2O_3,H_2O), in which state the whole of the iron is assumed to be. The multiplier for converting the number of cubic centimetres of decinormal bichromate used into grammes of this monohydrate (Fe_2O_3,H_2O) is 0·0089.

When 2 grammes is the amount of bog ore taken for solution, and one-fourth only of the total solution is used for titration, the amount of ore in that quantity is 0·5 gramme. If the number of cubic centimetres of bichromate used in titrating this quantity is multiplied by $(0·0089 \times 200) = 1·78$, the result is the percentage of ferric hydrate (Fe_2O_3,H_2O) in the oxide. The use of a constant weight of ore for the determinations simplifies the calculations, and is the method usually adopted in gas works laboratories, where a large number of tests have to be made rapidly. The method of extraction by boiling with hydrochloric acid given above, usually suffices to dissolve out all the iron from the descriptions of oxide offered to gas managers. The volumetric estimation of iron in bog oxide may also be carried out with decinormal solution of potassium permanganate in place of potassium bichromate. It is advisable for the purpose to have the iron in solution in sulphuric instead of hydrochloric acid. No external indicator is needed; but certain precautions must be observed in working with permanganate, for which the general text-books must be consulted, though some information may be gleaned from the method of testing Weldon mud, described on p. 166. The method presents no very obvious advantage over that with bichromate, and the standard solution is more difficult of preparation and less stable.

The moisture held mechanically in bog oxide may be estimated with tolerable accuracy by drying about 20 grammes of the roughly pulverized material in a hot-water oven for three or four hours, weighing carefully before and after. Some operators prefer to take a larger quantity of oxide for the estimation of moisture, and to weigh from the dried sample that required for the iron estimation. This method diminishes the errors inherent in the weighing of small quantities of moist material, and is likewise applicable to the estimations of moisture and manganese dioxide in Weldon mud.

Purification Value of Ferric Oxide.—Some artificial oxide of iron, obtained by precipitation of iron dissolved in sulphuric acid with ammonia, shows when moderately dry an affinity for sulphuretted hydrogen equal to that of the best bog oxide. This oxide appears to be in the best condition for purification purposes when about 20 to 30 per cent. of moisture is present. Lewis T. Wright found bog oxide to answer best with 10 to 20 per cent. of moisture, but some engineers have considered a smaller amount more favourable. As generally used, when new the bog oxide contains more than 20 per cent. of moisture, and most managers prefer it in this condition. The nature of the particular sample must largely determine the most suitable degree of moistness, and this can be ascertained by small scale experiments. It is customary to add some such material as sawdust or wood-chips to oxide before putting it in the purifier for the first time. The object of the addition of such inert material is twofold—firstly, to render the oxide more permeable by gas; secondly, to moderate undue activity of action. The amount added should be as little as will meet these ends, and is regulated by the amount of organic fibre in, and the physical state of, the oxide. It is a mistake to suppose that fibre is deleterious to oxide; it is a most important factor in presenting the material to the gas in a sufficiently finely-divided state, and is the cause of the immense superiority of native bog ore over most artificial oxides. The use of sawdust, however intimately it may be mixed with the oxide, can never entirely replace the natural fibre of bog ore, as the latter causes a greater porosity of the material, and consequently exposes a far greater surface to the action of the gas. Moisture is also an important factor in forming the requisite physical state of the oxide; but, generally speaking, only so much added water is required as is necessary to aggregate the oxide sufficiently to prevent it falling through the grids in the purifier. The water of hydration is probably chiefly responsible for the superiority of hydrated over anhydrous oxide on account of the greater porosity it gives to the material.

The final test of the suitability of oxide for the purification of gas is the fouling and revivification of small quantities of it, in imitation of the treatment to which it will be subjected on the large scale in the purifier, and the estimation of the amount of sulphur assimilated by it at each fouling. For the testing, about a quart of the oxide is brought to the estimated proper degree of moistness, a small sample is retained for the determination of the moisture, and a vessel of the shape shown in Fig. 24 is charged from the remainder, a plug of cotton wool being placed in the constriction of the vessel to prevent the oxide falling into the lower part. Glass tubes passing through corks in the orifices of the vessel form the inlet and outlet pipes, and the lower one is connected by caoutchouc tubing to a cock on the outlet main of the work's scrubbers. A stream of washed and scrubbed, but otherwise unpurified, gas is then allowed to pass through the oxide for twelve hours, when the vessel is disconnected and the oxide laid out in a small heap. If the material is even moderately active, the exposure to the air will cause rapid oxidation of the iron sulphides with considerable development of heat. Towards the end of the revivification, the material should be turned over a few times until all the black sulphide has disappeared from it. A small average sample should be taken from the heap, dried in the hot-water bath, and reserved for the estimation of the amount of sulphur present in it by the method described for the evaluation of spent oxide in Volume II. The remainder of the oxide is moistened to the required degree, and returned to the fouling vessel for a further twelve hours' treatment with foul gas. The oxide is again revivified in a precisely similar manner, and an average sample taken, dried, and used for the estimation of the sulphur content. The material is fouled and revivified a third time, and the amount of sulphur in a dried sample ascertained. Three successive foulings are generally considered sufficient to give a true indication of the value of a sample of oxide; but it may be necessary to repeat the series with the material more or less moist than at the first tests, to arrive at the most favourable results for each sample examined. The amount of moisture in the oxide as put into the fouling vessel should always be ascertained, and the tests for sulphur should always be carried out on dried samples. If the samples used for sulphur estimations are weighed in the condition in which they are taken from the purifier comparisons become useless, as the only legitimate basis on which to make them is on the dried material. The amounts of sulphur that may be expected in good oxide examined in this manner are :—

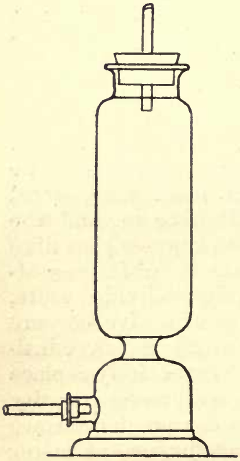


Fig. 24.—Vessel for fouling small samples of oxide, &c.

After the first fouling, . . .	14 to 18 per cent.
,, second ,, . . .	20 to 25 ,,
,, third ,, . . .	24 to 31 ,,

In addition to the sulphur set free during fouling in the manner described on p. 157, the revivified oxide contains as free sulphur almost all the sulphur absorbed as sulphides. The action of the oxygen of the air in converting the sulphides to oxide is very simple, and may be expressed by the equations :—

$$\begin{aligned} 2Fe_2S_3 + 3O_2 &= 2Fe_2O_3 + 3S_2 \\ 12FeS + 9O_2 &= 6Fe_2O_3 + 6S_2. \end{aligned}$$

These equations at least represent the final result of the exposure of properly fouled oxide to the air. In the actual purifying vessels results comparable with those obtained on the small scale may be expected, but care must be taken that the oxide, before it is put in, is properly prepared to give the most favourable results. The oxide is on the working scale generally fouled and revivified from ten to twelve times, and should, before being discarded for further use, be loaded with 50 per cent. of free sulphur. When so loaded, its purifying capacity becomes much diminished by the large bulk of inert material in it, and it is more economical to dispose of it to the sulphuric acid maker than to continue to use it for purifying purposes. The estimation of free sulphur in spent oxide is described in the sequel to this volume.

The cyanogen compounds normally present in crude coal gas consist mainly of hydrocyanic acid in combination with ammonia. This compound is absorbed to a considerable extent by the gas liquor in the washer-scrubbers, and may be wholly absorbed by means of special reagents, such as solutions of ferrous salts, applied preferably prior to the ordinary washer-scrubbers. The action of these reagents and the subsequent treatment of the compounds which they form with the hydrocyanic acid will be dealt with in the sequel to this volume. Where such special treatment of the gas for the extraction and subsequent recovery of the cyanogen compounds is not practised, it is possible to recover some cyanogen by means of the ordinary ferric oxide purifiers. The cyanogen compounds which escape retention by the gas liquor in the washer-scrubbers can be thus recovered, provided the gas is led direct from these machines to purifiers charged with ferric oxide, and provided no appreciable amount of ammonia is present in the gas at this stage. The latter condition is easily satisfied where provision is made for the efficient washing and scrubbing of the gas. If ammonia is present, in addition to cyanogen compounds, when the gas enters the oxide purifier, a large proportion of the cyanogen will become combined in the comparatively valueless form of sulphocyanide. In the absence of ammonia, the ultimate product in the revivified oxide is ferrocyanide, which is readily worked up to Prussian blue, or other commercially valuable cyanides or ferrocyanides. It is important to avoid an unduly high temperature during revivification when oxide is being worked up with a view to the extraction of its content of ferrocyanide. The reactions involved in cyanogen recovery by means of oxide, and the evaluation of spent oxide in respect of cyanogen, will be referred to in the sequel to this volume. No purifiers charged with lime should be placed anterior to the oxide purifiers in the series, if it is desired to use the oxide for the absorption of cyanogen compounds, as well as sulphuretted hydrogen.

Weldon Mud and Manganese Dioxide.—Weldon mud is a material of comparatively recent introduction for gas purification. Its activity is due chiefly, if not entirely, to the manganese dioxide it contains. Manganese dioxide has been suggested as a suitable material for removing sulphuretted hydrogen from the early days of the gas industry, being generally mentioned as being equally effective as ferric oxide. It does not appear to have been adopted on the large scale however. But, latterly, E. Donath has recalled attention to it,* and states that all the oxygen of the oxide may be replaced by sulphur by passing sulphuretted hydrogen over it, the flesh-coloured manganese sulphide being the product. It has, however, been difficult to obtain the manganese dioxide in a suitable physical condition for the complete removal of sulphuretted hydrogen from coal gas by its agency, and the introduction of Weldon mud to gas works marks the beginning of the practical application of manganese dioxide to gas purification. The use of an artificially prepared hydrated oxide of manganese, such as "Weldon mud," for the desulphurization of gases was patented in 1887 by J. J. Hood and A. G. Salamon.† They also proposed at one time to use Weldon mud for the removal of other impurities than sulphuretted hydrogen from coal gas, but their subsequent experience has not apparently led them to recommend its use for other purposes than the extraction of sulphuretted hydrogen from gases.

Preparation of Weldon Mud.—Weldon mud is produced in works where manganese dioxide is used for the liberation of chlorine from hydrochloric acid for the manufacture of bleaching powder. When the original manganese dioxide is completely dissolved, and the acid liquid contains chiefly manganese chloride, it is neutralized with calcium carbonate, and the oxide of iron and other deposited matters are allowed to settle. The clear liquid is mixed with milk of lime in a proportion more than enough to throw down the whole of the manganese by about one-third its content of lime. A current of air is blown

---

* *Dingler's polyt. Journal*, cclxiii., 248.

† English Patent, No. 10,127, July 19th, 1887.

through the liquid containing the precipitated manganese hydroxide in suspension while its temperature is kept at about 60° C. In the presence of excess of lime, the greater part of the hydroxide is thereby converted to dioxide. On allowing the manganese to settle from the blown liquor and removing the supernatant solution of calcium chloride, the Weldon mud remains. In the ordinary course this mud is used in place of fresh manganese oxide in the chlorine stills. It consists chiefly of manganese dioxide, manganese monoxide, calcium chloride, and calcium oxide with a large quantity of water. If partially dried, and then used for gas purification, this mud would become very wet owing to the moisture attracted by the calcium chloride. The patentees of the Weldon mud purification process therefore recommend the washing of the mud until the calcium chloride is reduced to 2 or 3 per cent.* The prepared mud as delivered for gas purification usually contains from 48 to 57 per cent. of water and 23 to 29 per cent. of manganese dioxide, the remainder being chiefly lime, calcium chloride, silica, and protoxide of manganese. The percentage of manganese dioxide in the dried material is tolerably uniform, being about 56 to 58, but the large quantity of water present in the mud as delivered is subject to variations according to the atmospheric conditions, and with it varies inversely the amount of manganese dioxide. Hence care should be taken that representative samples of the moist mud are tested for moisture and manganese dioxide, immediately after they are taken, as on standing in a warm place moisture separates from the mud, and, collecting in globules on the upper part of the containing vessel, is with difficulty properly re-incorporated with the mud. Where discrepancies in determinations of manganese dioxide in Weldon mud occur, they may often be accounted for by the different proportions of water in the samples, and a reference to the percentage of manganese dioxide on the dried material will generally throw light on conflicting results. Needless to say, where Weldon mud is bought and sold on the amount of manganese dioxide per ton of moist material, average samples should be taken at the time of weighing, preserved from exposure, and tested as quickly as possible after being taken. When a representative sample has to be kept some time before the determination is made it should completely fill the containing bottle, which must be tightly corked, and well sealed. The bottle should be kept in a moderately cool place. The nature of the material would indicate to chemists the necessity of such precautions in sampling and testing, if disputes are to be avoided. The manganese dioxide being the constituent of Weldon mud which gives the

---

* *Journ. Soc. Chem. Ind.*, 1888, p. 3.

latter its value for gas purification, it generally suffices for the evaluation of the material to estimate the amount of that ingredient. This estimation is made by the method adopted by the alkali makers or some slight modification thereof. The strength of a solution of ferrous sulphate acidified with sulphuric acid is determined by oxidation with standard bichromate or permanganate solution; a weighed quantity of the Weldon mud is dissolved in a known volume of the acid ferrous solution, and the unoxidized ferrous salt determined by the standard bichromate or permanganate. The oxidizing effect of the Weldon mud is thus known, and thence the percentage of manganese dioxide contained in it is calculated. As the determination is more familiar to alkali-works chemists than to gas-works chemists, one method may with advantage be given in detail here.

Mode of Testing Weldon Mud.—A decinormal solution of potassium permanganate is made by dissolving 3·156 grammes of the pure dry salt in a litre of distilled water at 16° C. When the salt is completely dissolved, the strength of the solution is checked by titration against a known weight of pure iron wire dissolved in dilute sulphuric acid, with the usual precautions, and correction for impurity in the iron wire, for which the text-books on volumetric analysis must be consulted. 0·112 gramme pure iron requires 20 c.c. decinormal permanganate solution for its oxidation from the ferrous to the ferric state. A convenient substance for standardizing potassium permanganate solution is sodium oxalate. 0·134 gramme of the pure dry salt is equivalent to 20 c.c. decinormal permanganate. The sodium oxalate should be titrated in solution acidified with sulphuric acid at a temperature of about 60° C. The end reaction is then very sharp. The permanganate solution, if not exactly decinormal, may be made such by addition of the calculated amount of the salt or water, or may be used and correction made for the error as found by titration against the iron wire or sodium oxalate. Standard permanganate must not be allowed to come in contact with organic matter such as caoutchouc, and in any case it is advisable to check its strength once a month. Unless the strength of the permanganate is exactly decinormal, or the error is accurately known, it is useless to attempt estimations with it. A solution of ferrous sulphate is prepared by dissolving 100 grammes of the pure, clean, crystallized salt in distilled water, adding 100 c.c. of pure concentrated sulphuric acid, and making up to a litre at 16° C. with distilled water. The strength of this solution is ascertained by titrating 20 c.c. with the decinormal permanganate. If the ferrous sulphate was pure and unoxidized, about 72 c.c. of the permanganate will be required to oxidize 20 c.c.

The amount of permanganate required is noted, and must be re-ascertained every day that the iron solution is used, as the latter gradually oxidizes, even though kept in a closely stoppered bottle. About 0·5 gramme of the Weldon mud is weighed out accurately, washed into a small flask, and 20 c.c. of the iron solution added (preferably from the same pipette as was used in standardizing it). The solution of the Weldon mud is aided by gentle heating and trituration by a glass rod against the bottom of the flask. When the mud is completely dissolved the solution is titrated with the standard permanganate, and the volume of the latter required for its oxidation noted. The following are figures actually obtained in an analysis :—

20 c.c. ferrous solution required, .	70·5 c.c.	$\frac{N}{10}$ permanganate solution for oxidation.
0·5 gramme Weldon mud was dissolved in 20 c.c. ferrous solution, which then required	42·8 c.c.	,, ,, ,,
Therefore the Weldon mud contained manganese dioxide equivalent to .	27·7 c.c.	$\frac{N}{10}$ permanganate solution.

But 1 c.c. decinormal solution is equivalent to 0·00435 gramme manganese dioxide, therefore 0·5 gramme Weldon mud contained 27·7 × 0·00435 gramme manganese dioxide. The Weldon mud, therefore, contained nearly 24·1 per cent. of manganese dioxide. This sample contained 57·1 per cent. of water, therefore the percentage of manganese dioxide on the dry basis was 56·2. It is generally advisable to perform two determinations of the manganese dioxide in each sample, and, if the results are within 0·2 per cent., to take the mean. If the variance is greater, a third determination should be made. It is advisable to remove the desiccating material from the balance case when such a moist material as Weldon mud is being weighed. Decinormal bichromate may be used instead of permanganate solution if preferred, while many analysts consider seminormal solution sufficiently delicate for the determination. The precise strength of the ferrous sulphate solution is immaterial, but it should be ascertained shortly before each determination.

The affinity of particular samples of Weldon mud for sulphuretted hydrogen may, if desired, be ascertained by fouling and revivification, in a similar manner to the testing of oxide as described on p. 161. In estimating the sulphur present after each fouling, it is desirable to remember the fact that a higher percentage of sulphur will be found, in most cases, if the spent mud be treated with hydrochloric acid, according to a method described in Volume II., instead of being directly extracted by carbon disulphide.

Action of Weldon Mud.—The action of sulphuretted hydrogen on the manganese dioxide of Weldon mud is very similar to its action on ferric hydrate. The flesh-coloured sulphide of manganese results, together with water, from the action. This sulphide, especially when moist, is very readily oxidized, with evolution of heat and deposition of free sulphur. The calcium oxide of the mud becomes converted eventually to sulphate, as does also a small amount of the manganous oxide. The action of Weldon mud on sulphuretted hydrogen appears to be more vigorous than that of bog oxide, and mere traces of the gas are more completely absorbed by the former material. In three foulings of Weldon mud containing 56·2 per cent. of moisture and 25·3 per cent. of manganese dioxide, the following percentages of sulphur in the dry material, after revivification, were found (by simple extraction with carbon disulphide):—

After fouling and revivifying, the dried mud contained 28·1 per cent. sulphur.

After second fouling and revivifying, the dried mud contained 34·8 per cent. sulphur.

After third fouling and revivifying, the dried mud contained 40·6 per cent. sulphur.

The application of Weldon mud and its advantages over oxide of iron are alluded to in the description of the scheme of gas purification that follows.

Other Purifying Materials.—The materials in common use for the purification of gas have now been briefly discussed. Sundry other substances have at times been used, such as other metallic oxides than those named, heated clay, &c., but they are no longer deemed serviceable. Many empirical preparations, generally containing ferric oxide in admixture with alkali, have been sold for gas purification, and some are extensively used in Continental gas works. They do not, however, seem to possess any distinct advantages over good "oxide" and lime used separately, either in distinct vessels or on different tiers in the same vessel. Allusion will be made later on to the principles of the wet methods of purifying gas, which depend on the absorption of carbonic acid, sulphuretted hydrogen, and carbon disulphide by ammonia and its compounds, derived originally from the gas itself; but the extent of their adoption at present will not permit of their ranking by the side of the common method of purification which is now described.

Grids and Purifiers.—For the support of the materials used in the dry or ordinary system of gas purification, wooden grids are placed in layers extending across the whole area of the purifying vessel. These vessels are usually oblong or square in form; in old works circular ones are sometimes found. The dimensions vary according to the amount of gas for which they are designed; but in large works, where several sets are in use and the vessels in each set are made as large as is consistent with convenient working, each vessel will be from 30 to 40 feet square, or about 30 feet by 40 feet, and about 6 feet in height. The purifier is usually of cast iron and the lid of sheet iron, supported by angle irons and trussed internally by tie-rods if necessary. The sides depending from the lid dip into the water-seal or lute in the purifier, the depth of which varies to suit the maximum pressure at which the gas is driven through the vessel. In large works the lute will give a water-seal of 36 inches, the channel being slightly deeper than that. When the purifier is in action the lid is held down by suitable bars passing over the corners and secured by clamps to the sides of the vessel. Various contrivances are adopted for raising and supporting the lid when the purifier requires emptying. An apparatus frequently used consists of two standards, each mounted on two grooved wheels, which traverse rails on each side of the purifier. The standards are kept apart at the top by a stout connecting girder. On one standard is a winch, which by cog-wheels or pulleys raises the purifier lid by means of a hook or hooks attached to the girder. When the lid is raised the standards are pushed along the rails until it is clear of the vessel to which it belongs, and no obstruction is offered by it to the work of the purifying gang. The materials are very generally taken from the vessels in sacks and shot where desired; but in some vessels, arranged on the upper floor of a building, an outlet is provided in the bottom of the vessel through which the spent material is

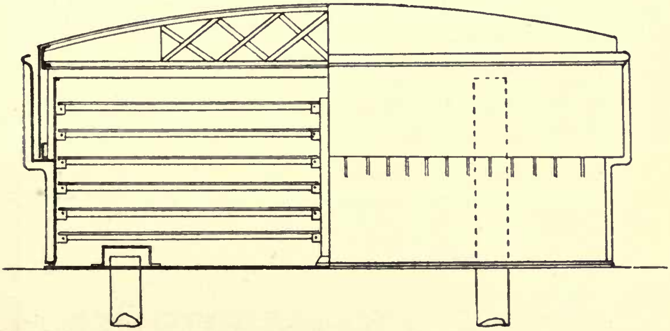


Fig. 25.—Ordinary gas purifier; part section, part elevation.

thrown into trucks on the ground floor. Likewise, the materials are, as a rule, carried into the vessels in sacks and levelled on the grids by means of a rake. But where a floor above that on which the purifiers stand is available, the fresh materials are raised to it by an elevator, and dropped through a flexible shoot, which is carried by the man in charge over the whole surface of the purifier, any inequalities in the deposition of the material being suppressed by means of a rake. This plan saves much labour, but entails large expenditure on the building containing the vessels. The placing of the purifiers on a floor above the ground level has, however, the great advantage of leaving the valves and connections visible, and readily accessible from below. An ordinary purifier, partly in section, partly in elevation, is shown in Fig. 25, and the arrangement mentioned above of the purifiers on the middle of the three floors in the house is shown in Fig. 26. The floor space on the upper floor can be used for the preparation or storage of the materials employed.

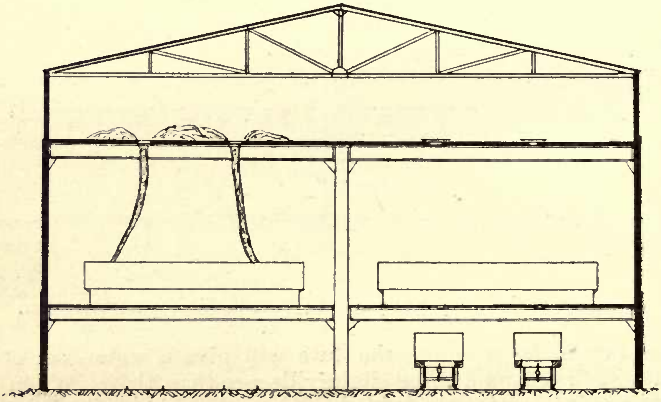


Fig. 26.—Cross-section of three-floor purifying house.

The grids are supported on a light framing of angle iron in the purifier, and are, of course, taken out as they become cleared in the emptying of the vessel, and replaced as wanted when the vessel is being charged. They consist of strips of pine wood $1\frac{1}{2}$ to 2 inches deep, and $\frac{1}{2}$ inch wide, bolted together with $\frac{1}{2}$-inch bolts, spaces of $\frac{5}{8}$ inch being secured between the strips by the insertion of small blocks of wood of that thickness, through which the bolts pass. A drawing of a typical grid is given in Fig. 27. Cast-iron grids are occasionally used in place of the more usual wooden ones. In large works the purifying vessels will each contain five or six tiers of grids, the material being spread to a thickness of about 8 inches on each. Where six to eight vessels, each containing this depth of material on each of the five or six tiers, are used, the pressure at which the gas enters the purifiers is usually equal to that of a 20- to 30-inch column of water.

A method of packing the purifying material into the vessels and directing the stream of gas through it, which appears to present some distinct advantages, has lately been introduced into several Continental gas works. The ordinary horizontal grids are superseded by composite grids, which, when packed into the vessel, according to Jäger's scheme, compel the gas to traverse the material mainly in a horizontal course instead of vertically as in purifiers packed in the customary manner. The purifier is in effect divided into two or more compartments, each packed from top to bottom throughout their length with the special grids loaded with the purifying material. The gas streams into the interspace, and its only means of escape is by traversing the material to the spaces on the other side of the compartment or tier of grids, which spaces are in connection with the outlet main. The advantages claimed for this system of packing purifiers are, that the same vessel holds 25 to 50 per cent. more purifying material than with the ordinary horizontal grids, and that the material is permeated more uniformly by the gas, and is therefore more completely fouled throughout. A number of attendant advantages, such as saving of labour, &c., by fewer changes of vessels, will at once be foreseen. The system has not yet, to the author's knowledge, been tried on a large scale in this country, though it is about to be introduced.

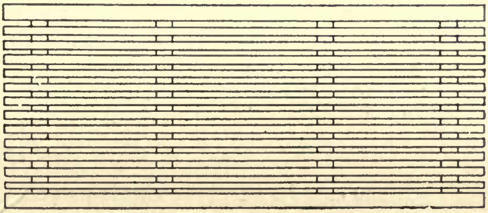


Fig. 27.—Purifier grid.

C. Carpenter has proposed* to divide large purifying vessels into sections, by means of vertical diaphragms, and by means of distributing valves and separate inlets to each section, to let the gas pass through one, two, or all of the sections according to the quantity to be dealt with. Thus, supposing the purifier

---

* *Journ. of Gas Lighting*, lxxviii., 637.

were large enough to deal with the maximum winter output, he would insert two vertical diaphragms, dividing it into three sections or compartments, in order that when only about two-thirds of that output had to be dealt with, only two-thirds of the purifying area—*i.e.*, two sections—might be kept in use. The minimum summer output would often be little more than one-third of the maximum in winter, and only one section would be kept in action to deal with it. The scheme assumes that it has been ascertained that a particular rate of flow of the gas and duration of contact with the material have been ascertained to give better results than other rates of flow, &c., and that this rate is not exceeded when the output of gas is at its maximum. Carpenter has obtained the best results with the area of the purifiers limited to 170 to 180 square feet per million cubic feet of gas passing through them per diem. A common allowance in large works is 400 square feet minimum area of purifier per million cubic feet of gas to be purified per diem. It is assumed in all cases that the rate of flow of the gas, and the duration of contact of the gas with the material, should be the same whatever the material and the duty it is called upon to perform. It does not appear, however, to have been definitely established that the same rate of flow and time of contact are required with vessels charged with lime for the removal of sulphuretted hydrogen as with vessels charged with sulphided lime for the removal of either carbonic acid or carbon disulphide, or with vessels charged with ferric oxide for the removal of sulphuretted hydrogen.

Carpenter's scheme can in effect be carried out by a multiplication of small purifying vessels, but this would involve a larger capital outlay on the plant. These smaller vessels, however, would facilitate recharging. There are other schemes for subdividing the stream of gas in its passage through the vessels somewhat analogous to Carpenter's, but entailing special structural alterations to the purifiers. They all aim, and in most cases with a large measure of success, at fouling the material more uniformly and completely without allowing unpurified gas to pass through until the entire mass of material is nearly wholly fouled.

The water seal of purifiers is sometimes replaced by other modes of obtaining a tight joint. These generally consist in clamping down the purifier lid, which is without sides, on to a faced flange on the top of the sides of the vessel, and ensuring a gas-tight joint by inserting a layer of indiarubber or similar packing between the facings on the lid and sides.

Scheme of Purification.—The removal of carbonic acid from gas is the duty of the first and often of both the first and second vessels in the series of purifiers. Lime carefully slaked is loaded into the vessel and levelled on each tier of the grids. In many works the lime is used in a comparatively dry state for convenience in handling, but it must be remembered that its full absorptive power is not thereby attained. When possible the lime should be used in such a state of moistness that it agglomerates readily, and forms a soft pasty mass when pressed together. Generally, however, it will be more convenient to handle the lime in the condition obtained on slaking with the quantity of water mentioned on p. 151. About 6 cubic yards of quicklime brought to that degree of moistness will remove the carbonic acid from a million cubic feet of ordinary coal gas, or about 70 lbs. of quicklime will purify the gas from 1 ton of common coal. The gas entering the lime purifier contains both sulphuretted hydrogen and carbonic acid. The strongly basic nature of the lime causes it to combine with both these gases, and so long as it is not nearly neutralized by them, both are removed from the gas. When, however, the lime has become nearly saturated, the greater stability of calcium carbonate compared with calcium sulphide is shown by the gradual decomposition of the latter salt by the carbonic acid coming in with the gas. Sulphuretted hydrogen is given off on the decomposition, and passes forward with the gas and is removed from it at a later stage of the purification. The superior affinity of lime for carbonic acid thus enables a vessel to be converted entirely to carbonate, although sulphuretted hydrogen is passing in with the gas. As the lime becomes saturated with carbonic acid, that gas begins to pass on unabsorbed, and the course of the fouling of a lime vessel may be traced by testing the gas issuing from cocks placed above each tier in one side of the purifier. This testing is carried out by the simple process of bubbling the gas from a capillary tube through perfectly clear lime or baryta water. The lime water is prepared by agitating boiled water with slaked lime, and decanting off the clear liquid which separates after some hours of rest. The gas to be tested is bubbled through the lime water contained in a glass tube, to which a cork is loosely fitted to hinder free contact with the air. If the gas is free from carbonic acid, no cloudiness will be visible in the lime water after a minute's bubbling; if carbonic acid is present in appreciable amount, a distinct cloudiness will rapidly become visible in the lime water. When traces of carbonic acid are found at the fourth or fifth tier of the first purifier, it is absolutely necessary to put a second lime purifier into action in succession to the first one which is nearly completely fouled. The first need not, however, be shut out as soon as carbonic acid is found at its outlet, as by keeping it in action for some time longer, the more perfect carbonation of the lime is ensured. It must, as a rule, be shut out in time to be discharged and recharged with fresh lime before the second purifier shows traces of carbonic acid at its fifth tier, as it is usually wanted to take the gas from the outlet of that vessel as soon as carbonic acid appears at that point. The two vessels are thus continually changing their relative positions with regard to the stream of gas passing through them, and unless their size is altogether inadequate for the quantity of gas passing, one can be emptied and recharged while the other is fully efficient. If this is impossible, a third vessel must be given to lime, and the three worked in rotation, one being recharged while the other two are in action. If the vessel is shut out of action immediately there is carbonic acid at the top tier, a considerable portion of the material will be sulphide, not carbonate, and the sulphur therein is not recoverable. In most cases, therefore, economy will point to the necessity for keeping a vessel in action until the lime is nearly wholly converted to carbonate, but where purifying room is cramped this is sometimes impossible. It may be taken as a cardinal rule that whatever "system" of purification is adopted, carbonic acid should not be allowed to pass out of the last lime vessel in the series, as it is likely to cause serious derangement in subsequent vessels. The lime in the vessels absorbs other substances besides carbonic acid and sulphuretted hydrogen, but necessarily only in small quantities. Cyanogen that has escaped the washers is taken up, and the sulphur compounds other than sulphuretted hydrogen are slightly diminished in amount. If air or ammonia passes into the lime purifiers with the gas, the actions are somewhat modified, and the judicious admission of either increases the amount of carbon disulphide absorbed from the gas in these vessels. The oxygen of the air probably converts some of the calcium sulphide or hydrosulphide in the purifier into the hydroxysulphide, which then absorbs carbon disulphide. Moist calcium sulphide also absorbs a portion of the carbon disulphide in gas, but like calcium sulphide the compound formed is decomposed by carbonic acid, and hence when vessels are completely carbonated, the quantity ultimately so absorbed is very small. Ammonia probably unites in the presence of lime with carbon disulphide, and calcium thiocyanate and calcium sulphide are the ultimate products of this reaction. The presence of much thiocyanate imparts a bright red colour to the spent lime. The blue and green tints of spent lime are due to iron from the chalk, the fuel ash, and the water used in slaking. Oxygen converts calcium sulphide to thiosulphate, and various basic thiocarbonates are also present in spent lime.

From the above it will be gathered that sulphuretted hydrogen is driven out with the gas from the carbonate vessels, by the action of the carbonic acid on the calcium sulphide, and also as a product of minor reactions in which the carbon disulphide plays a part. Hydrated ferric oxide is commonly employed to absorb this sulphuretted hydrogen, and in most works two purifiers will be given to it. These are worked in a similar manner to the lime vessels, that is to say, the gas passes through the cleanest oxide purifier last; the first one in the series is recharged as soon as it is completely fouled, and the relative positions of the two vessels with regard to the stream of gas then become reversed. The reactions which occur between ferric oxide and sulphuretted hydrogen are given on p. 157. The material is disposed on the purifier grids in a similar manner to lime, and is generally considered most active when it contains about 15 per cent. of moisture.

Revivification of Ferric Oxide.—When oxide is completely fouled it is removed from the purifier in the same manner as lime, and spread on the floor of a shed to a depth of 18 inches for revivification. Revivification is the name given to the conversion of the iron sulphide to oxide by means of the atmospheric oxygen. This is attended with the production of heat, and very active oxide must be watched during the early stages of its revivification, lest the heat cause ignition of the sulphur or sawdust mingled with it. As the black colour disappears from the surface of the oxide, it should be turned over so as to expose fresh material to the action of the air, and this turning of the oxide must be carried out at intervals until all the black sulphide has disappeared from the mass. Revivification is then complete, and the revivified material may be again used for the removal of sulphuretted hydrogen from gas. The activity of the material is, of course, somewhat impaired by the sulphur deposited in it on each revivification. The action between sulphuretted hydrogen and good oxide is sharp and decisive, though oxide does not readily take out the last traces of sulphuretted hydrogen from gas. The material does not become unpleasantly moist in the purifiers, and the emptying of the vessels is not a specially disagreeable work.

Many attempts have been made to conduct the revivification of oxide of iron in the purifier itself. A method which naturally suggests itself is shutting out the vessel as soon as the oxide is fouled and, without raising the lid, passing air by means of an exhauster through the spent material. There is no difficulty in starting the revivification by this means, but considerable care is needed to secure the change with safety throughout the mass. The revivification is apt either to occur sluggishly and incompletely, or to take place with great vigour and consequent heating. By carefully regulating the amount of air admitted according to the temperature attained in the mass, the desired chemical change may be effected without undue slowness or celerity. Heating of the oxide to about 70° C. favours complete revivification; but if the temperature rises much higher, air should be blown through the vessel in largely increased quantities, or steam injected. The increased volume of air will carry away heat from the material; the steam will damp it and so hinder the reaction, which takes place most vigorously with dry oxide. Heating the material largely conduces to rapid revivification by the withdrawal of moisture from the mass. If during the revivification in the purifier the temperature rises much above 100° C., the deposited sulphur may be fused, and even caused to fire. The chief objection to this method of revivifying oxide in the purifier is the diminished porosity of the material, which is especially evident when the temperature has been high during revivification. The increased pressure thrown by oxide so revivified is very marked, and though various means of diminishing it have been suggested, this trouble and the risk attendant on the revivifying of a large mass of material in a closed vessel have prevented the extensive adoption of the system. Needless to say, evil-smelling gases are driven from the vessel during revivification by means of a stream of air.

Revivification of oxide while the vessel is in action was proposed many years ago, and has formed the subject of many patents. Air, proportioned in volume to the amount of gas, is continuously forced in with it, the air being, according to some patentees, previously carburetted by being passed over heated tar or naphtha. This carburetting of the air employed, of course, avoids the loss of "illuminating power" due to the dilution of the gas with nitrogen, but entails expenditure on naphtha or the extraction of the lighter constituents from tar. From 2½ to 3 per cent. by volume of air is theoretically required to be added to gas containing the common quantity of 600 to 700 grains of sulphuretted hydrogen per 100 cubic feet, to revivify completely the oxide while in action; and this is about the quantity that former experimentalists found empirically to be most suitable. Theoretically an oxide purifier, revivified by the continuous admission of the proper proportion of air with the gas, should remain active until the oxide is sufficiently loaded with sulphur for disposal to the sulphuric acid makers. But as a matter of fact, experience shows that this result cannot be reasonably expected in practice. The oxide is found to become less porous after it has remained in the vessel some time, during which it has been revivified *in situ*, and, consequently, throws a constantly increasing pressure. It soon becomes necessary to remove the oxide from the purifier and break up the masses, and as this will generally have to be done at least twice during the life of the oxide, the saving of expense over the ordinary method of using oxide is not very great when the expense of pumping and metering a proper proportion of air is considered. The higher temperature of an oxide vessel in which continuous revivification is proceeding favours its activity, and prevents the loss of "illuminating power" to the gas by the deposition of hydrocarbons in the vessel. The deleterious influence of the nitrogen of the air which remains in the purified gas is thereby masked, and to some extent compensated for. The use of pure oxygen in place of air suggests itself; but for the purpose of revivifying oxide *in situ* it has been little tried, though H. Veevers claims excellent results from its use.* The economy of the process is, however, open to question. Oxygen as an aid to gas purification is probably more effectively applied at other stages of the purifying, and its general use will be considered later. Where the oxide vessel is followed by "sulphide" vessels for the removal of carbon disulphide, the admission of air, if carried out at all, must be in less quantity than the theoretical amount, as it is essential that oxygen should not pass out of the oxide vessels into the sulphide vessels. Oxygen, passing in even small quantity into the sulphide vessels, causes oxidation of the active sulphide, and if it do not give more serious trouble by driving sulphur forward, will at least impair the life of the material in the vessels. Consequently, where separate sulphide vessels are used it is impossible to revivify completely oxide by admitting a small percentage of air with the gas, though sufficient air may be admitted to extend considerably the life of a vessel. Practically not more than 2 per cent. of air may safely be added to the gas entering oxide purifiers when these are followed by "sulphided lime" vessels.

Use of Weldon Mud.—Weldon mud is now largely used as a substitute for iron oxide in vessels in the position in the series which we are now considering. The superior absorptive power of this material for sulphuretted hydrogen has already been indicated, and it may be used in a similar manner to that in which oxide is ordinarily worked, but the great advantages it presents are thereby much curtailed. Unlike oxide of iron, Weldon mud is specially fitted for revivification *in situ*, as the pressure thrown by it becomes less as the amount of sulphur absorbed increases. For the reasons given above, however, it is impossible to admit with the gas the full amount of air requisite for the complete revivification of the manganese where "sul-

---

* *Journ. of Gas Lighting*, lx., 945.

phide" vessels follow the Weldon mud. Hence, in practice, when the Weldon mud is used in this position in the series, about 1 per cent. by volume of air is admitted with the gas, and further, complete revivification is brought about by occasionally putting the vessel out of action and blowing a large volume of air through it. On these occasions the heat of the vessel must be closely watched lest the sulphur be fused or the grids burnt at the high temperature sometimes developed by too intense activity of the material undergoing oxidation. The cessation of carbonizing on Sunday at many works furnishes a good opportunity for revivifying Weldon mud in the oxide position in the series without interruption of purification or the slipping of a vessel during working hours. The quantity of moisture in Weldon mud becomes, on an average of the whole mass in the vessel, much reduced by the passage of gas, especially if air is admitted continuously, and the heat further maintained by blowing steam into the lutes. Thus spent Weldon mud should not contain, on an average, over 20 per cent. of moisture, and as it will not have lost, but rather gained slightly in weight, by its use in the purifier, the moisture lost must have been replaced by sulphur. Oxide of iron, on the other hand, will generally be found to have lost weight during use. The use of air with Weldon mud permits of it being completely fouled in vessels in the oxide position without removal from the vessels. In this lies its chief superiority to oxide, though its freedom from organic matter and sawdust favours the extraction of pure sulphur from the spent material, which is not necessarily consigned to the sulphuric acid makers, as is the case with spent oxide. This recovery of sulphur, which is of immense importance in the choice of a purifying material, speaks strongly in favour of Weldon mud, and the relative values of sulphur in oxide and in Weldon mud will be again referred to in the sequel to this volume.

Removal of Carbon Disulphide.—The gas as it leaves the oxide purifiers, arranged after lime vessels as described, is free from carbonic acid and sulphuretted hydrogen. The remaining impurity of importance is carbon disulphide, the amount of which will not, by the processes given, have been greatly reduced by the passage of the gas through the preceding vessels. There will be still present from 30 to 40 grains of this impurity in 100 cubic feet of the otherwise purified gas, and about 6 grains of yet other sulphur compounds (not sulphuretted hydrogen) in that volume. In many towns the amount of carbon disulphide bnd other sulphur compounds that may be present in the distriauted gas is limited by statute, and the regulations on this matter imposed on the London gas companies at the present time are quoted later. For the most part those imposed on provincial companies are less stringent, and corporation works are often entirely free from obligation in this respect. The description of the method adopted for the nearly complete removal of carbon disulphide from gas, will apply to all cases where any attempt is made to limit its amount. The 6 grains or so, in 100 cubic feet of gas, of sulphur compounds other than sulphuretted hydrogen or carbon disulphide, are at present allowed to pass forward unchecked, though included in the maximum quantity of sulphur compounds permitted in the gas as distributed.

Preparation and Nature of Sulphided Lime.—The oxides or hydrates of certain metals readily combine with carbonic acid, and calcium hydroxide is used in gas works for the removal of that compound from gas. The chemical analogy between oxygen and sulphur would lead us to infer that certain metallic sulphides or hydrosulphides should possess an affinity for carbon disulphide, and, as a matter of fact, sulphided lime is the material employed in gas works for removing that body from gas. The material for removing carbon disulphide is formed in the vessel in which it is afterwards to do its work, by passing gas containing sulphuretted hydrogen, but free from carbonic acid, through slaked lime, preferably still warm from the slaking. The slaked lime is spread on the grids in the usual manner, the vessel closed, and gas from the outlet of the "carbonate" vessels passed into it. It is essential to the formation and maintenance of a good "sulphide" vessel that the gas passing through it should be free from carbonic acid and oxygen. The sulphided lime so obtained by fouling slaked lime with sulphuretted hydrogen is the active agent employed for removing carbon disulphide from gas. When sulphided, the vessel is put in the series after the oxide purifiers, and as the total amount of impurity to be removed by it is small, it should remain in action for several months without opening. As the lime compound, which is active towards carbon disulphide, is somewhat unstable, and as the affinity between it and the disulphide is not strong, the sulphide vessel is very liable to derangement, and consequently, it is customary to use two such vessels in series. But even with this precaution care is needed to avoid the admission of air or carbonic acid to the vessels, since their proper working is thereby imperilled, and quantities of carbon disulphide may be driven off from the material, and the amount of sulphur compounds in the gas increased instead of diminished. Throughout, it must be borne in mind that the oxygen compounds of calcium are more stable than the corresponding sulphur compounds. If the bearing of this fact on the working of sulphide vessels is fully grasped, their so-called fickleness will be found to be unsubstantiated, and a complete acquaintance with the actual facts of each case of defective working of a sulphide vessel will generally at once lead to a simple explanation. The trouble really lies in the facts not being in all cases forthcoming.

The precise composition of the active material of sulphide vessels has long formed a subject of debate for gas chemists. It might reasonably be supposed to be calcium sulphide, more or less moist from the water used in slaking the lime. It has been shown experimentally that damp calcium sulphide is an absorbent of carbon disulphide, but the absorption is not a complete one, and it seems possible that it may really be due to a decomposition product of calcium sulphide in the presence of water. The published work on the subject does not actually enable us to refute those who contend that damp calcium sulphide is the active material of sulphide vessels, but it may be positively stated that the reaction which takes place in them is not represented by the equation—

$$CaS + CS_2 = CaCS_3,$$

though this is still often used in writings on gas manufacture, to express the action of sulphided lime on carbon disulphide. No such product, as a simple pure calcium thiocarbonate is the result of the reaction that occurs in the purification of gas.

The active material of sulphide vessels has been considered by Lewis T. Wright, among others, to be calcium hydrosulphide, CaS,H_2S or $Ca(SH)_2$. On analogy this seems extremely probable, as it is the sulphur compound of calcium corresponding to calcium hydrate, $Ca(OH)_2$, and might, therefore, reasonably be expected to have an affinity for carbon disulphide, as the hydrate has for carbon dioxide. But, according to V. H. Veley, calcium hydrosulphide is inactive towards carbon disulphide. He formed the salt by passing sulphuretted hydrogen into water containing lime in suspension, and found it to crystallise in acicular needles. It is, however, extremely unstable, and in the presence of air or even inert gases, passes into the hydrated sulphide, thus—

$$Ca(SH)_2 + H_2O = Ca(OH)(SH) + H_2S$$

with evolution of heat. This hydrated sulphide is precipitated when carbon disulphide is passed into a solution of calcium hydrosulphide, sulphuretted hydrogen being evolved, and the absorption of carbon disulphide is said not to commence until such precipitation has taken place. The carbon disulphide, on absorption, throws down crystals of a basic calcium thiocarbonate, which deepen in colour from yellow to red, and dissolve to form a red liquid, which, on evaporation, yields a basic thiocarbonate corresponding with the formula $Ca(OH)_2CaCS_3,7H_2O$. Such a red liquid drains down from the sulphide vessels during their activity, and is removed by siphons. From these data and the fact that the absorption of carbon disulphide is accompanied by evolution of sulphuretted hydrogen, V. H. Veley considers the reactions which take place in the sulphide vessels may probably be represented by the equations—

$$2CaSHOH + CS_2 = Ca(OH)_2CaCS_3 + H_2S$$
$$3CaOHSH + CS_2 + H_2O = CaCS_32Ca(OH)_2 + 2H_2S.$$

For the reasons given above, it must not be assumed that these are the reactions that actually occur, and further investigation is still urgently needed. Veley's conclusions have not actually been disproved, though they have been before the gas world for a considerable time,* and his work on the subject does not pretend to be exhaustive. It must be granted that he has made out an excellent case on behalf of calcium hydroxyhydrosulphide (Ca,OH,SH), as the active material of sulphide vessels, and until more conclusive evidence than has at present been brought forward is forthcoming as to the inaccuracy of his deductions, they must be taken as legitimate. It is of little use to attempt a research on the action of sulphide vessels with impure materials and a gas of uncertain composition, and many would-be investigators of the matter have failed through carelessness in this respect. Chemical reactions must be studied, in the first instance, apart from all disturbing influences; when the actions of gases of definite and tolerably simple composition on pure materials have been sufficiently studied, we can pass to the study of more complicated gaseous mixtures, and make due allowance for the presence of disturbing elements. The haphazard and unscientific methods on which many so-called investigations on gas purification have been carried out are sufficient ground for excluding mention of them from a general review of the subject. Veley's researches, suggested and more or less inspired by A. Vernon Harcourt, were conducted on sound lines, and further investigations in continuation of his work on sulphur purification are eminently desirable.

It is a matter of common experience that a sulphide vessel may be inactive through over-fouling of the lime, or, what is more common, by formation of the sulphide at a low temperature. The admission of air to the vessel will often bring a sluggish material into an active state, and it has been stated in explanation of this action that the hydrosulphide is oxidized by the air to the above-named active compound. It is certain that air effects a gradual oxidation of the lime sulphide and causes

---

* *Journ. Soc. Chem. Ind.*, 1885, 633.

an emission of sulphuretted hydrogen from it; but other gases besides oxygen have the same effect. The calcium thiocarbonate formed by the absorption of carbon disulphide is a rather unstable compound, and is decomposed by carbonic acid with liberation of carbon disulphide. Hence the importance of preventing carbonic acid going forward into the sulphide vessels. The lime for a sulphide vessel should never be fouled at a temperature below 40° F., if possible, as sulphide vessels made below that temperature are sluggish in action, and some have even asserted that different compounds are formed with the lime by the action of sulphuretted hydrogen at comparatively low and comparatively high atmospheric temperatures. Practice shows that sulphide vessels are generally less active in winter than in summer, a fact that is troublesome to the gas engineer, whose greatest make occurs in the former season.

Check Vessels.—In addition to the traces of sulphuretted hydrogen that escape the oxide purifiers, that gas is evolved in small quantity from the sulphide vessels, and it, consequently, becomes necessary to take further steps to effect its complete removal from the gas. Where the regulations imposed on the gasworks are very stringent, and no readily recognisable trace of sulphuretted hydrogen may go out in the distributed gas, it is customary to devote two vessels to this final stage of the purification. These vessels, known as "checks," may contain either lime, iron oxide, or Weldon mud. Ferric oxide would naturally appear to be more economical than lime, as the sulphur is easily recoverable; but, unfortunately, it does not appear to absorb readily the last traces of sulphuretted hydrogen. In many works, however, it is in use, and only where the method adopted for ascertaining the presence of sulphuretted hydrogen is a somewhat exacting one does it give place to lime. Until quite recently lime was invariably used in the check vessels in the Metropolis, and other places where absence of sulphuretted hydrogen was demanded, and the test was a severe one, and it is certainly efficient. Recently, Weldon mud has taken the place of both lime and oxide in the check vessel position in many works, and as it has the sharp action of the former and the economy of the latter, the change appears justifiable. Moreover, the Weldon mud, by the admission of a small percentage (about 0·25 per cent. of the volume of gas) of air at the inlet of the check vessel, can be kept in action almost indefinitely, as it is continuously revivified, whereas lime and oxide require changing tolerably often to ensure the outlet gas being perfectly clean. In fact, the life of a Weldon mud vessel, worked under proper conditions in the check position, is determined by other considerations, such as the periodical cleaning of inlet and outlet pipes, than its efficiency; and as the sulphur taken up is recoverable, it may almost be regarded as an ideal check material. Where lime is used, the pressure thrown by the check vessels increases with the period of their action; but the pressure thrown by Weldon mud rather decreases with length of service. The only objection commonly raised to the use of Weldon mud is the wet and sloppy condition it is apt to assume in the purifier, making its removal a somewhat unpleasant task. The check vessels are usually similar in shape and design to the other purifiers, and the material is shifted and disposed in them similarly. The gas passing from the outlet of the check vessels should not blacken moistened "lead" paper (see Vol. II.) when allowed to impinge on it from a small orifice for twelve hours, at the rate of 5 cubic feet an hour. If the "lead" paper is properly made, this test is sufficiently severe to ensure the gas distributed being returned as free from sulphuretted hydrogen at the testing places. Needless to say, the lead paper should be enclosed in a glass or metal case, from which the gas can escape, but which will not admit (possibly foul) air throughout the time of the test.

General View of the Scheme of Purification.—The course of the gas through the purifiers, which are made to subserve four distinct ends, has now been traced. Though one vessel should suffice for each stage of the purification process, it will have been gathered from the above that it is customary for convenience of working and thoroughness to duplicate the vessels, and hence a set of purifiers for the complete scheme of purification indicated above will consist of eight separate vessels. These will be two "carbonate" or lime vessels for the absorption of carbonic acid, two ferric oxide or Weldon mud vessels for the absorption of sulphuretted hydrogen, two vessels of sulphided lime for the absorption of carbon disulphide, and two "check" vessels of lime, ferric oxide, or Weldon mud, for absorbing the last traces of sulphuretted hydrogen. The gas which has passed such a set of purifiers in good working order should be free from sulphuretted hydrogen and carbonic acid, and contain on the average about 10 grains of sulphur and perhaps 1 grain of ammonia per 100 cubic feet, as indicated by the tests prescribed by the Metropolitan Gas Referees. The trace of ammonia in purified gas is generally to be attributed to the gas leaving the scrubbers being not absolutely free from ammonia, though being without action on the test papers. The sulphuretted hydrogen and carbonic acid present in the gas at that stage mask the alkaline reaction of the ammonia, and hence as much as 2 grains of ammonia may be present in scrubbed gas, which appears without alkaline reaction on red litmus paper. But after the removal of the acid impurities in the purifiers, the trace of ammonia asserts its presence, and is, as always, detected by the Referees' test for ammonia in gas. Traces of ammonia may be retained in the material in the purifiers in cold weather, and given off rapidly when warmer weather supervenes. Under such circumstances, quite a large quantity of ammonia—say 4 to 10 grains per 100 cubic feet—may appear in the purified gas, and give rise to considerable trouble. Hence very thorough scrubbing at all times is absolutely necessary for the ultimate perfect purification of gas, and too much reliance must not be placed on the evidence of test papers as to the "cleanness" of gas at the outlet of the scrubbers.

Modifications of the foregoing Scheme.—Such a high degree of purity is often not required, and to meet these cases, and those where special working conditions prevail, various other systems of purification have been elaborated. If the principles on which the complete scheme quoted above is based are grasped, the comprehension of most other processes is not difficult. They may be regarded for the most part as modifications of it, in so far as their action is concerned, though many of them are of earlier date and in reality the precursors of the scheme here given. In many provincial works, especially those directly controlled by municipal authorities, no sulphur compounds other than sulphuretted hydrogen are removed from the gas, and hence the sulphide vessels are unnecessary. In some cases no further purification than passage through an oxide vessel is extended to the gas. though in other works passage through lime only is substituted, The choice of material, where sulphuretted hydrogen is the only impurity to be removed, must be determined by the relative prices of ferric oxide and lime at the works, though the usefulness of lime in removing the deleterious carbonic acid must be considered unless the "illuminating power" of the gas is of no moment. On the other hand, lime has a more direct deteriorating effect on the illuminating power of the gas, as it appears to retain more hydrocarbon vapours than ferric oxide. If the scrubbing surface is insufficient some ammonia will go forward to the purifiers, and red masses of calcium thiocyanate will be found in the lime vessels, as well as the ordinary calcium compounds, and the amount of carbon disulphide in the gas will be perceptibly diminished.

The choice of lime or oxide as a purifying material, where neither carbonic acid nor carbon disulphide has to be removed from coal gas, is also in many cases affected by the question of the recovery of cyanogen from the gas. Where the cyanogen compounds are not in large measure removed prior to the purifying vessels by the application of special absorbents in washers or scrubbers, a large, but variable, quantity of cyanogen remains in the gas and is absorbed by lime or oxide—whichever of these two materials is used in the first purifier. When, therefore, lime is used in the first vessel in the series, or in all the vessels, the cyanogen compounds are completely retained by it, and the gas no longer has the poisonous and corrosive properties which these compounds impart to it. But, in this respect, lime presents a serious disadvantage as compared with ferric oxide applied under similar circumstances. The cyanogen absorbed is not practically recoverable from spent lime, whereas it is readily recoverable from spent oxide if present in appreciable quantity. On the other hand, the ferric hydrate of most "oxide" purifying materials is not a very ready or complete absorbent of hydrocyanic acid or its ammonia salt, and some cyanogen may escape absorption when oxide alone is relied upon for its removal. This faulty absorption may be ignored so far as the properties of the purified gas are concerned, and hence it is merely a question whether oxide becomes more economical than lime in virtue of the value of the cyanogen (and sulphur) which it contains, when spent, in a state in which it is available commercially for the preparation of marketable cyanides. The assay of spent oxide for its content of sulphur and cyanogen will be described in the sequel to the present volume. But it must be borne in mind that, in order to obtain spent oxide containing an appreciable amount of cyanogen, the oxide must have been used prior to lime in the series of purifiers, and that overheating in revivification, whether effected *in situ* or on a revivifying floor, is injurious—as is also the presence of ammonia in the gas—to the cyanogen content of the oxide. In places where lime is not used at all in the purification of coal gas—such as the majority of German gasworks—the practice prevails of so employing oxide in the purifiers that it absorbs practically the whole of the cyanogen compounds in the washed gas at the same time that it absorbs the sulphuretted hydrogen. Revivification *in situ* is commonly carried on in these works without detriment to the cyanogen recovery by means of the oxide. Care is taken to avoid the admission of an excess of air, the occurrence of overheating, or the presence of ammonia in the gas.

A different order of the usual vessels has been suggested by the patentees of the Weldon mud process of gas purification specially for use with that material. This consists in reversing the usual positions of the oxide and sulphide vessels, so that the latter immediately follow the carbonates. The gas freed from carbonic acid but charged with carbon disulphide, and an amount of sulphuretted hydrogen varying with the extent to which the material in the carbonate vessels is carbonated, passes direct into the previously formed sulphide vessels, where the carbon disulphide is absorbed while the sulphuretted hydrogen passes on to vessels charged with Weldon mud. It is essential to the proper working of this system that the absorption of carbonic acid in the carbonate vessels shall be complete, and this can only be ensured by putting in a clean lime vessel as soon as the second carbonate shows carbonic acid at the third or fourth tier, and placing the half-fouled vessel first in the series. Gas containing sulphuretted hydrogen, but free from carbonic acid, will not cause derangement in the sulphide vessels, though statements to the contrary are often made. The placing of the sulphide vessels in this position in the series puts them out of risk of disturbance by air or oxygen, which is then admitted to the gas after it has passed the sulphide vessels and is entering the oxide or Weldon mud vessels. Thus a more perfect revivification of the oxide or Weldon mud can be secured without risk of injury to the sulphided lime. Hood and Salamon recommended the carbonating and sulphiding of lime while hot from slaking, and the maintenance of warmth during the action of the vessels, and claim thereby to obtain a purer carbonate for the spent material, and a more active sulphide vessel. This is in keeping with the well-known experience of gas engineers, that a sulphide vessel formed at a low temperature is inactive, or acts very sluggishly; but the author is not aware that the suggestions of Hood and Salamon have been carried out to the full on a working scale.

Where the number of purifying vessels is very limited, and where objectionable odours, on the opening of foul vessels, must be as far as possible avoided, another method of working is very commonly adopted. In this, the use of separate "sulphide" vessels is abolished, and a partially sulphided lime vessel is practically the absorbent material for carbon disulphide. Air or oxygen is admitted to the gas in regulated proportion, either immediately before the first purifier or at an earlier stage in the course of the gas from the retorts. In the latter case a somewhat varying amount of oxygen is absorbed in the scrubbers, and the exact quantity entering the purifiers with the gas is unknown. This is especially objectionable when pure oxygen is used, hence that is more commonly admitted at the entrance to the purifiers proper. The oxygen, either pure or in air, effects an oxidation of the sulphur compounds of the lime, and sulphur is deposited as such in considerable quantities in the foul lime. The amount of oxygen admitted must not be sufficient to prevent the stability of a certain amount of sulphided lime in the last vessel, or no material will be present for the absorption of carbon disulphide. Consequently, oxygen or air must be used in amount insufficient for the oxidation of the whole of the sulphuretted hydrogen in the gas; that is, oxygen must not be present in the gas at the outlet of the last lime purifier. The air or oxygen may be admitted continuously with the gas in regulated proportion, or, less preferably, admitted in somewhat larger quantity at intervals only. The amount of air admitted with gas containing about 600 grains of sulphuretted hydrogen per 100 cubic feet, should not exceed 2 per cent. by volume, and many engineers prefer to work with less. In fact, $\frac{3}{4}$ to 1 per cent. of air is the amount more commonly admitted to the lime purifiers, and the unabsorbed sulphuretted hydrogen goes forward to an oxide or Weldon mud vessel. With careful working, and the avoidance of an excess of air or oxygen, this system gives good results, as far as the reduction of sulphur compounds in the gas is concerned, but it is not economical, as a considerable quantity of sulphur is deposited and retained in the lime, instead of all going forward to oxide or Weldon mud, from which it is recoverable. On the other hand, the oxidation maintains the temperature in the vessels, and the spent lime is dry and innocuous, except that on the top tier, which is invariably sloppy. This so-called "rotation" system of gas purification is largely used where the gas works is situated in the heart of a populous district, on account of the unobjectionable character of the spent lime. Whether pure oxygen or air should be used in connection with lime purification is a much-debated question, which turns mainly on the cost of obtaining oxygen and the cost of enrichment. That a small percentage of air admitted before the lime purifiers has not a deteriorating effect on the "illuminating power" of gas is conceivable, and is, indeed, proved by experience, but that the corresponding amount of oxygen would give a better result is granted by nearly all. Whether the slightly improved result is worth the cost of the pure oxygen is extremely doubtful, though with very impure gas, and with complete revivification of Weldon mud *in situ*, the use of oxygen seems desirable. Many processes have quite recently been devised for producing oxygen at a far cheaper rate than formerly, and if any one of them should prove a commercial success, we may expect a considerable extension of the application of oxygen to gas purification. Up to the present, Brin's process for the production of oxygen is the only one that has been considerably used on gas works. W. A. Valon has especially argued in favour of the use of oxygen in gas purification, and has made out an excellent case for it, but up to the present no such scheme has been adopted in a really large works.

Purification with Gas Liquor.—Very brief reference only can be here made to the schemes for the complete purification of coal gas by washing it with gas liquor or other liquids. There have been very many of these; one of the most important was devised by C. F. Claus, and its essential parts were covered by patents Nos. 7,580, 7,582, 7,584, and 7,585, dated 6th June, 1886. This process has been fully described by C. W. Watts * and C. Hunt.† Briefly, scrubbers packed with broken gannister brick are provided, to allow a space of 8 cubic feet per 1,000 cubic feet of gas passing per day, and spent liquor is led into the last scrubber and passed along the series until, on leaving the first, it is saturated with impurities. The carbonic acid and sulphuretted hydrogen are driven off from the liquor by heating it, while the ammonia is retained by scrubbing. Ammonia driven off from the liquor enters the second scrubber in order to remove a further quantity of acid impurities from the gas, while the spent liquor is returned to the last. The excess liquor is withdrawn at intervals. One of the sulphur compounds of ammonium, probably the disulphide, $(NH_4)_2S_2$, has an affinity for carbon disulphide, and the sulphur compounds in the gas can be reduced to 20 grains per 100 cubic feet by the systematic use of Claus' system. The process has been tried on a tolerably extensive scale, with fairly satisfactory results in some cases, but it has not been commonly adopted. The results of prolonged trials on a large scale of the Claus system at Belfast have been published by J. Stelfox (see below), and are unfavourable to it. It was found impossible to free gas continuously for any considerable length of time from carbonic acid and sulphuretted hydrogen by its means, while breakdowns of some parts of the plant were very frequent, and considerable leakages of ammonia occurred. Most of the trials at Belfast were made under the supervision of C. W. Watts, whose previous experience of the system had been considerable, so that there appeared to be no ulterior reasons for their results being unfavourable. Clearly the Claus system needs modification and improvement to make it deserving of adoption in modern gas works. With regard to this and other schemes for the purification of gas by liquor, it may be pointed out that Lewis T. Wright has argued for and against liquor purification on theoretical grounds, from the relative amounts of acid and alkaline constituents of gas liquor, and the proportions in which they are expelled from the liquor on moderate heating.‡ His arguments are based on the combining equivalents of ammonia and carbonic acid and sulphuretted hydrogen, and the relative proportions of these bodies in the crude gas. He con-

---

* *Journ. Soc. Chem. Ind.*, 1887, p. 25.

† *Journ. of Gas Lighting*, 1886, p. 1181. And more recently by J. Stelfox, *Journ. of Gas Lighting*, 1897, lxix., 1475.

‡ *Journ. of Gas Lighting*, 1886, pp. 280, 329, 373, and 511.

cludes that the expenditure of heat in raising the temperature of sufficient liquor for the purification of the gas from a ton of coal, to that required for the expulsion of a large proportion of its acid constituents, is not prohibitive to the success of a scheme of liquor purification, and it is difficult to see precisely why such a process has not more generally succeeded.

CHAPTER IV.

CARBURETTED WATER GAS.

Carburetted Water Gas.—The mixture consisting essentially of hydrogen and carbonic oxide, obtained by the decomposition of steam by incandescent carbonaceous material, is commonly known as water gas. This gas burns with a non-luminous flame, and without admixture is useless for lighting purposes, except where it is used to raise refractory earthy films to incandescence. Even for this use it has not hitherto proved fully satisfactory, and gas containing an admixture of hydrocarbons has been generally preferred. Where cannel and rich bituminous coals are scarce, and anthracite or coke and mineral oil are plentiful, a mixture of water gas and oil gas has been freely used in place of coal gas. The proportion of oil gas to water gas may be varied according to the "illuminating power" required of the mixture, but in England it is customary to make the latter of from 18 to 25 candle-power. In North America it is more often nearer 30. This is, perhaps, owing to the fact that there, where carburetted water gas is distributed without, or with little, admixture of coal gas, oil is cheap, and a high candle-power gas can be manufactured at a very low cost. It has been found convenient and economical to produce the oil gas and water gas simultaneously in parts of the same plant, and to allow the water gas to mix with the oil gas immediately the latter is formed. The subjection of the mixture to a high temperature with a view to ensure the permanency of the oil gas generally follows. It is to gas made under these conditions that the term carburetted water gas is generally applied. Where oil and anthracite are abundant, the manufacture of carburetted water gas is very considerable. It has been estimated that two-thirds of all the gas made in North America at the present day is of this variety. A treatise on illuminating gas, if in any degree pretending to comprehensiveness, must, on this account alone, cover the production of carburetted water gas, but the introduction of late years of the manufacture on an extensive scale into this and other European countries gives the subject still greater importance. The scarcity of good cannel coal and the rapid exhaustion of our home supplies, together with the cheapness of mineral oil and the increasing facilities for its transport, have led to the introduction of oil as an enriching material into this country, and the system of incorporating oil gas with water gas, which was devised and elaborated in the United States, has naturally been adopted, in the first instance, in preference to new and untried methods of utilizing oil. The use of large quantities of oil in place of cannel has depreciated the value of the latter, and the question—which is the cheaper enriching material?—must be decided according to their cost at the works at the prevailing market prices. The works which can avail itself of either or both, at will, is distinctly in the best position, and can take advantage of fluctuations in the prices of either. Nevertheless, it may be remembered that cannel would now be at prohibitive prices in most parts of England but for the extensive use of oil in several large gas works. The manufacture of carburetted water gas undoubtedly affords a higher illuminating duty from the oil than the manufacture of simple oil gas according to ordinary methods.

The varieties of plant proposed for the manufacture of water gas are far too numerous for mention here, but they may at the outset be classed under two heads—(1) Forms in which the requisite temperature of the carbonaceous matter used for reacting on the steam to produce gas is secured and maintained by the cessation of gas making at regular intervals, during which a blast of air is passed through the carbon till it is in a state of vivid incandescence; (2) forms in which fuel is used to maintain continuously the temperature of a mass of carbonaceous material sufficiently high for the decomposition of steam, which is admitted uninterruptedly to form water gas.

The first system is commonly known as the **intermittent**, and the second as the **continuous**. The second entails the use of a separate chamber for the carbon used in the formation of gas to that for the fuel used in maintaining the temperature, and, consequently, the heat must pass *through* a wall of refractory material, as in the case of the ordinary coal-gas retorts, with inevitable loss. In this variety of plant the heat is almost invariably applied externally only to what is virtually a retort, consequently the surface from which radiation can take place is very great in comparison with the mass of carbon raised to gas-making temperature, and the loss of heat therefrom is considerable. These objections, of course, apply to the ordinary methods of raising coal to the temperature of gasification; but in the manufacture of coal gas no other system is feasible, and the carbonization of coal does not *per se* entail the absorption of much, if any, heat, whereas the water-gas reaction is, as will be hereafter shown, endothermic, and much heat is required purely to maintain it. Indeed, the absorption of heat is so great that it may be demonstrated that no gas retorts are capable of allowing the transfer of heat to take place sufficiently rapidly, while a sufficiently high temperature for the water-gas reaction is maintained. In the production of water gas there is the first or intermittent system as an alternative, and it is not surprising, therefore, that the second or continuous process of gas producing has been commonly discarded in extensive water-gas installations. The various continuous water-gas systems which have from time to time been worked in the United States and elsewhere are not, therefore, of sufficient interest to require detailed description here.

In addition to the continuous and intermittent systems of manufacturing true water gas there is a third method, which results in the production of a non-nitrogenous semi-water gas. It consists in passing neat oxygen through the carbonaceous material along with the steam at such a rate that the heat liberated by the continuous combustion of a portion of the carbon serves to maintain the proper temperature of the carbonaceous material and to supply the heat required for the consummation of the reaction between the carbon and the steam. If the oxygen is introduced in the proper quantity relatively to the steam, and suitable conditions are maintained, this method should result in the continuous production of a gas consisting essentially of 7 volumes of carbonic oxide to 3 volumes of hydrogen. In some respects this gas is superior to true water gas, and the method is a practicable one, if only neat oxygen is obtainable at a sufficiently low price. At present, however, neat oxygen is too costly for this elegant method of producing a rich semi-water gas to be practically applied.

Intermittent System.—The intermittent processes for the production and carburetting of water gas are many, but only a few are extensively worked at the present day. They may be regarded as derived by successive modifications from the Tessié du Motay system, and to have culminated, for practical purposes, in the modern forms of the Lowe plant, which is that most extensively adopted in this country and in the United States. Before considering the details of the plant, it will be convenient to state briefly the reactions involved in the production of water gas.

Action of Carbon on Water Vapour.—The reactions that take place between incandescent carbon and water vapour are determined, primarily, by the temperature, and the relative masses of the reacting bodies. Other conditions are either dependent on these or of secondary importance. The reactions are best studied, in the first instance, by assuming that pure carbon and water vapour only are present. At 600° C. carbon decomposes water vapour appreciably in accordance with the equation :—

$$C + 2H_2O = CO_2 + 2H_2. \quad . \quad . \quad . \quad (1)$$

At a slightly higher temperature a small quantity of carbon monoxide is formed, and at about 1,000° C. the products of the action of excess of carbon on steam are appreciably carbon monoxide and hydrogen, which may conceivably be formed according to the equation :—

$$C + H_2O = CO + H_2. \quad . \quad . \quad . \quad . \quad (2)$$

As a matter of fact the reaction never appears to be quite complete, and a small percentage of carbon dioxide remains in the product. This is not surprising, when we recall what happens when carbon dioxide is brought in contact with excess of carbon. At 600° C. practically no reaction takes place; but as the temperature rises an increasing amount of carbon monoxide is found in the product, until at 1,000° C. not more than 3 per cent. of carbon dioxide remains, while even at a higher temperature nearly 1 per cent. persists. The completed reaction is :—

$$C + CO_2 = 2CO. \quad . \quad . \quad . \quad . \quad (3)$$

Another reaction which has to be considered is that between water vapour and carbon monoxide. When any action takes place it is in accordance with the equation :—

$$CO + H_2O = CO_2 + H_2. \quad . \quad . \quad . \quad (4)$$

At 1,000°, however, this does not extend to the whole mass, though the carbonic acid formed increases with an increase in the amount of water vapour. Under conditions which may occur in a water-gas generator any of these reactions may take place. A fifth reaction which might conceivably occur is the reversal of the last, viz. :—

$$CO_2 + H_2 = CO + H_2O, \quad . \quad . \quad . \quad (5)$$

but it does not in fact take place at the temperatures which prevail in water-gas plants. As the ideal water gas should contain a minimum amount of carbon dioxide (and, consequently, a maximum amount of carbon monoxide), a study of these reactions will indicate the most favourable conditions for the production of this ideal gas.

The Thermic Exchanges of the Reactions.—Since the five reactions named above are attended with different thermic phenomena, and as the amount of heat liberated or absorbed is practically the primary factor in determining how long a given reaction will continue under given conditions, it becomes important to compare the thermic phenomena of the several reactions.

The heat liberated (+) or absorbed (−) in these reactions is stated below in a number of convenient measures:—

Equation.	Heat Liberated (+) or Absorbed (−).				
	For the Molecular Quantities	Per Kilogramme of		Per Pound of	
		Carbon.	Water (vapour).	Carbon.	Water (vapour).
	Cent. Units.	Calories.	Calories.	B.T.U.	B.T.U.
(1) $C + 2H_2O = CO_2 + 2H_2$,	−19,680	−1,640	− 547	−2,952	− 984
(2) $C + H_2O = CO + H_2$,	−28,644	−2,387	−1,591	−4,296	−2,864
(3) $C + CO_2 = 2CO$,	−37,608	−3,134	...	−5,641	...
(4) $H_2O + CO = CO_2 + H_2$,	+ 8,964	...	+ 498	...	+ 896

(It has been assumed in compiling this table that the water decomposed or formed is in a state of vapour (at 0° C.) and not in the liquid state.)

Before proceeding to argue from these figures, the temperatures at which the reactions occur must be taken into consideration, as the heat which has to be furnished to the materials merely to raise them to the requisite temperature considerably affects the practical application of the foregoing thermic quantities.

The first reaction, $C + 2H_2O = CO_2 + 2H_2$, occurs at about 600° C., and the heat required to raise the reacting substances to this temperature (taking the specific heat of carbon at 0·2 or 2·4 for the molecular quantity, and that of water according to the formula: Molecular specific heat $= 7{\cdot}56 + 0{\cdot}006552\, t$) is—

$$(600 \times 2{\cdot}4) + 2 \times 600\,(7{\cdot}56 + 3{\cdot}931) = 1{,}440 + 2 \times 6{,}895 = 15{,}230 \text{ calories.}$$

Hence the total heat which must be supplied per molecule of carbon or two molecules of water in a state of vapour is (19,680 + 15,230 =) 34,910 units in order that the reaction may complete itself.

The second reaction, $C + H_2O = CO + H_2$, occurs at about 1,000° C., and the heat required to raise the reacting substances to this temperature is similarly—

$$1{,}000 \times 2{\cdot}4 + 1{,}000\,(7{\cdot}56 + 6{\cdot}552) = 2{,}400 + 14{,}112 = 16{,}512 \text{ calories.}$$

Hence the total heat which must be supplied per molecule of carbon, or per molecule of water in a state of vapour, in order that the reaction may complete itself, is about 28,644 + 16,512 = 45,156 units.

The third reaction, $C + CO_2 = 2CO$, occurs at about 1,000° C., and taking the molecular specific heat of carbonic acid according to the formula $8{\cdot}272 + 0{\cdot}013112\,t - 0{\cdot}0000023628\,t^2$, the heat required to raise the reacting substances to this temperature is—

$$1{,}000 \times 2{\cdot}4 + 1{,}000\,(8{\cdot}272 + 13{\cdot}112 - 2{\cdot}3628) = 2{,}400 + 19{,}021 = 21{,}421 \text{ calories.}$$

Hence the total heat which must be supplied per molecule of carbon, or per molecule of carbonic acid at 0° C., in order that the reaction may complete itself, is about 37,608 + 21,421 = 59,029 units.

The fourth reaction, $H_2O + CO = CO_2 + H_2$, occurs tolerably completely at over 1,000° C.—say 1,100°—and assuming that the molecular specific heat of carbonic oxide is 6·06, the heat required to raise the reacting substances to this temperature from 0° C. is—

$$1{,}100 \times 6{\cdot}86 + 1{,}100\,(7{\cdot}56 + 7{\cdot}207) = 7{,}546 + 16{,}244 = 23{,}790 \text{ calories.}$$

Hence the total heat which must be supplied per molecule of water in a state of vapour, or per molecule of carbonic oxide at 0° C., in order that the reaction may complete itself, is about 23,790 − 8,964 = 14,826 units.

It will be convenient now to tabulate these total quantities of heat required :—

Equation.	Heat absorbed in raising the Reacting Substances from 0° C. to the Temperature of Reaction, and in completing the Reaction.				
	For the Molecular Quantities	Per Kilogramme of		Per Pound of	
		Carbon.	Water (vapour).	Carbon.	Water (vapour).
	Cent. Units.	Calories.	Calories.	B.T.U.	B.T.U.
(1) $C + 2H_2O = CO_2 + 2H_2$, .	34,910	2,909	970	5,236	1,745
(2) $C + H_2O = CO + H_2$, .	45,156	3,763	2,508	6,773	4,515
(3) $C + CO_2 = 2CO$, . .	59,029	4,919	...	8,854	...
(4) $H_2O + CO = CO_2 + H_2$, .	14,826	...	818	...	1,482

Now, without pursuing this study of the heat exchanges for the different reactions further, it is evident that, starting with carbon and water vapour, the ultimate products will depend very much upon the heat which is available to raise the reacting materials to the requisite temperature and complete the reaction.

In practice the heat in a water-gas generator worked on the intermittent system is furnished by the combustion of a portion of the carbonaceous fuel by air during the periods when the air-blast is applied, which periods are known technically as "blows." The heat liberated by this combustion is in part expended in raising the remainder of the carbonaceous fuel and the walls of the generator to a high temperature. The application of a large proportion of the total heat liberated during the "blows" in this manner is common to practically all recognised processes of water gas manufacture on the intermittent system. It is in the application of the balance of the total heat liberated during the "blows" that differences between the processes become evident; the other chief point of difference between them being that more or less of the total heat of combustion of the fuel consumed during the blows is directly applied for raising the fuel in, and the walls of, the generator to a high temperature. The consideration of the different processes from these standpoints will be taken up later; for the present it is only necessary to recognise that the fuel in and the walls of the generator are raised to a very high temperature during the blows. They thus constitute stores of heat available to be drawn upon for the reactions which take place during the succeeding periods, or "runs," when the water gas is actually made. The only heat available for the reactions is the heat thus stored up in the fuel and linings of the walls of the generator and heat imparted to the steam in any detached superheater or economizer. The practical limit to the heat which may be imparted to steam in a superheater is, however, relatively low, and the bulk of the heat required for the consummation of the reactions must be derived from the heat which at the commencement of each "run" is stored in the fuel and linings of the generator. But, obviously, there must be a practical limit to the heat which a given mass of the fuel may thus store up, conditioned by the specific heat of the fuel and the average temperature to which it is raised. The heat stored in the linings of the generator similarly depends on their specific heat and temperature. The conductivity of the fuel and linings of course largely determines the rate at which heat may be imparted to and withdrawn from them, and as their conductivity is in all cases low, it does not practically answer to prolong the period devoted to heating them up merely with the object of allowing the high temperature which is readily reached at the surface layer to extend far into their interiors. So far as the fuel is concerned, the reaction must be influenced mainly by the surface exposure relatively to the mass and the temperature of the surface layer. Hence fairly rapid alternations of "blow" and "run" in working a water gas plant favour the reactions taking place at high speed, and consequently conduce to a relatively large output of water gas in a given time. Now, granting that the fuel in (and linings of) the generator have been raised to a very high temperature, mainly limited to the surface layer, it will be apparent that the heat thus stored up—mainly again in the surface layer of the fuel—will suffice to support either of the four reactions considered above to an extent dependent on the heat which is absorbed in them. Taking the primary reactions between carbon and water vapour—viz., (1) and (2), and assuming that the steam is supplied in the proper proportion for each, it is evident that the store of heat will fail rather sooner, per pound of carbon consumed, if the reaction is (2) and not (1). But, further, if the steam is brought into contact with the carbon at a relatively high rate the store of heat in the fuel will soon fail for the consummation of reaction (2), and reaction (1), which for a given supply of steam requires only $\frac{2}{5}$ the heat required for reaction (2), will take place ultimately, to the exclusion of reaction (2). If, moreover, the steam has been supplied at so high a rate that it is in excess of the amount which the carbon can react with in a given time, even according to reaction (1), then if there is any carbonic oxide present, owing to a partial occurrence of reaction (2), the carbonic oxide and steam will react according to reaction (4), which requires, for a given quantity of steam, less heat for its consummation than either of the other reactions into which steam enters. Hence, if the store of heat is small, relatively to the amount of steam, or if the heat stored cannot be withdrawn and utilized in the reactions at a sufficiently rapid rate, it is evident that reaction (1) will take place rather than reaction (2), and that it will be supplemented by reaction (4), so that the ultimate products will be substantially only carbonic acid and hydrogen If, on the other hand, the store of heat is ample, relatively to the amount of steam, and the heat can be withdrawn and utilized at a sufficiently rapid rate, reaction (2) can occur ; and if reaction (1) does occur and carbonic acid is formed the heat available will support reaction (3), which requires much heat for its consummation, and the ultimate products will be substantially only carbonic oxide and hydrogen. The mixture of carbonic oxide and hydrogen thus formed is ideal water gas, and hence the consideration of the thermal conditions requisite for the consummation of the several possible reactions in a water-gas generator will have indicated the working conditions which must be observed for the production of ideal water gas. These working conditions may now be discussed in the light of the foregoing considerations.

Conditions required for Producing Water Gas.—The temperature of the body of incandescent carbon should not be below

1,000° C.; but as a portion of it is necessarily cooled by the entering steam, some carbon dioxide remains, and must be got rid of through the conversion of carbon dioxide to carbon monoxide by carbon, at a temperature of 1,000°, such conversion being effected by passing the gas through a further layer of carbon at that temperature. Hence the necessity of a bed of carbonaceous material sufficiently deep for the gas first formed to pass through a layer of carbon at a temperature of at least 1,000° C. before it passes from the generator. Further, the carbon must be in excess, in order that no steam may pass out from the generator with the gas, as there is a risk of it reacting on the carbon monoxide formed to produce carbon dioxide, in accordance with the fourth equation. An amount of steam over and above that which would be decomposed by the incandescent carbon in passing through it would generally considerably reduce the temperature of the carbon in a short time, and thus indirectly also affect the quality of the gas. The first points required in a water-gas generator for the economical production of good gas are, therefore, the means of producing, and maintaining during the making of gas, a high temperature in the generator, a sufficient depth of fuel, and the regulation of the amount of steam admitted. How these requirements are attained in one fairly typical plant may be seen from the description of it on p. 201. Up to this point purity of materials has been assumed, but it is, of course, in practice impossible to use pure carbon. Pennsylvanian anthracite is probably the purest carbon that is used on a large scale for the purpose, and is admittedly unsurpassed for yield and purity of gas. It stands to reason that, as it is carbon which reacts with steam to form water gas, the efficiency of a carbonaceous material for the manufacture must, *cæteris paribus*, depend on the carbon content of the material, or, in other words, the greatest yield of gas is obtained from that material which, weight for weight, contains most carbon. This fact is indisputable and cannot be evaded, though its truth may be obscured in certain cases by inattention to details of working. Where gas coke is used for the production of water gas it should, therefore, be as free as possible from non-carbonaceous matter, or, speaking broadly, it should leave little ash on combustion. The density of the material and its degree of division are of great importance indirectly. The more dense a material, the less depth required in the generator for a given current of steam, is a broad general rule, dependent on the fact that it is a given mass and not a given volume of carbon that decomposes a given mass of steam. Hence a considerably greater depth of gas coke than of anthracite is required in a generator for the same amount of steam admitted, or, practically, generators intended to use coke should be deeper than those intended to use anthracite, on account of the difference in the densities of these materials. Further, the steam should flow equally through the carbonaceous matter, a consummation only to be attained by the interstices between the lumps of material being of approximately equal dimensions. They are so only when the lumps of material are of fairly uniform size, hence the anthracite or coke used must be broken and screened accordingly. With coke attention to this point is particularly necessary, lest the steam make its way through the mass by a few passages only, and the apparatus have a decreased efficiency. This state of things is aggravated by the readiness with which the ash of many cokes fluxes; the masses of clinker hinder the proper diffusion of the steam. In practice it is found that gas coke, in pieces from 2 to 4 inches diameter, screened from all dust, answers well. Occasional raking and pricking of the mass tends to break up lumps and secure the equable diffusion of the steam in its passage through it. The working of a generator may be very accurately gauged by the percentage of carbon dioxide in the produced gas. This must be low; 3 per cent. is a sufficient maximum to allow with coke in the generator. It is evident that carbon dioxide not only means so much incombustible gas in the product, but also means a loss of the equivalent quantity of the combustible carbon monoxide. When water gas is to be used for illuminating purposes the carbon dioxide is usually removed, because it affects adversely the photogenic value of illuminating gases.* Economy, both in the production and in purification of water gas, can, therefore, only be secured by keeping the percentage of carbonic acid low. On the other hand, the volume of gas made per hour must be as high as possible, or the highest duty is not obtained from the plant. Therefore, it is well to find by trial the greatest amount of carbonic acid that can be allowed in the gas without the outlay, involved by its presence therein, being in excess of the gain from the increased volume of gas made. This maximum amount of carbonic acid permissible having been ascertained, the amount of steam admitted to the generator should be as much as possible, always provided the said amount of carbonic acid is not exceeded. The amount of carbonic acid in the gas should be ascertained by tests made at regular intervals, according to one of the methods described later. 3 per cent. may be taken as a maximum when the gas is to be used for lighting by flat-flame burners; a greater amount involves a ruinous outlay on purification or enrichment. Of course these remarks on the admission of steam and the percentage of carbonic acid in the

---

* See p. 138.

gas assume that the fire is kept in good condition—*i.e.*, at the proper temperature, free from ash, and the fuel in a proper state of division. When this is the case, it will be found that the amount of steam admitted can be kept nearly the same at every run when once the proper quantity has been ascertained. An abnormal percentage of carbonic acid in the gas will then indicate that the fire is not in a proper state of efficiency, and attention should at once be directed to it. It is advantageous gradually to reduce the amount of steam admitted as the run advances, because, owing to the gradual cooling of the fuel bed, it is not able to deal efficiently with so much steam towards the end as at the beginning of each run.

Where carburetted water gas is being manufactured for illuminating purposes, the process of carburetting follows immediately on the production of the crude water gas. In the earlier forms of apparatus, oil was run into the generator while gas was being made, and was more or less vaporized by the incandescent fuel; and the vapours were carried away by the water gas, and were more completely incorporated with it in a subsequent chamber, known as the fixing chamber or superheater. This method of vaporizing the oil had many obvious faults. The top layer of the fuel in the generator varied in temperature according to the lapse of time since fresh fuel was added to it, consequently much of the oil was at one time lost through imperfect vaporization, and at another time suffered from overheating, which caused deposition of carbon. Especially was the method inapplicable to heavy distillates and crude oils, such as are now largely used for carburetting water gas. The need of vaporizing the oil at a definite and uniform temperature having been demonstrated, the introduction of a chamber which could be kept at the proper heat for the purpose, into most modern water-gas plants, followed as a matter of course. In some types heat is applied to the chamber externally, in others internally, between the intervals of gas making, while others make use of both methods in succession. By whatever plan it is carried out, the oil must be completely converted to vapour, and carried away as such by the water gas, and, on the other hand, the heat applied must be short of that at which carbon is deposited on the surfaces of the chamber. The system which provides for the gradual heating of the oil, and in a measure fractionates it, will, *cæteris paribus*, be productive of the best results.

The oil vapours mingled with the water gas are, at this stage of the process, only to a limited extent permanent gases at ordinary temperatures, and if the mixture was not subjected to further treatment, it would be totally unfit for distribution.

It is found that, by subjecting the mixture for a short time to a high temperature, the less stable vapours are broken up and converted into more permanent gases. Therefore, most plants have either an extended vaporizing chamber, which, by virtue of its length, keeps the vaporized oil at a high temperature during its passage through its posterior portion, or a separate superheating chamber into which the mixture of water gas and vaporized oil passes, and in which it is subjected to a high temperature. The latter plan has advantages over the former, inasmuch as it allows of the regulation of the temperature of one chamber independently of the other. The superheating chamber must not be hot enough to separate carbon from the oil vapours, but if it does not nearly approach the temperature at which such separation occurs, the gas will suffer from the want of permanently gaseous hydrocarbons. The means by which the heat of the vaporizing and superheating vessels is maintained, differ slightly in different descriptions of plant, but must admit of easy control of the temperature of either vessel. The regulation of the temperature affords scope for the expenditure of much care, and should be in the hands of a man accustomed to the plant and the description of oil used. When the gas leaves the superheater it is ready for the ordinary processes of condensing, scrubbing, and purifying, though these are often conducted in different order, and in differently-constructed apparatus to the similar processes in coal-gas manufacture.

Lowe Plant.—The improved Lowe plant, for the manufacture of carburetted water gas, is extensively used in the United States, and, with slight modifications, has been adopted in London works. It is not protected by letters patent in this country, though many improvements and modifications of the original form have recently been patented. Being worked on the intermittent system, two sets of apparatus form the smallest number that can be operated economically. They may vary in dimensions, but those in use in London have a capacity equivalent to a nominal make of half a million cubic feet of gas per set per twenty-four hours, and when gas of not less than 24 candle power is made, this nominal make is below the actual producing power of a set. This size of plant is a convenient one, and may be taken as typical of the system. Two sets capable of making one million cubic feet of gas of about 25 candle power with the greatest ease, and with the highest duty per unit of oil and fuel will have dimensions, and be worked somewhat as follows :—

General View of the Plant.—The **generator** shell will be about 10 feet in diameter, and have a height of about 18 feet from the base to the lid seating, the fire bars being about 4 feet above the bottom. There will be a large door in the shell below the bars, for the removal of ash, and the ash pan will, of course, contain water, the vapour of which will serve to cool the bars. The shell will be lined internally with firebrick, which may leave the interior still of circular section, or, preferably, according to some authorities, the bricks should be placed so as to give a polygonal cross-section. Four doors are placed at equal distances apart, about 4 feet above the level of the fire bars, for use when cleaning the fire. The upper part of the generator should be the frustum of a cone, the lid, about 2 feet in diameter, being on a faced seating, and pivoted at one side, so as to revolve horizontally for opening and closing the generator for feeding purposes. When shut, the lid is kept tight on the seating by a screw turning on a cross-bar, and actuated by a T-handle. Near the top of the generator is the gas-outlet pipe, which leads into the next vessel, of about the same height as the generator, but packed with small bricks arranged chequerwise. In the top of this vessel, which is termed the **carburettor,** is an inlet pipe for heated oil, which is dispersed, when admitted to the vessel, by a cone on to which it plays. The outlet of the carburettor is near the bottom, and leads into the next vessel, known as the **superheater.** This is about 6 feet higher than the preceding vessels, but is, like the carburettor, packed with bricks chequerwise. From the side of this vessel, near its top, proceeds the gas-outlet pipe, leading down to a small vessel which acts as a **tar extractor,** and in which the end of the pipe is sealed with tar. In this vertical pipe is placed a smaller pipe, through which the oil passes on its way to the carburettor, being heated by the hot gas, and, consequently, entering the carburettor in a partially vaporized state. On the top of the superheater is the seating for a heavy valve, actuated by levers from below, and opening under the mouth of a shaft. This valve is shut during the process of gas making, but open during the blowing-up process, to allow the products of the combustion of the generator gas to pass up the shaft, and so out of the building. From the tar extractor the gas passes into a **scrubber** about 6 feet in diameter and about 20 feet high, filled with bundles of wood, down which water trickles. Thence it passes into a **tubular condenser,** through which cold water circulates, and thence to the gasholder and purifiers.

To the bottom of the generator there enters also a blast pipe, and blast pipes are also attached to the carburettor and superheater. The blast is generally obtained from fans running at high speed, but there is no reason why other blowing engines should not be used. The pressure of air required is not great;

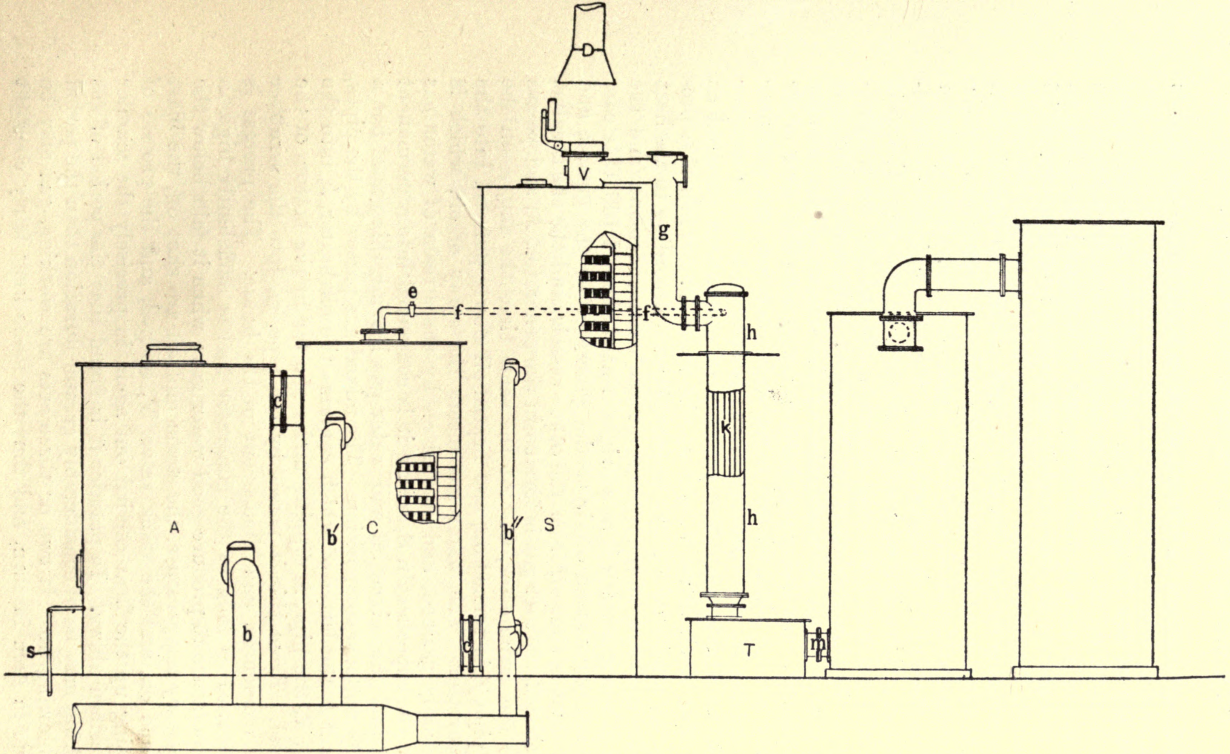


Fig. 28.—Improved Lowe carburetted water-gas plant.

A, Generator; *b*, *b*′, *b*″, blast pipes; *c*, pipe leading from generator to carburettor; C, carburettor; *c*′, pipe leading to superheater; S, superheater; V, stack valve; D, shaft; *e*, tap on oil pipe; *f*, oil pipe; *g*, *h*, mixed gas pipes; *k*, oil heater; T, seal; *m*, pipe leading to scrubbers; *s*, steam supply pipe.

sufficient to support a column of water 12 to 15 inches high is adequate.

Outline of the Process.—Fig. 28 shows the more important details of the plant. Supposing that there is a clean fire in the generator, A, at a dull red heat, and it is desired to make gas, the process would be, roughly, as follows:—Air at about 13 inches of water pressure would be admitted to the bottom of the generator by the blast pipe, *b*, and, passing through the fuel, would form producer gas, and the reaction being exothermic, the temperature of the fuel will gradually rise. The producer gas passes out of the generator by the pipe, *c*, into the carburettor, C, where it meets a blast of air from the pipe, *b′*, and is partially consumed, the heat of combustion raising the temperature of the chequer bricks in the vessel. The unconsumed gas and the products of combustion of the consumed gas pass by the pipe, *c′*, into the superheater, S, where a further blast of air enters by the pipe, *b″*, and completely consumes the producer gas, raising by the combustion the temperature of the chequer bricks in the vessel. The products of combustion pass out at the open stack valve, V, and up the shaft, D. When this process has continued for five to ten minutes, according to the heat of the fuel and of the vessels at the commencement, and the fuel in the generator is at a bright heat of about 1,100° C., steam is admitted instead of air to the generator by the pipe, *s*, and the blast is shut off from the other vessels, and the stack valve, V, closed. Water gas is formed in the generator, A, and passes into the carburettor, C. At the same time the tap, *e*, on the oil pipe, *f*, is turned on, and heated oil slowly pumped into the carburettor. The water gas meets the spray of oil, which is gradually gasified, and carried on by the stream of water gas into the superheater, S, where it is converted into a permanent gas, and the mixed oil and water gas leaving this vessel has a fairly uniform composition. The mixed gas passes by the pipes, *g* and *h*, the latter of which contains the oil heater, *k*, into the seal, T, the pipe, *h*, dipping under the tar in the bottom of the vessel. From this it passes by the pipe, *m*, into the scrubber and condenser, and thence out of the house. The process is continued as long as the generator fuel is sufficiently high in temperature to produce good water gas; when it falls below the necessary temperature, the steam and oil are shut off, the blast turned on, and the stack valve, V, opened, and the process of getting up the heat carried out again in precisely the manner described above. In practice it is found that the period of gas making may be of considerably greater duration than the period of blowing up. If two or three sets are working, gas may be made in each in turn, and thus the make kept fairly constant throughout. In this manner one scrubber and one condenser will serve for the two or three sets, the gas from each in turn passing into them. Also, the blast changes in turn from one set to the other, and thus may be kept constant; a very convenient arrangement when a fan supplies it.

Management of Plant.—The steam used for producing gas must be superheated, or, at high pressure, say 130 lbs. per square inch. If it is at all damp, it readily condenses on the fuel with which it first comes in contact, and reduces the lower layer in the generator to an inactive state, from which it cannot be again raised to incandescence by the blast. This congealing of the lower layer of fuel always takes place to a certain extent in the ordinary generator, but it is much intensified by the employment of damp steam. It may be almost entirely avoided by arranging the plant, so that the steam may periodically be admitted at the top of the generator, and the gas produced taken off at the bottom. This arrangement has been adopted in the more recent installations in this country. The amount of steam admitted must, as already indicated, be regulated by the amount of carbonic acid in the gas made. The gas may conveniently be tested by samples taken in some simple gas burette from a cock on the generator lid. The percentage of carbonic acid in the gas increases as the run proceeds, as may readily be seen by taking off more than one sample during the run. Thus, if the run or period of gas making lasts five minutes, a generator in good working order, with gas coke as fuel, and dry steam for decomposition, should produce gas which, on testing, gives results somewhat as follows:—The gas is allowed to blow through a burette for one minute, when the burette is closed and removed, and another substituted. Then the gas in the burette taken off

At the end of the first minute should contain about 0·3 per cent. of carbonic acid.
,, ,, second ,, ,, ,, 0·6 ,, ,,
,, ,, third ,, ,, ,, 1·4 ,, ,,
,, ,, fourth ,, ,, ,, 2·6 ,, ,,
,, ,, fifth ,, ,, ,, 4·2 ,, ,,

The increase in the percentage of carbonic acid in the gas may be avoided or minimized by gradually checking the inflow of steam as each run nears its end.

The amounts quoted above may sometimes be exceeded, especially when the fire is shortly to be cleaned, but the average amount of carbonic acid in the gas made during the run should not be much over 3 per cent. For tests to control the working of the apparatus, it will suffice to take off two samples of gas, one midway through the run, and the other at

LIBRA
OF THE
UNIVERS
OF

the end of the run. Then with a six minutes' make, the following results may be considered satisfactory. Sample taken off

At the end of the third minute contained 2·2 per cent. of carbonic acid.
,, ,, sixth ,, ,, 5·8 ,, ,,

In the course of a seven minutes' run the author found the following percentages of carbonic acid in the (uncarburetted) water gas from the generator of one of the sets at the Southall Gas Works in 1901.* The set was working under the normal conditions prevailing at those works, and the full supply of steam was maintained throughout the run :—

During the first minute of run, . . .	0·66 per cent.
,, second ,, . . .	0·77 ,,
,, third ,, . . .	1·08 ,,
,, fourth ,, . . .	1·32 ,,
,, fifth ,, . . .	1·82 ,,
,, sixth ,, . . .	2·47 ,,
,, seventh ,, . . .	3·42 ,,
Mean, . . .	1·65 ,,

The duration of the "blows" on the day the samples for these analyses were taken was four minutes.

If fresh fuel is put on at regular intervals, and the fire cleaned at regular intervals, a time not immediately after the first operation, nor shortly before the second, may legitimately be chosen for taking the samples by which the working of the apparatus is to be judged. Samples should be taken from each generator twice or thrice during the twenty-four hours and tested.

The fuel should be fed into the generator at regular and tolerably frequent intervals. A hopper with loose conical-shaped bottom, which is let down into the generator, to spread the fuel, by means of a chain winding on a wheel and axle on the top of the hopper, is useful for feeding the generator. It may conveniently hold about 5 cwts. of coke, and is mounted on wheels for ready transference from the coke store or elevator to the generators. The fuel must be put on as soon as a run ceases, before turning on the blast. There is no danger in opening the generator lid at this time, when the apparatus is at a proper working heat; but when starting a set which has been let down, a slow fire should be put in a day or so beforehand, and before the blast is used, the generator should be filled

---

* *Vide* paper read by the author before the Institution of Gas Engineers (*Journ. of Gas Lighting*, lxxvii., 1,299), and paper by S. Cutler, jun., read before the Institution of Junior Engineers (*Journ. of Gas Lighting*, lxxvii., 621).

to the top with fuel. After the blast is started, the generator should not be again opened until the apparatus is at a working heat. By this means explosions which shake the firebrick lining may be avoided. It will generally be found convenient in working, to add the fuel at intervals of about two hours; care must be taken that the bed of fuel in the generator is kept at a high level.

Sight cocks should be provided, one on the generator lid, one about 5 feet from the bottom of the carburettor, another in a similar position on the superheater, and one on the superheater about 5 feet above the working-stage, which is on a level with the tops of the generator and carburettor. By using these cocks the temperature of the vessels may be judged roughly by practised eyesight. The glass or talc requires cleaning from tarry matter occasionally, and should of course be protected from the heat by keeping the cock closed until it is necessary to view the heats. Beside the upper sight-cock on the superheater should be a small pet-cock, through which a little gas may be blown off during making. By allowing the gas to impinge on a piece of white paper a rough idea of the working of the apparatus is afforded. The stain on the paper should not be very tarry in nature, nor should it consist of dry carbon particles. The first kind of stain shows that the heats are too low, the second that they are too high to yield the best results obtainable from the oil.

In the pipe leading down from the superheater to the seal the oil heater is generally placed. It then consists of a tube or series of tubes through which the oil passes on its way to the carburettor. Many patterns have been tried, and some designs patented, but it has been found that heating surface must be sacrificed to gain durability; the multitubular heater, which exposes a large surface to the hot gas, rapidly beginning to leak at the joints. Whatever form of oil heater is adopted spare ones should be kept in readiness, so that as soon as the one in use shows signs of leaking it may rapidly be replaced. In some plants the oil is heated by means of superheated steam in a separate chamber. It is then more readily accessible for cleaning or repair, while there is less risk of deposition of carbon or thick tar owing to overheating of the oil. Spare doors, valves, and seatings for the remainder of the plant should likewise be kept in readiness, to minimise the delay in case any of those in use crack. The scrubber is generally packed with bundles made up with lengths of inch-square deals with intervening spaces about an inch wide, the arrangement being as far as possible chequerwise. The condenser generally used consists of a cylinder closely packed with 2-inch tubes; the joints must be carefully made to prevent leakage of the condensing water, and consequent dilution of the tar. The tar overflows from the seal into the tar well. The condensation of the gas by this apparatus is effected very suddenly, and in a manner quite contrary to the principles followed in coal gas condensation in this country. It appears extremely probable that were the atmospheric condenser used for carburetted water gas, the illuminating power would be higher, and less liable to decrement on storage of the gas than that of gas condensed by the method adopted at present. The tubular water condenser is, however, economical of space, and can easily be included in the building containing the gas-making plant. Siphons must be placed at the lowest points of the mains leading to the gasholder and purifiers, to draw off water and light oil thrown down after the condensers. Light oil is also slowly deposited in the holder when the gas is stored without admixture of poorer gas. The character of the light oil thrown down from crude carburetted water gas is very similar to that of the so-called oil-gas hydrocarbon, and will be briefly decribed in the second part of this work.

Products of the "Blow."—It has been stated in the foregoing account of the process of making water gas in a Lowe type of plant that the air blown into the generator for the purpose primarily of raising the heat of the fuel therein, produces, by interaction with the carbon of the fuel, "producer gas." This expression was used in its usual technical sense, meaning a mixture of nitrogen with carbonic oxide and carbonic acid in varying proportions, but with the carbonic oxide predominating. The usual composition of producer gas has been indicated in Chapter ii. (*e.g.*, on p. 85). The water-gas generator, however, though acting as a simple producer during the "blows," is in fact acting as such under conditions which do not normally prevail in an ordinary gas producer. The heat of the latter is tolerably uniform throughout its ordinary working, which moreover is continuous. As explained in Chapter ii., this uniformity of heat in the fuel bed, and hence uniformity in the composition of the gas produced, are secured by the admission of a certain proportion of moisture with the air supply, and the careful regulation of the latter. The moisture prevents the fuel in the producer attaining an extremely high temperature. But, in a water-gas generator, the object of the "blow" is essentially to bring the fuel to the highest practicable temperature in as short a time as possible. The "blow" starts with the fuel at a relatively low temperature, say 700° C., and should not cease until a comparatively high temperature, say fully 1,200° C., has been attained.

The fuel in an ordinary gas producer, on the other hand, remains at an average temperature of 1,000° C. to 1,100° C. The composition of the gas made in a producer is—disregarding for the time being the influence of more or less moisture with the air supply—primarily determined by the temperature of the fuel bed, and the amount of air presented to unit area of carbon surface in unit time. The temperature of the fuel bed in a water-gas generator during the "blow" rises gradually from the moment the air blast is turned on until it is stopped, and hence the gas formed during the "blow" may be expected gradually to alter in composition as the "blow" proceeds. On the other hand, an ordinary gas producer, having a virtually constant temperature in the fuel bed, may be expected to yield gas of tolerably uniform composition throughout. These expectations are, in fact, realized in practice. With the types of Lowe generator, as used in this country, the author has found the proportions of the oxides of carbon in the gas formed during the "blow" to vary between the limits named:—

Minutes Elapsed since Turning-on of the Blast, ...	One.	Nearly Four.
Carbonic acid, . vols. per cent.,	8·5 to 15·0	5·0 to 8·0
,, oxide, . ,, ,,	20·0 ,, 10·0	27·0 ,, 22·0

It will be seen, therefore, that regarded as a producer, the water-gas generator only begins to yield good producer gas towards the end of the "blow," and that when the "blow" commences, the gas formed is but an indifferent product if regarded as a sample of producer gas. If the gas produced throughout the "blow" in a Lowe type of water-gas generator were passed direct from the generator to a gas-holder and thoroughly mixed, the mixture thus collected would range in composition, according to the precise form of generator and conditions of operating, from that of a fairly good sample of producer gas to that of decidedly indifferent producer gas. Thus, it would usually have its principal ingredients present in proportions lying somewhere between the following limits:—

	Volumes per cent.
Carbonic acid, ...	6 and 12
,, oxide, ...	24 ,, 14
Nitrogen, ...	68 ,, 72
Minor constituents, ...	2 ,, 2

It will be seen that the figures given in the first column represent fairly the composition of a tolerably good sample of producer gas, in the production of which the supply of moisture with the air has been unusually restricted. Actually the "blow" products of a Lowe type of water-gas generator, as ordinarily worked, seldom have an average composition such as this. More often their average composition lies about midway between the figures given in the two columns.

The limitation of the supply of moisture relatively to the air during the "blow" in a Lowe type of generator constitutes an important difference between the behaviour of that generator and of an ordinary gas producer. Further, in the Lowe water-gas generator, the air for the "blow" is supplied at relatively high pressure as compared with the air passing into a common gas producer, and the difference of pressure between the air-inlet and the gas-outlet, or between the bottom and top of the fuel bed, is greater in the water-gas generator. Hence the rate of flow of the air through the fuel bed is higher in the water-gas generator, and, given similar conditions in other respects, the amount of air presented in unit time to unit surface of carbon will also be greater in the water-gas generator. Provided the temperature of the carbon is the same for the time being, this relatively greater flow of air implies that more carbonic acid will be produced in unit time, and that a smaller proportion of the total amount of carbonic acid produced will meet with the conditions requisite for its reduction to carbonic oxide. Further, if the flow of air is maintained at a constant rate, the proportion of the total carbonic acid formed, which undergoes reduction to carbonic oxide, increases with the temperature of the carbon with which it is in contact. Thus, in the Lowe type of water-gas generator, with a virtually uniform pressure of air blast throughout the "blow," the proportion of carbonic acid would, on this account, naturally fall, and that of the carbonic oxide rise, as the temperature of the fuel bed rises as the "blow" proceeds. If the flow of air through the generator were increased *pari passu* with the rise of temperature, the relative proportions of the carbonic acid and of the carbonic oxide in the "blow" products might be maintained constant, broadly speaking, throughout the "blow."

It is advantageous, within limits, that the carbon of the fuel bed should be consumed so as to yield carbonic acid rather than carbonic oxide, because, as explained in Chapter ii. (p. 71, *et seq.*), the heat thus liberated is very much greater, and hence the bed of fuel is raised in temperature more rapidly. In water-gas generators, which, unlike those of the Lowe type of plant, have no attached carburetting and superheating chambers requiring to be heated to the proper temperatures for gasifying oil and fixing oil gas, the sole object of the "blow" is the raising of the bed of fuel as rapidly as possible to as high a temperature as possible. With such generators, therefore—there being no use for any carbonic oxide formed—it is of paramount importance that the carbon consumed in the "blows" should be burned wholly to carbonic acid. Attempts have been made to achieve this end in types of plant designed for the production of simple water gas. One of the most noteworthy is that of Dellwik, whose generator is supplied with air at relatively high pressure from inlets at the sides as well as at the bottom of that vessel, while the fuel bed is a comparatively shallow one. The products of the "blow" in Dellwik generators have been found by several investigators to contain on the average very little carbonic oxide, and nearly the maximum attainable proportion of carbonic acid. The bed of fuel is raised to the desired temperature by a relatively short "blow" (usually about 1½ minutes duration) in consequence of the intensive and complete combustion of the carbon. The air blast appears, however, to be maintained, as in the Lowe type of generator, at uniform pressure throughout the "blow." As already explained, an air flow, which is just adequate at the low temperature of the fuel bed when the "blow" starts, becomes more and more inadequate as the "blow" proceeds and the temperature of the fuel bed rises. (If the air flow is in excess of requirements initially, there is loss of heat through the surplus air, as explained in connection with the direct combustion retort furnace [*ante*, p. 74].) In the Lowe type of plant, it is of comparatively little moment that a uniform air flow is usually maintained throughout the "blow," because there is use, for heating the carburettor and superheater, for a certain amount of carbonic oxide, and it is immaterial for that use whether the carbonic oxide is formed uniformly throughout the "blow" or mainly towards its close. The amount of carbonic oxide required for heating the carburettor and superheater of a Lowe type of carburetted water-gas plant varies, broadly speaking, with the superficies of those vessels and the amount of oil to be gasified per "run." If the products of the "blow" contain, on the average, about 14 per cent. of carbonic oxide, and this is fully burnt in the carburetting and superheating chambers of the customary "Lowe" type of water gas set, having a nominal productive capacity of half a million cubic feet of gas per diem, the chambers should thereby be adequately heated for the production of gas of 25 candle-power. This figure is only a rough average, based on the author's observations, and the proper proportion of carbonic oxide required in the "blow" gas should be determined for each set individually under the local working conditions. On its proper determination, and the observance of it in regular working subsequently, economy of consumption of fuel in a water-gas generator will largely depend.

The object of burning the carbon of the fuel in the generator of a plant for producing only simple water gas, so that carbonic acid is formed practically to the exclusion of the formation of carbonic oxide, has been aimed at by J. Kramers in a different manner to that adopted by Dellwik. Kramers has proposed to reduce the effective depth of the fuel bed during the "blow" by disposing the fuel in a series of chambers, through which the air of the blast passes *in parallel*, while during the "run" a great effective depth of fuel bed is secured by passing the steam through the chambers while connected *in series*.* The proposal is a good one, if the greater complexity of the plant and the manipulation of additional valves, which it involves, do not render it impracticable when applied on a working scale.

Purification of Carburetted Water Gas.—To treat properly of the purification of carburetted water gas, the nature and average amount of the impurities present in it must be stated at the outset. Gas made from good gas coke, and under proper manufacturing conditions, should, as stated above, contain a little less than 3 per cent. of carbonic acid. It will also contain from 90 to 150 grains of sulphuretted hydrogen per 100 cubic feet, or 0·15 to 0·25 per cent. by volume. It will be practically free from ammonia, and carbon disulphide and sulphur compounds other than sulphuretted hydrogen are present in trifling quantities only, the amount never to the author's knowledge exceeding 10 grains of sulphur per 100 cubic feet of gas. Hence purification from carbonic acid and sulphuretted hydrogen only is needed. The amount of carbonic acid is commonly such that a lime purifier becomes exhausted when a volume of water gas less than half the volume of coal gas which it would take has passed through it. Hence the purifying vessels must be large, and arrangements must be made for frequently recharging the "carbonates." Two "carbonate" and two "oxide" vessels in series should suffice for the complete purification of water gas; but a check vessel would frequently be added to prevent the possibility of a trace of sulphuretted hydrogen escaping. The dark stain on lead papers sometimes caused by deposition of oily particles from rich gas must not be mistaken for the sulphide mark, as it would not be evident after the gas had been admixed with a large quantity of low quality gas. The lime in the first vessel especially absorbs a quantity of light oil, and this and the toxic properties of carbonic oxide render the work of emptying the vessels unpleasant and unhealthy. Nevertheless, the purification of water gas is, from the absence of "sulphur compounds,"

---

* *Journ. of Gas Lighting*, lxxix., 1783.

far simpler than that of coal gas. The quantity of carbonic acid in the gas entering the purifiers may be estimated as often as desired, by a standardized solution of barium hydrate applied to a measured volume of gas taken from the inlet pipe, in the manner described in the second part of this work. Or the test may be made on the gas at the outlet of the exhauster or inlet of the gasholder. The gas going to the testing apparatus should pass through an oxide purifier to remove the sulphuretted hydrogen; and in order to prevent the gas in the service being stagnant two or three small burners should be fixed to the service close to the inlet to the testing bottle, and the gas should be burning at them continuously. In most cases it will be necessary to have a governor on the service between the main and small purifier to reduce the gas pressure to 2 or 3 inches of water. Otherwise the varying pressure will cause the solution in the testing bottles to be sucked up the inlet tube at intervals, and a great pressure renders a deep lute to the purifier a necessity. By the use of this test, which may be arranged to run for from an hour to twenty-four hours, the average amount of carbonic acid in the gas from several sets for a given short period, or throughout the day, may be readily ascertained, and any improper working of the plant remedied before it is indicated by the rapid fouling of the lime purifiers. It is seldom necessary to estimate the sulphuretted hydrogen in water gas; but, if desired, it may be done on the same supply as the continuous carbonic acid test, by slipping the oxide purifier and using one of the methods of estimation described in Vol. II. of this work.

Composition.—The composition of carburetted water gas as made by the Lowe process may now be considered. The impurities have been enumerated above, and, therefore, may be ignored here, the gas now considered having undergone the usual process of purification for the complete removal of carbonic acid and sulphuretted hydrogen. This process will have deprived the crude gas of some of the readily condensable hydrocarbon vapours originally present in it. Carburetted water gas being virtually a mixture of oil gas and water gas, it will at once be evident that its composition must vary according to the proportions of its two component gases, and, consequently, according to the amount of oil used per run in the manufacturing plant. In the plant for the nominal make of half a million cubic feet of gas per set per day it has been found that the greatest economy of oil accords with the production of gas of an illuminating power of from 20 to 26 candles. The chief constituents will be present in this gas, if of about 26 candle power, in about the following proportions:—

	Per cent. by volume.
Hydrogen,	34·0
Methane,	15·0
Hydrocarbons absorbable by fuming sulphuric acid,	12·5
Carbonic oxide,	33·0

In addition there will be a small amount, ranging from 0·5 to 5·0 per cent., of nitrogen, and a trace of oxygen. The specific gravity of this gas will be about 0·62 (air = 1). The following is the composition of unpurified carburetted water gas, analysed by the author, as made at the Southall works of the Brentford Gas Company in 1901.* The gas had an "illuminating power" of about 22 candles prior to purification:—

	Per cent. by volume.
Hydrogen,	35·17
Carbonic oxide,	33·92
Methane,	13·58
Hydrocarbons absorbable by fuming sulphuric acid,	12·83
,, paraffins other than methane,	1·20
Carbonic acid,	1·54
Nitrogen,	1·76

In some analyses (*vide supra*) hydrocarbons not absorbable by bromine or other reagents figure, and are denominated paraffins. They are thrown down by the application of extreme cold or pressure to the gas; they commonly amount to from 1 to 2 per cent. of the total volume. The hydrocarbons absorbed are seldom differentiated in analyses, and, consequently, their nature is little known; hence the degree of absorption is but a poor criterion of the "illuminating power" of a gas, except for comparative purposes in the case of samples produced under precisely identical conditions of temperature and apparatus. With the Lowe plant as usually worked with Russian solar oil, a large proportion of the hydrocarbons are of the aromatic series; but with the older plants, such as the Tessié du Motay, where the breaking up of the oil was less complete, unsaturated fatty hydrocarbons predominated.

Other Plants.—Of the other plants for the manufacture of carburetted water gas, few have attained to any degree of importance. The **Springer** resembles the Lowe in its general principles, but the blast enters at the bottom of the generator, and the steam enters at the top and passes downwards. The hot water-gas heats the oil in very similar fashion, but the superheater is placed above the generator, instead of alongside it. For the apparatus, a saving of ground space for the erection of the plant, as compared with the Lowe, may legitimately be

---

* *Journ. of Gas Lighting*, lxxvii., 621.

claimed, but this advantage has evidently not been generally thought sufficiently tempting to justify preference being given to the Springer. More recently a modified form of Lowe plant, known as the Merrifield-Westcott-Pearson apparatus, in which the superheater is above the carburettor, has been introduced here, as also in the United States and Canada. In this plant also there is a saving of ground space, owing to the carburettor and superheater being superposed. The Economical Gas Apparatus Construction Co., Ltd., London, are the makers of this modification of the Lowe type of plant. The **Van Steenburg** plant does not possess separate superheating chambers, but the oil being run in some distance down the generator, the layer of incandescent fuel above is relied upon to crack it and fix the vapours. This small superheating surface renders the plant unfit for producing a permanent gas from oils of high boiling points. The ordinary Lowe type of plant, as described in this work, is now erected by at least three firms in this country, with only small modifications of the parts. These modifications are often of considerable merit, but space precludes further reference to them here. The pamphlets issued by the makers in question—viz., Humphreys & Glasgow of London, S. Cutler & Sons of Millwall, and W. & C. Holmes & Co. of Huddersfield—may be consulted by the reader for further details. Several attempts have been made to reduce the amount of carbon monoxide in carburetted water gas to a minimum. Where the gas is to be used undiluted with coal gas, it may be granted that the removal of this poisonous constituent is a desirable consummation, but where the gas is used in small proportion to enhance the illuminating power of common coal gas, it appears undesirable to complicate the process and the apparatus for its production by taking elaborate care to remove the carbonic oxide. The reduction of the carbon monoxide to one-half the volume in ordinary carburetted water gas has been attempted more than once by means of the alternate reduction of iron oxide by producer gas, and its oxidation by steam with liberation of hydrogen, which is allowed to mingle with water gas produced in the ordinary way. Except in so far as hydrogen is a more desirable diluent than carbon monoxide for the development of the illuminating power of admixed gaseous hydrocarbons, no appreciable good can result from the use of this gas in place of the ordinary water gas in works where the enrichment of coal gas only is aimed at. Coal gas contains about 7 per cent. of carbon monoxide; enriched with carburetted water gas to 17 candles, analyses show that it contains about 11 per cent. of that constituent; the same enrichment with the hydrogenized gas, which, with an illuminating power of 20 candles, is stated to contain 15 per cent. of carbonic oxide, would give a gas containing not less than 9 per cent. of that component. The difference in the toxic action of the gases enriched by the two enriching gases, would be inappreciable, and is certainly not sufficient to justify discarding the simple generator for a triple-chambered one. Where carburetted water gas is distributed as such, it is desirable to reduce the carbon monoxide to about 16 per cent., if the cost of reduction is not prohibitive by reason of complication of plant or less economical working. If a more highly hydrogenized gas than water gas can be produced at an equal or less price than the latter, the diminution of carbonic oxide should speak in favour of the former.

Toxic Action of Water Gas.—According to O. Wyss,* 0·1 per cent. of water gas (uncarburetted) renders the air of a room **injurious** to health, while 1·0 per cent. makes it **fatal** to warm-blooded animals. This lethal quantity would be reached in a room 9 feet high and 13 feet square in one hour, by allowing neat water gas to stream from an ordinary gas tap, according to the same authority, but this really requires the gas tap to deliver 15 cubic feet per hour. With carburetted water gas, the quantity required to render the air of a room lethal would be much greater (supposing the toxic action to be entirely due to carbonic oxide), and a burner suited for the economical consumption of 25-candle gas would have to deliver such gas into a room for about ten hours before a lethal atmosphere would be produced, and this on the assumption that there was no interchange of air between the room and the atmosphere outside. Dr. J. S. Haldane has breathed air containing 0·05 per cent. of carbonic oxide for some hours without experiencing any definite symptoms of poisoning. The interchange of air between the interior and exterior of an ordinary room would suffice to prevent this amount being exceeded in the event of an escape of unlighted gas from an ordinary gas burner, provided carburetted water gas were present therein to a not greater extent than would generally suffice to give ordinary coal gas an illuminating power of about 20 candles. Though slight leaks of carburetted water gas would undoubtedly cause great injury to the health of the inmates of a house in which they occurred, no fatal results need be anticipated from any ordinary mishap leading to an escape of gas for a few hours, and the penetrating odour of the gas would lead to the detection of leaks more readily than with coal gas. The supply of pure water gas to houses for heating purposes, and lighting on the incandescent system, would be much more dangerous, even if the gas were rendered odorous. The danger of accidental poisoning from carburetted water gas is virtually confined to the works where it is made; there ample

---

* *Zeitschrift für angew. Chem.*, 1888, 465.

time must be allowed for accumulations of the gas to be dispersed before a man proceeds to work in the vicinity of the same. Agitations against the distribution of mixtures of coal gas and water gas are from time to time raised by persons ignorant of the real composition of either, and too frequently a scarcely less ignorant medical practitioner may be found ready to seek a cheap advertisement by fomenting the agitation. It is scarcely probable that he will have had opportunities of watching actual cases of poisoning by water gas or carbonic oxide, and, therefore, it were better he should leave the question of their toxic action to skilled physiologists and chemists, who alone are competent to deal with it on *a priori* grounds. Neither competent physiologists and chemists, nor men who have dealt with carburetted water gas on the manufacturing scale, have condemned its employment as an enriching agent for ordinary coal gas.

This statement, made in the earlier editions of this work, has been confirmed by the recommendations of a Committee appointed by the Home Secretary to enquire into the "Manufacture and Use of Water Gas and other Gases containing a large proportion of Carbonic Oxide." This Committee came to the conclusion that 20 per cent. of carbonic oxide was the highest proportion which should be allowed in gas supplied to the public under present conditions of gas supply, and that only under special circumstances. This percentage corresponds with a mixture of about equal volumes of coal gas and carburetted water gas. A limit of 16 per cent. of carbonic oxide (corresponding with about 35 per cent. of carburetted water gas in the mixed gas) seemed preferable to this Committee, and in some cases, especially during the ordinary hours of sleep, when the danger of poisoning from an undetected leak is greater, they thought that as low a limit as 12 per cent. of carbonic oxide might be enforced. It is fair to add that the Committee's recommendations were largely based on statistics of gas poisoning in Massachusetts, where the conditions of gas supply and use differ very much from those prevailing in this country, and that, though made so long ago as 1899, it has not been found necessary yet to give effect to them by Act of Parliament.

Uncarburetted Water Gas.—The use of uncarburetted water gas for lighting on the incandescent system has not found adoption to any considerable extent, and need be only alluded to here. The water gas is produced in the usual manner, the producer gas made during the blowing-up process being only applicable to superheating the steam for gas making, or heating the air for the blast. The removal of carbonic acid is of no great importance, but it is necessary to remove the iron carbonyl contained in small quantities in the cold gas. This compound causes a deposit of iron oxide on the mantles or combs used for emitting light, and rapidly reduces their efficiency. It has been proposed to remove the iron carbonyl by passing the gas through strong sulphuric acid, or by heating it to a red heat at a point near the place of combustion, and H. Strache, of Vienna, has patented schemes for purifying water gas by these means in several countries. There are now several processes in use, among which the Dellwik-Fleischer process is prominent, for the production of simple water gas for use as fuel and for admixture with coal gas.

The employment of neat water gas for lighting by means of incandescent burners is not, however, yet seriously contemplated in this country. The gas engineer is, therefore, mainly concerned with processes for the manufacture of simple water gas only, in so far as he may require that gas for diluting coal gas. At the moment the most promising way of using simple water gas as a diluent of coal gas is by admitting the water gas in a more or less continuous stream to retorts in which coal is being carbonized. The results achieved by this procedure have been already quoted (*ante* pp. 129-131). Schemes have been brought forward for making a mixture of coal gas and simple water gas in plant specially designed for conducting the carbonization of coal and the generation of water gas in unison. One of the most comprehensive of these schemes is that of E. R. Besemfelder, by which the water gas is passed continuously through the carbonisers in which coal is undergoing destructive distillation.* It should thus secure all the advantages achieved by passing water gas into ordinary retorts, already referred to, while other special economies are claimed for it. The author is not aware, however, that Besemfelder's scheme in its entirety has yet been worked on a large scale.

Simple water gas is also occasionally employed as a diluent of coal gas by being mixed with it after it has left the retort. For instance, prior to the recent adoption of the practice of introducing water gas into coal-gas retorts, water gas was in some works introduced into the hydraulic main of the coal-gas plant. The latter plan secured in a modified degree the advantages of the admission of water gas into the retorts, for the water gas, by reducing the partial pressure of the more readily condensable constituents of the coal gas in the hydraulic main, admitted of a larger proportion of these constituents being retained permanently in the mixed gas than would have been retained by the coal gas without admixture of water gas. Thus the water gas acquires in the hydraulic main a certain degree of

---

* *Journ. of Gas Lighting*, 1902, lxxix., 146, 207, 276; and 1904, lxxxvi., 95.

enrichment—less, however, than it would acquire if introduced into the retorts—whereas, if it is mixed with the coal gas after the latter has passed through the condensing plant, it cannot acquire any appreciable amount of enrichment from the coal gas or its condensation products. The fact that water gas, when passed into the retorts or hydraulic main of coal-gas plant in action, acquires, without express addition of carburetting material, a certain degree of enrichment, has led to the expression "self-carburetting process" being applied to this procedure for mixing water gas with coal gas. The expression is commonly restricted to the plan of introducing the water gas into the retorts, but is equally applicable to its introduction into the hydraulic main, as it is only in the degree of "self-carburetting" that the two plans differ.

Simple water gas is occasionally "carburetted" by the addition of the vapour of some highly volatile hydrocarbon, such as benzol. Such "cold-carburetted" water gas is usually mixed with coal gas. The carburetting is often carried out on the mixed gas instead of on the water gas prior to the admixture. Water gas requires a considerably greater addition of benzol per "candle" of "illuminating power" than coal gas, and practically the direct enrichment of water gas for admixture with coal gas is being superseded or supplemented by "self-carburetting" (*vide supra*).

CHAPTER V.

OIL GAS.

Oils Used.—The oils most suitable for gas making have been briefly described in Chapter i., and the manufacture of carburetted water gas from oil was treated in the last chapter. This chapter will deal only with the methods used for producing neat oil gas with the view mainly to its subsequent use as an enricher of poor gas. Except where other oils are specifically mentioned, it is assumed that the oil used is either Russian Solar distillate or Scotch Gas Oil, both of which are readily obtainable in this country. Almost every conceivable form of retort has at one time or another been suggested for the manufacture of oil gas, and there is no great uniformity in the patterns of the retorts adopted in the processes that have been or are commercial successes. It might consequently be surmised that the shape of the retort exercises only a minor influence on the production of gas, and to a considerable extent this surmise is borne out by the facts. In the processes of a few years' standing that have been largely adopted the configuration of the retort appears to have no considerable influence on the gas produced, and consequently the retorts used will here be very briefly alluded to.

Pintsch's System.—The Pintsch system of gas making is very largely used for the production of oil gas for storage under compression for the lighting of railway carriages. The oil is gasified in a double retort—that is to say, it is run on to a tray in one end of a retort, and passes from the other end of that into a retort of similar shape and size placed below the former. The gas formed in the upper retort, in passing through the lower retort, is subjected to a high temperature with a view to rendering it more permanent. Each retort is rather more than 6 feet in length, 10 inches wide, and nearly 10 inches high. The retorts are of cast iron, the upper one being furnished with trays on which the oil drops as it enters the retort; the lower one has no trays. The manufacture is carried on with a considerable pressure (= 4 to 6 inches of water) in the retort, and a bright cherry-red heat is used. The rate at which the oil is supplied varies somewhat according to the quality of oil and the temperature of the retort, but it may be taken at about 2½ gallons of oil per double retort per hour. The richer the gas required, the quicker the rate at which the oil is admitted. A yield of 85 cubic feet of gas per gallon of oil is excellent; generally it is rather lower. In the siphons and condenser, which is of simple form, tar is deposited in amount equal to about one-third the volume of oil used. When Scotch oil is used, this tar consists mainly of the higher members of the paraffin and olefine series, with about one-fifth its volume of aromatic hydrocarbons. From the condensers the gas passes through a washer, and thence to a purifier lightly charged with lime or oxide of iron and sawdust. From the purifier it passes to the gasholder, where it is kept under a slight pressure.

The Pintsch gas is generally used for storage under pressure. The gas passes from the holder to the compressing pumps, which force it into cylindrical steel reservoirs to a pressure of about 12 atmospheres. In the pumps and reservoirs a thin, tarry liquid is deposited by the gas, and is known as "hydrocarbon." About 1 gallon of "hydrocarbon" is deposited from 1,000 cubic feet of gas. This hydrocarbon liquid consists mainly of the lower members of the aromatic series. Some particulars of its composition will be found in Volume II. The gas is led from the reservoirs by special flexible pressure tubing to the portable reservoirs affixed to railway carriages, floating buoys, &c. In these the pressure never exceeds 10 atmospheres, and is reduced by special regulators on the outlet pipe to about 0·5 inch of water before consumption. The gas loses in illuminating power by the compression, but even after it has undergone compression, it gives, in suitable burners, an illuminating power equal to 45 to 50 candles, reckoned to a consumption of 5 cubic feet per hour. The burners used consume 0·5 to 0·75 cubic foot per hour. Oil gas made by Pintsch's system is very largely used by several railway companies for carriage lighting, and it answers the purpose excellently. The Great Eastern Railway and some other companies use it almost exclusively throughout their passenger trains. It is also extensively used on buoys and lightships—the floating reservoirs being replenished at intervals of a month or so by a small vessel having storage cylinders. As to the method of manufacture, the oil is cracked at the moderate temperature of the tray on which it falls in the retort, and the vapours are then subjected to the radiant heat from the sides of the upper retort. The oil is thus completely vaporized in the upper retort, and the vapours passing through a neck into the lower retort, are there subjected to a higher temperature of nearly 1,000° C. from heat radiated from the sides of the retort. The temperature thus increases gradually as the vapours pass through the retort, and surface contact at the high temperature is largely avoided. Carbon is deposited chiefly on the tray on which the oil is vaporized. A considerable quantity of the illuminating gases of the gas is dissolved in the tar and hydrocarbon, and might be recovered and restored to the crude gas.

Pope's System.—Pope's oil gas is also very extensively used for lighting railway carriages, several large companies using little else in their passenger trains. A double retort is used, but there are no trays in either limb. The oil is introduced in a fine spray into the lower retort, and the vapours pass into the upper one for fixing. Contact with heated surfaces is avoided as far as possible, and the oil vapours are subjected to the action of the heat radiated from the sides of the retort. The gas is treated afterwards very similarly to the Pintsch, and is stored, under pressure, in the same manner.

Keith's Apparatus.—Keith's oil-gas apparatus has a retort of about the same size as a single Pintsch, but it is flattened towards the middle of its length, being there shallower but broader. This apparatus, therefore, favours the contact of the oil vapours with the hot surfaces at the constriction, and the result is apparent in the large volume of gas which is produced, though the quality appears to suffer somewhat. This apparatus is used for the supply of lightships, &c.

The oil-gas installations used by some of the railway companies are modifications of one or other of the above systems, in some cases different parts of the installation belong to the competing systems. The retorts are often much modified in design. The systems all agree in subjecting the gas to a temperature of 900° to 1,000° C. before it leaves the retort.

The **Alexander and Paterson retort** (patent specification, No. 3,323, 2nd December, 1885) is rather differently designed. It is a cylindrical, cast-iron retort set horizontally, and having two or more iron pipes passing through the lid to the back of the retort. The oil passes through these pipes, and is heated and partially vaporized therein, the vapours then pass back along the hot retort, where they are permanently gasified, to the outlet pipe near the front of the retort. The pipes are attached to, and are removed with, the lid. The gas on leaving the retort passes through a condenser, and thence direct to the holder, a purifier being considered unnecessary for the Scotch intermediate or burning oils, for which it is specially intended. 14 to 15 gallons of oil are used to produce 1,000 cubic feet of gas, which is of very high illuminating power—*i.e.*, over 70 candles. The retorts are small, each making about 1,000 cubic feet of gas in twelve hours. The process has been used for the supply of gas to country houses and institutions remote from gas works, and is also proposed for the production of gas for the enrichment of coal gas.

Gas made from Oil in the presence of Steam.—Besides the pure oil-gas plants, of which those described may be taken as typical, there are also several in which the oil is cracked in association with steam. The steam either acts as an injector or meets the partially vaporized oil in the retort, in either case being largely decomposed along with the oil. These plants generally have retorts of small diameter, or one retort within another, the annular space being used as a fixing chamber for the gas, and the retorts are often packed with firebrick so as to bring as large a heated area as possible in contact with the gas. The superheated steam prevents to a considerable extent the breaking up of the hydrocarbon vapours with deposition of carbon. Systems depending broadly on the principle of cracking the oil vapours in the presence of superheated steam have been patented by R. B. Avery, A. G. Meeze, H. W. Brooks, and many others, and some few have been extensively tried in the United States. Generally a rather greater volume of gas is obtained than in systems where steam is not used, but the illuminating power is not quite so high. Unless used with caution the steam may prove very disastrous to the life of the iron retorts, and the processes do not appear readily applicable to works where a large quantity of oil gas has to be made.

The Tatham Process.—Rich oil gas is very difficult of consumption in such a manner that its full illuminating value is developed. Thus an ordinary gas burner smokes very much when rich gas is consumed in it; the gas is only partially consumed and the light is obscured. When a burner having a sufficiently small orifice to burn the gas without smoking is used, the temperature of the small flame is sensibly affected by the proximity of the burner, which conducts the heat from it, and the light developed suffers accordingly. Hence very rich gas, say of over 45 candle-power, cannot be burnt to its maximum power, and its value must be greater than our burners show. This may be proved by mixing a rich gas in definite proportions with a poor gas, and observing the increase in illuminating power so caused. It will then be found that the enriching value of a rich oil gas is far greater in proportion to its nominal candle-power than that of a poorer oil gas. An ingenious method of developing the full value of a rich gas in burners of moderate size is covered by the Tatham patents. The Tatham process of oil gas manufacture includes the use of certain patterns of retorts which do not differ greatly from those used in other processes, and it may be surmised that the gas made in them is not greatly superior to that made by other methods. Before consumption, however, about 15 per cent. of oxygen is added to the rich oil gas, with the result that it shows on burning an illuminating power of about 100 candles. In fact, it may be taken that the addition of a proper proportion of oxygen to rich oil gas before consumption raises its illuminating power by nearly one-third what it would be if burnt in the most suitable burner without the addition of oxygen. Moreover, a burner of very ordinary proportions may be used for its consumption. The Tatham process, therefore, promised to be a successful rival to the oil-gas processes which aim at the production and consumption of a rich gas. The admixture of oxygen does not affect the stability of the gas under compression but rather aids it, and the proportion, lying under 20 per cent. in all cases, of oxygen is far within the limit of security from explosion. The Tatham process might, therefore, be expected to be applied to the lighting of railway carriages, &c., as the cost of oxygen should in no case exceed that of its volume of good oil gas, and is likely to become lower year by year. The oil-gas installation will of course only be complete with an oxygen-producing plant. The oxygen used has up to the present been made under Brin's process. The condensation products from the gas are returned to the retorts, and the only bye-product finally obtained is a small amount of coke. In this respect the Tatham process is curiously akin to other modern methods of making oil gas.

The Tatham oxy-oil gas has been proposed for use as an enriching material for poor gas, such as ordinary coal gas, and has been tried in a few instances. The valuable effects of the oxygen would not appear to be retained, however, when the oxy-gas is subjected to any considerable degree of dilution. The gas is mixed with the coal gas prior to passing through the purifiers, and, consequently, the oxygen will serve to aid purification, as in the ordinary processes of using oxygen in the purifiers. To retain any advantages the oxygen of the oxy-oil gas may give to the mixed gases on combustion, it is evident that an additional and sufficient amount of oxygen for purification purposes must be added to the gas before it enters the purifiers. The oxygen of the oxy-oil gas should then remain in the mixture at the outlet. But where purification from sulphur compounds is carried out, in order to retain oxygen at the outlet of the vessels, and purify the coal gas from sulphur compounds, the oxy-oil gas would of necessity have to be added to coal gas after the latter had passed the "sulphide" vessels, for if added earlier the oxygen would be retained in them, if only in small amount, and if in large quantity it would decompose the purifying material and render it ineffective. It has been shown that the addition of a small quantity of oxygen, say 1 per cent., to coal gas of about 16 candles, slightly improves the "illuminating power," but a quantity much exceeding this deteriorates it. The question of the enriching value of oxy-oil gas appears, therefore, to be narrowed to the issues whether the 1 per cent. of oxygen exercises the same enriching effect on the poor gas as the same volume of oil gas would do, and if not, whether the cost of the oxygen is so much less than oil gas as to compensate for its less value. Probably no one is prepared to maintain that oxygen, volume for volume, is as good an enricher of poor gas as rich oil gas, and the cost of oxygen does not appear to be much less than oil gas of 50 candle-power. If the cost of the production of oxygen is much lowered, its addition to gas may become desirable; but at present the claims of the Tatham process appear to rest on the assumption that the oxygen mixed with the oil gas exercises a greater effect on the illuminating power of the final product than would the same proportion of oxygen added to a mixture in the same proportions of coal gas and oil gas (minus oxygen) immediately before combustion. This assumption might be proved in practice, or the oxygen might be found to exercise in some other way a mysterious effect on the ultimate illuminating value; and several men have been prepared to vouch for the greater value of the Tatham oxy-oil gas over other oil gas as an enriching medium, but the author thinks satisfactory proof of the superiority is still wanting in the published reports on the process. An exception is the experience of W. H. Herring with the process, in the plant for which he has introduced improvements. He has found the oxy-oil gas to have a higher enriching value than simple oil gas made by him from the same oil. He has worked the plant to give a standard production of 27,500 cubic feet of oxy-oil gas per ton of Scotch oil used; the gas having a direct "illuminating power" of 70 candles, and an illuminating value, deduced from its enriching power on coal gas, of 132 candles. He has found the cost of raising coal gas of 16 candle-power to 18·71 candles by means of oxy-oil gas to be extremely low; so far as the cost of oil and oxygen only was concerned, it was less than 0·3 penny per candle per 1,000 cubic feet. This abnormally low figure for enriching material per candle enrichment was undoubtedly largely due to Mr. Herring's ability and supervision, but, nevertheless, goes far to discount the theoretical objections to the oxy-oil gas process for enriching coal gas.

The Peebles Process.—In recent years a considerable extension of oil gas manufacture has been taking place, owing to the introduction of new processes, of which that devised by Young and Bell, commonly known as the Peebles process, takes first rank. The first important specification dealing with this process is No. 12,421, dated July 5, 1892, and is by W. Young and A. Bell, for "decomposing mineral oils for the production of illuminating gas." Broadly, the process as covered by this patent, and with the subsequent modifications, consists in cracking oil or tar at a low temperature, and washing or scrubbing the gas and vapours produced with oil or tar, which afterwards is itself cracked in similar fashion. The condensing and washing arrangements may be varied considerably, the scrubbing of the gas by the oil being most thorough when it is intended for storage without dilution by coal or water gas. The internal temperature of the retorts, which are cylindrical or nearly so, about 30 inches in diameter and about 8 feet in length, and generally of cast iron, is not much above 550° C. for ordinary mineral gas oil, but is considerably higher for tar and tar oils. The retorts are sometimes heated merely by the waste heat from settings of coal gas retorts. The bottom of the retort is, in recent patterns, protected by an iron plate to prevent leakage of oil through cracking of the retort itself. The gas passes from the retort into a hydraulic main, and thence to a series of condensing tubes and a washer, the patterns and disposition of which may vary, but which serve to subject the gas to contact with the oil that is passing from the reservoir to the retort. The oil washes and condenses from the gas all hydrocarbon vapours that are not of the nature of an ordinarily permanent gas, and these are, therefore, returned to the retort with the fresh oil. It will thus be seen that the process is practically one of distillation at a temperature that effects only partial cracking up of the hydrocarbons, and fractionation of the products of the distillation, all but the most volatile being eventually returned to the cracking chamber. The carbon set free on the breaking up of the hydrocarbons is deposited in the retort, along with some pitch. The flow of oil to the retort is interrupted at intervals, and the residue within completely carbonized. It is then removed as a good homogeneous coke free from ash, and the process of gas making is resumed. The process thus produces only permanent gas and coke of good quality, and, moreover, does this in such a manner that the cracking is not severe, and, consequently, the yield of coke is low compared with the gas produced and the oil carbonized. The amount of coke from Scotch gas oil is 5 to 6 cwts. per ton of oil. The volume of gas from such oil is about 22,000 cubic feet per ton, and its "illuminating power" is generally stated at about 90 candles, a value calculated from its enriching power on poor gas. These figures would give a yield of from 1,500 to 1,600 candles per gallon of oil; but it will be found that if the "illuminating power" of oil gas made by other processes is taken at its enriching power, the result is very similar. The figures are perhaps in favour of Peebles gas, which has also the advantage of greater permanency. The process undoubtedly submits the oil and gas to a systematic treatment, but it is open to question whether the lighting value of the hydrocarbons is not sacrificed to a certain extent for the sake of assured permanency of the gas. The illuminants of the Peebles oil gas consist chiefly of the lower members of the olefine and paraffin series of hydrocarbons, and are gaseous at ordinary temperatures. The resolution of the whole of the oil into such hydrocarbon gases and the ordinary diluents and coke may not in all cases be economically advantageous, as the vapours of higher paraffins and of the lower members of the aromatic series are more potent enriching agents for coal gas than ethylene, ethane, &c. If the light hydrocarbon vapours were fractionated from the oil used for washing the gas, and after condensation used for cold carburetting by one of the processes described in the succeeding chapter, a still higher illuminating value might be obtained from a gallon of oil than that now afforded by the Peebles process. Such a scheme would not be feasible in cases in which the oil gas is used alone, or forms a considerable constituent of a mixture. But coal gas is certainly capable of holding in suspension more hydrocarbon vapours than it naturally has, and it is economical to enrich with such vapours as far as is practicable in preference to cracking them into permanent gases. A lower yield of gas and coke from the oil would be compensated for by the value of the light hydrocarbon spirit. For the enrichment of coal gas by a few candles, absolutely permanent gases are by no means essential, and the use of the carefully-devised and scientifically-grounded Peebles process for enriching gas would be furthered if some of the light hydrocarbon vapours were preserved. S. Glover has tried the expedient of admitting coal gas to the hydraulic main of the oil-gas plant, and has thus succeeded in increasing the candles-per-gallon of oil (sp. gr. 0·865) to about 1,635. He used about 10 per cent. of coal gas to achieve this result.* The abbreviation of the washing of the gas by oil also permits some of the light vapours to pass on to the coal gas. A more systematic method of securing their value would consist in the utilization of waste heat to evaporate them from the oil before returning it to the retort. After condensation they could be used in a carburetting apparatus as required. In the Peebles process, the retorts are by the early specification heated externally, in similar fashion to coal gas retorts, and for small installations this is the most convenient method. In a later development of the process the inventors utilize the economy of internal heating, and produce a certain amount of water gas in the same plant. This modification is covered by Wm. Young's patent, No. 12,355, dated June 23rd, 1893, entitled, "Improvements in the production of illuminating gas from mineral oils, and in apparatus therefor, and

---

* *Trans. Incorp. Inst. of Gas Engineers*, iv., 152.

for producing water gas." The washing and condensing arrangements are very similar to those of the earlier neat oil-gas process; but the oil is sprayed into the upper part of a tall producer, in the lower part of which is a bed of fuel. Producer gas and water gas are produced by blowing air and steam intermittently through the fuel, and while the blast is shut off, or when only a small amount of water gas is being made, the oil gas is made in the upper part of the producer, the oil being cracked by the heat radiated from the sides of the chamber, or if this is insufficient, by the upper layer of the fuel. The carbon thrown down by the decomposition of the oil is deposited on the fuel. When the heat of the fuel has fallen considerably, air is blown in, and the carbon monoxide burnt by a secondary air supply in the upper part of the chamber. The process is largely regenerative, and several modifications of the plant have been devised to meet various needs. The Young process, as thus developed, is really a carburetted water-gas process, but is described here since it was the outcome of the simple Peebles oil-gas process. The new process obviates the difficulties of cracked retorts which were frequent with the older one, and where a large make is needed, is certainly more economical. The Peebles process, in one or other of its forms, has been adopted pretty extensively, especially in Scotland, and as far as published results at present show, it has given satisfaction.

CHAPTER VI.

ENRICHING BY LIGHT OILS.

Carburetting Gas and Air.—The method of enriching, or raising the illuminating power of gas of which this chapter treats is commonly known as carburetting, or more explicitly, as cold carburetting. It consists in adding to gas a proportion of the vapour of very volatile liquid hydrocarbons, such as are described under the fifth class of raw materials on p. 62. Occasionally air is saturated with such light hydrocarbon vapours to form an illuminating gaseous mixture, but owing to the large volume of nitrogen necessarily present in such a gas, it is evident that the resources of the hydrocarbon are wofully misspent in such a method of consuming it for the development of light. This so-called air gas can only be safely consumed in special valved burners, and with precautions to avoid the explosion of the gas in the services and holder. The uneconomical nature of this gas, and the danger attending its use without special precautions, are sufficient grounds for preventing its common adoption in this country. Fuller reference to air gas is made in the work on "Acetylene" by F. H. Leeds and the author, published by Charles Griffin & Co., Ltd.

Carburetting with Carburine.—The great advantage of carburetting gas with light oil vapours is the ease and rapidity of the process, and the small bulk and simplicity of the apparatus employed. Where a statutory illuminating power has to be maintained, the method may be the sole means of enriching used, or may serve as supplementary to the carbonization of cannel and heavy oils. In the largest works it has hitherto been used only to supplement other processes of enriching, and for this purpose it is admirably adapted. In this country the carburetting material used is almost invariably carburine, or light petroleum oil, and it is used with apparatus constructed under the Maxim patents, which are the property of the Gas Lighting Improvement Company, Limited. The apparatus is in use at several London works and distributing stations. Fig. 29 is a sketch of it, with the necessary accessories and connections. P is the gas main, which may be either the inlet main to the gasholders or the distributing main. The store-tank for the carburine, A, is provided with inlet and outlet pipes, B and C respectively, for the fluid, and a float, D, to indicate the amount contained. The pump draws the carburine from the store-tank through the tube, F, into the evaporator, E. The evaporator resembles a vertical tubular boiler, and is fitted with water gauge, G, and pressure gauge, H. Steam plays round the tubes and escapes through J, evaporating the spirit in the tubes, the vapour being forced by its own pressure through the tube, M, to the regulating valve, N, and injector, O, which is connected to the gas main, P, by the pipes, Q and R, a short distance

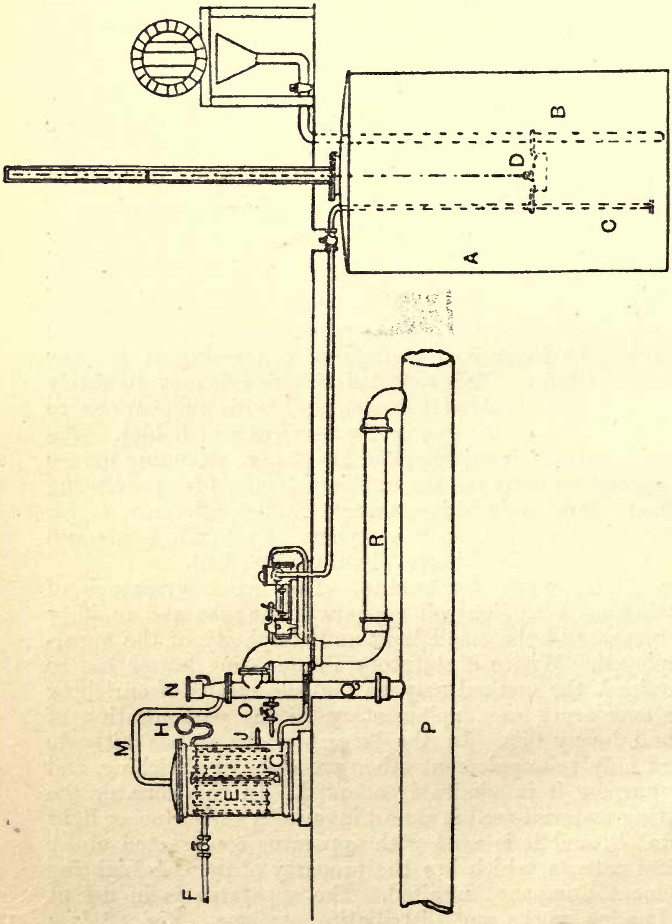


Fig. 29.—The Maxim carburetting apparatus.

P, Gas main; A, store-tank; B, C, inlet and outlet pipes to carburine store-tank; D, float; F, pipe leading to evaporator; E, evaporator; G, water gauge; H, pressure gauge; J, steam escape orifice; M, outlet pipe for vapour; N, regulating valve; O, injector; Q, R, pipes leading to gas main.

apart. The storage tank is generally of steel, and sunk in the ground; it has a small diameter ventilating tube passing through the crown, and carried up to a safe height. The pressure at which the steam is admitted to the evaporator determines its temperature and, consequently, the rate of evaporation of the spirit. Hence, regulation of the temperature through the steam pressure affords a means of controlling the amount of vapour passed into the gas and the degree of the enrichment of the latter. The amount of carburine vapour admitted to the gas at any time is, in practice, controlled by the regulating valve, N, and may be adjusted to a nicety. With gas of about 15 to 17 candles, it appears from observations made by men of repute, that 1 gallon of carburine, having a specific gravity of about 0·680 suffices, when vaporized in this apparatus, to raise about 8,000 cubic feet of gas 1 candle in illuminating power. The gas so enriched is as permanent as gas of the same quality produced by most other methods. The quantity of hydrocarbon vapour that gas can carry at any particular temperature obviously depends, primarily, on the vapour tension of the hydrocarbon at that temperature. Carburine being a mixture, it is difficult to calculate exactly from vapour tension determinations the amount of its vapour required to saturate gas at any temperature. Practically no considerable error is, however, introduced by regarding carburine as hexane, and then from the vapour tension of hexane it may be calculated that gas saturated with carburine vapour contains at 0° C. 8·0 per cent. by volume, and at 15° C. (59° F.) 15·6 per cent. by volume of that vapour. A gallon of carburine gives 28·3 cubic feet of vapour at 0° C., or 29·85 cubic feet at 15° C., and, therefore, saturates about 355 cubic feet of gas at 0° C., or 190 cubic feet at 59° F. Even supposing that the gas, after enrichment with carburine, will be subjected to a temperature of 0° C., it is evident that there is ample margin for it to retain in suspension carburine vapour equivalent to an enrichment of several candles in lighting value. It may be mentioned that Professor Wm. Foster has given 162 cubic feet as the minimum volume of 16-candle London gas, which can retain the vapour of 1 gallon of carburine at 59° F. and the normal barometric pressure. This value was found experimentally.

Petroleum spirit having a specific gravity of about 0·700 consists largely of heptanes, and has a lower vapour tension than carburine. One gallon yields only about 26 cubic feet of vapour at 59° F. It has, however, volume for volume, a higher carburetting value than carburine, and when the degree of enrichment required is not high it may be safely used. According to tests made by H. Leicester Greville with Price's carburetting apparatus (described below), 1 gallon of petroleum spirit, specific gravity 0·700, sufficed to raise 10,286 cubic feet of coal gas of 16·01 candle-power by 1 candle.* With another form of vaporizer, J. F. Bell found 1 gallon of similar spirit raise only 5,000 cubic feet of gas by 1 candle. Spirit of this grade is usually cheaper than carburine or gasoline.

The advantages of so simple and expeditious a method of enriching gas, as carburetting with light petroleum vapour, are too obvious to need more than mere enumeration. They are the saving of coke, and the production of no inferior coke from cannel coal; absence of purification, and of storage gasholders for the enriching medium; compactness of enriching plant, and saving of labour. The economy of the process depends on the current market rates for carburine, and the cost of enrichment by it may readily be calculated for any particular case from the price of carburine and the data given above.

Another pattern of carburetting apparatus has been patented by W. E. Price (Eng. pat. No. 20,066, 1894). By it the carburine or spirit flows in a zigzag course over a plate heated by the passage beneath it of steam. The gas to be carburetted flows through a chamber above the spirit, and carries away the vapour thereof. As already mentioned, this carburettor has been successfully applied to carburetting coal gas with petroleum spirit of 0·700 specific gravity.

Carburetting with Benzol Vapour.—Passing to enrichment by benzol vapour, which has lately had many advocates in Germany, it may be stated, preliminarily, that the process is but little used on a large scale in this country, and that the results of early attempts in that direction, and the balance of opinion of competent English gas engineers are against it. The results of experiments in Germany are, however, so favourable to it, that carburetting by benzol must certainly be considered an alternative to other good methods of enrichment. Dr. H. Bunte, who has strenuously advocated benzol for enriching purposes, discusses the problem on the same lines as have been followed above for carburine.† The vapour tension of benzene, the chief constituent of commercial 90 per cent. benzol, is at 0° C. (32° F.) 25·3 mm., and at 15° C. (59° F.) 58·9 mm. From these numbers it may be deduced that benzol vapour will form 3·3 volumes at 0° C., or 7·75 volumes at 15° C. per cent. of a gas saturated with it. These numbers are lower than the corresponding ones for hexane, and hence it might be considered that benzol would be a less efficient carburetting agent than car-

---

* *Journ. of Gas Lighting*, lxv., 535.

† *Journ. f. Gasbeleuchtung*, xxxvi., 442; and *Journ. of Gas Lighting*, lxii., 717.

burine. According to Dr. H. Bunte, however, benzene vapour has, volume for volume or weight for weight, a far higher enriching power than hexane or other paraffins. Weight for weight, he finds benzene secures nearly two and a-half times the lighting effect of hexane, and he argues that the aromatic hydrocarbons have a far greater lighting effect than the members of the paraffin and olefine series which have the same number of carbon atoms to the molecule. He estimates * that 1 gallon of benzol will raise at least 24,500 cubic feet of coal gas of about 16 candles by 1 candle in illuminating power. J. F. Bell found that 1 gallon of 90 per cent. benzol was capable of raising about 20,000 cubic feet of coal gas from 15 to 16 candle-power. Therefore, volume for volume, benzol does three times the work of carburine as an enriching agent, or, weight for weight, about two and one-third times the work. The use of benzol for carburetting has been attended with excellent results at the Munich gas works,† according to the testimony of H. Ries and E. Schilling. The apparatus used consists of a vessel containing a drum, which is moistened continuously by the benzol, through which the gas passes. The large surface wetted with benzol, presented to the passing gas, ensures the thorough saturation of the latter with benzol vapour. The amount of gas passing through the carburettor is proportioned to the degree of enrichment required, but, in all ordinary cases, is small in proportion to the total volume of gas to be enriched. A branch service from the main leads to the carburettor, and another service conveys the gas from the latter again into the main stream. By careful adjustment of valves, the amounts of gas going direct along the main and through the carburettor are regulated to give the precise required degree of enrichment to the gas. The comparatively low vapour tensions of benzene and toluene, at ordinary temperatures, would seem to put the permanency of enrichment by them much in question, but there appears to be ample margin even at 0° C. (32° F.) for the retention by gas of sufficient benzol vapour, to give it an illuminating power of 25 candles. The cost of carburetting by benzol can be calculated from the current market prices, approximately, by the aid of the above data. The material should conform in its range of distillation to the limits for 90 per cent. benzol; 50 per cent. benzol is far less reliable; but the source of the material is of little importance, as the presence of volatile hydrocarbon impurities is of no moment for carburetting, though deleterious

---

* *Journ. f. Gasbeleuchtung*, xxxvii., 81; and *Journ. of Gas Lighting*, lxiii., 485.

† *Journ. f. Gasbeleuchtung*, xxxvii., 1, 549; or, *Journ. of Gas Lighting*, lxiii., 197, and lxiv., 735.

to benzol intended for use in chemical works. It is but fair to add that the high value of benzene as an enriching agent, compared with other hydrocarbons, has been doubted by Lewis T. Wright[*] and others. C. Hunt states that he has found 1 gallon of almost pure benzene raise by 1 candle the illuminating power of only 9,500 cubic feet of coal gas. In the same way, however, he found carburine having a specific gravity of 0·6805 raise by 1 candle only 2,800 cubic feet of gas.[†] The relative efficiencies stated above of benzene and carburine as carburetting agents are confirmed by these figures, though the absolute values in both cases are abnormally low.

---

[*] *Journ. Soc. Chem. Ind.*, xiv., 107.

[†] *Journ. of Gas Lighting*, lxv., 371.

CHAPTER VII.

FINAL DETAILS OF THE MANUFACTURE AND SUNDRY SCHEMES FOR MAKING AND ENRICHING GAS.

The ordinary processes of gas manufacture and enrichment have now been described, and the course of the gas traced up to the last stage in its purification. The measurement, storage, and distribution of gas scarcely fall within the scope of this work, but the more important apparatus for these purposes will be considered very briefly in the latter half of this chapter, and the treatment of the gas, up to the time that it leaves the works, thus dealt with for the sake of completeness, though the final stages lie almost wholly within the engineer's province. There are, however, a few subsidiary processes for gas enrichment, &c., which do not fall appropriately within any of the classes adopted in the earlier chapters, but which are of sufficient interest to demand some notice, and to these the next few pages will be devoted.

Dinsmore's Process for Carbonizing Tar.—Many schemes for the carbonization of tar and tar oils are merely simple adaptations of the ordinary oil gas and carburetted water-gas processes. But the methods of carbonizing tar, patented by J. H. R. Dinsmore, fall in a somewhat different category. He endeavours to gasify as much as possible of the tarry vapours in the crude gas, and the tar deposited near the retorts, in the presence of the coal gas itself. By one of his patents he condenses the tarry matter from the gas by passing it, as it leaves the retort, through inclined ducts, the ends of which are artificially cooled. The tar so condensed runs down to the hot part of the retort, and is there vaporized. The Dinsmore process has been tried at several works, but has succeeded best at Widnes, where it has been in use for some years. The engineer in charge of this works, Isaac Carr, has obtained better results than others, even with what would commonly be considered bad coal for gas making. The gas passes from the ordinary retorts through a heated retort or duct, where tarry matters are to a very large extent gasified, and the quality and quantity of gas obtained from the coal greatly enhanced. On the working scale other operators have not been so successful as Isaac Carr, and perhaps his success may be largely due to a careful regulation of heats, and the passage of gas of tolerably uniform composition through the secondary retort. To judge by the present attitude of gas managers to the Dinsmore process, it would seem that it is not likely to be adopted extensively, and, indeed, were it not for the notable exception at Widnes, it might be relegated to the list of well-conceived schemes that have failed to justify themselves on trial on the practical scale. It may be observed in this connection that Lewis T. Wright in a paper entitled, "What shall we do with our tar?" read before the Society of Chemical Industry,* gives results which go to prove that no rich gas can be obtained from coal tar or tar oils, and that tar is practically useless as an enricher. On the other hand, his results for benzol are at variance with those more recently obtained in Germany, and as the method of destructive distillation applied by him to tar differed in many essential points from that of the Dinsmore process, he cannot be considered to have proved the results claimed for the latter at all improbable. Most methods of carbonizing tar are fruitful of blocked ascension pipes and mains; but the Dinsmore process is an exception.

Self-Carburetting Process.—The method of introducing water gas into the retorts or hydraulic main of coal-gas plant while in action, which is known under this title, has already been referred to (p. 218). In the retorts, a stream of water gas slightly reduces the make of coal tar, and in any case the "self-carburetting" is effected more or less at the expense of the lighter hydrocarbons otherwise present in coal tar.

Acetylene as an Enriching Agent.—A scheme for enriching poor gas, or making a high-value illuminating gas, emanating from the United States, consists in the employment of acetylene produced from calcium carbide. This is dealt with fully in the work on "Acetylene," by F. H. Leeds and the author.

Station Gas Meters.—Reverting to the treatment of coal and other gas after it has passed through the purifiers, it will almost invariably be led thence to a station meter for the exact measurement of its volume. The meter is a necessary adjunct to a gas works, to record the amount of gas made per day and hour, and if the works is a large one, a meter will be assigned to the output of each retort house, or connected to the outlet of each set of purifiers, according to the arrangement of the works. The use of separate meters to each house or each section in a large works, affords a useful indication of the relative carbonizing efficiency of the houses. The works or station meter is invariably of the variety known as "wet," from the use of water as a confining medium within it. The meter is usually placed

---

* *Journ. Soc. Chem. Ind.*, 1886, 558.

between the outlets of the last purifying vessels in each set and the inlets to the gasholders. It consists of an outer case, rectangular in the larger, cylindrical in the smaller, meters. Within this case is a cylindrical drum having a horizontal axle, by which it revolves within the case. The drum consists of three or four equal chambers—the partitions being set angularwise to the axis, so as to offer little obstruction to the revolution of the drum under water. To one end of the cylindrical drum is affixed a cover forming a convex end to the cylinder. The inlet pipe passes through this cover in the line of the axle, and is turned upwards within the cavity between the cover and the chamber walls. The meter is throughout filled with water to a level slightly above the axle, and the inlet pipe must turn upwards until well clear of the water. The gas passes into the cavity between the cover and chambers of the drum, and by a suitably-placed inlet slit into one of the chambers. The gas entering the chamber as it is partially immersed in the water, by its lightness, tends to raise that chamber and draw it out of the water. The drum axle being set in bearings, and the drum, consequently, not free to rise bodily, the effect of the gas entering the chamber is to cause the drum to revolve. As soon as the chamber is filled with gas, the inlet to it has, by the revolution of the drum, passed beneath the water level, and sealed the gas up; the inlet to the next chamber rising at the same time above the water level, and permitting the gas to enter that chamber. As the inlet to each chamber becomes sealed, an outlet slit opening into the cavity between the drum and the outer case is unsealed, and water entering by the inlet forces the gas through this slit to the afore-mentioned cavity, from which it is conveyed by the meter outlet pipe, which merely passes through the outer case some distance above the water level. The same process occurs with each chamber, the pressure of the entering gas driving it through whichever chamber inlet slit may be unsealed, and thereby, owing to the gas drawing that chamber from the water, causing revolution of the drum. When a chamber is filled with gas, the revolution of the drum automatically seals the inlet slit and unseals the outlet slit. The axle of the meter is carried outside the case, and has fixed on its extremity a toothed wheel, which gears into a clockwork mechanism for recording from the number of revolutions of the drum and axle, the volume of gas passed through the meter. It is evident that the capacity of the chambers of the drum is affected by the level of the water in the meter, and a rise or fall in the water will diminish or increase the volume of gas passed at each revolution of the drum, and cause an incorrect registration of the volume of gas passing through the meter. The meter is, therefore, furnished with a small continuous supply of water, and a siphon overflow pipe is provided to draw off the water as soon as it rises above the normal water-line. The recording mechanism is affixed to a series of small dials, arranged so that each registers quantities ten times those registered on the preceding dial. The volume of gas passed may, therefore, be found at any time by setting down in order, from right to left, the figure on each dial which its pointer is passing, or has last passed, beginning with the dial for the unit quantity (generally 100 or 1,000 cubic feet) recorded by the meter, and multiplying the number so obtained by the said unit. By subtracting the reading at one time from that at a later period, the quantity of gas passed in the interval is found. Various mechanical contrivances have been devised for compensating for alteration of water level in small meters not provided with a continuous water supply and overflow.

Station Governor.—The governor is an apparatus designed to deliver gas at a uniform pressure from a source where the pressure is subject to variations, the latter being in many instances sudden and considerable. It further enables the pressure to be regulated and fixed at any desired amount by some simple adjustment. A governor is generally attached to an exhauster to maintain a uniform pressure, and prevent either the vacuum or pressure becoming too great. A portion of the gas is led by a small pipe off the main into the bell of a small gasholder. The rise and fall of the bell under the varying gas pressure are made to act on a throttle valve in the steam-supply pipe to the exhauster, so as to alter the speed of the latter according to the pressure of the gas. In some instances, the rise and fall of the bell of the small holder of the governor is used to control a valve on a bye-pass between the inlet and outlet pipes of the exhauster; the opening of the valve allows a certain quantity of gas to pass back from the outlet to the inlet main. This form of governor is especially used to control the exhausters used for maintaining a definite pressure in the hydraulic main and retorts. When the pressure on the inlet side of the exhauster becomes too low, the governor-bell connected to the bye-pass valve opens the latter, and allows some of the gas to return. Exhausters are generally used for providing the requisite pressure for the distribution of the gas, and as this pressure must be readily regulated and uniform, governors are used to control it, or in smaller works the pressure of the holder, which is there sufficient for the purposes of distribution. As the pressure thrown by the holder, especially if it be telescopic, varies considerably, and as, generally, two or more holders throwing different pressures are used in turn, it becomes essential to have a means of easily controlling the pressure at which the gas leaves the works. For these purposes various forms of station governor have been designed, most of them being primarily dependent on the same general principle.

The early station governor consisted of a small gasholder, the weight of the bell of which was balanced to the required degree by weights attached to the free end of a chain passing over pulleys, and having the opposite end attached to the centre of the bell crown. The gas inlet pipe passes up the centre line of the holder, terminating a little above the water line, but having the end partially closed by a flange. The outlet pipe is either formed by the annular space between the inlet pipe and a larger co-axial pipe, or is at one side of the inlet pipe. Suspended by a chain from the centre of the bell crown is a conical weight within the inlet pipe, the apex of the cone pointing upwards, and the base being of considerably smaller diameter than the inlet pipe, but larger than the orifice of the latter. A rise in the gas pressure forces the bell upwards, and so draws the cone up to the flanged outlet of the inlet pipe, partially closing the latter, and diminishing the volume of gas admitted to the bell until the pressure within the latter again falls. The conical weight or valve plug has in practice generally given place to one of which the sides are made to a parabolic curve, such that, for equal rises in the valve plug, the opening from the inlet tube becomes restricted to an equal extent. This renders the weighting of the holder bell to deliver gas at any desired increase or decrease of pressure a simple matter, and also permits a rough estimation of the amount of gas passing from the height of the plug, on which the size of the opening is dependent in a regular proportion. This simple governor is shown in Fig. 30. The pressure of the

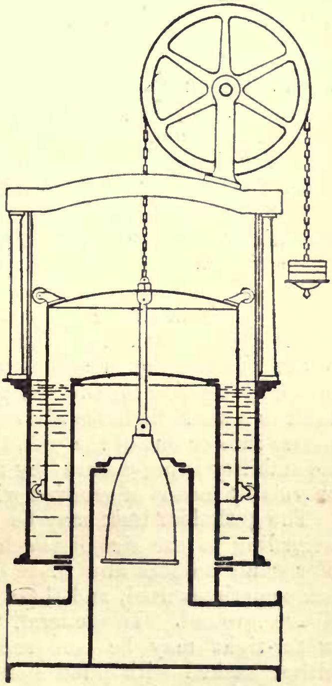


Fig. 30.—Simple governor.

outgoing gas is in practice controlled by adding to or taking from the balance weight, weights each equivalent to a definite alteration in pressure. The area of the base of the plug must be considerably less than that of the bell, or the changes in pressure of the entering gas will affect the outgoing gas. To prevent the disturbing effect produced by changes of pressure, even with governors having tolerably large bells, various compensating arrangements have been devised, and one or other of them is now generally incorporated in this form of governor. With the early governors the bell might by accident become tilted, and permit an escape of gas; the more modern forms are not open to this objection. For some purposes it is desirable to have a governor fitted with an apparatus for automatically changing the pressure at certain fixed times, and such an automatic pressure changer has been put upon the market.

The Gasholder.—The gasholder is at present constructed on essentially the same principle as in the early days of gas lighting. It consists of a bell-shaped vessel having its lower open end immersed beneath water in a tank, and maintained in equilibrium by a suitable fixed framework. The interior of the bell serves as the gas reservoir, the confining media being the sides and top of the bell and the surface of the water in the tank. The inlet and outlet pipes for the gas pass up through the bottom of the tank to a short distance above the surface of the water; as gas passes into or out of the bell, the latter rises or falls accordingly, its stability being ensured by the external framing on which it travels by means of grooved wheels.

The **gasholder tank** may be constructed of various materials, according to the size of the holder and the nature of the soil. For small holders and those on a very porous soil, iron tanks are sometimes used, and these may be either partially or wholly above ground. In general, however, sound tanks perfectly water-tight may be constructed of concrete, brick, or stone, either backed with puddle or not according to circumstances. Where the soil is good plastic clay, little or no puddle is required, and the tank walls need be but thin, as the soil will give support and the requisite impermeability. In this case also little more than an annular excavation need be made, the greater part of the original soil being left as a mound in the tank, covered with a thin layer of good Portland cement concrete, or masonry. Where the soil is less firm, the excavation may have to be carried on until a nearly level bottom to the tank is obtained. Some engineers invariably use puddle as a backing to the walls and bottom of a tank, and thereby secure the impermeability of a clay soil. Others rely on good concrete, or brick or stonework rendered with Portland cement. The inlet and outlet pipes of the holder are carried under the retaining wall of the tank, and up within it to a short height above the water level. The tank walls generally rise somewhat above the natural level of the land, the earth removed in the excavation serving to raise the level in the immediate neighbourhood of the tank. The tank walls are provided with guide rails at regular intervals throughout the circumference, on which the guide rollers on the lower curb of the gasholder bell travel as the latter rises or falls in the tank. In the tank walls are constructed substantial piers of stonework or concrete, for the support of the standards of the guide framing. In each pier, 6 or 8 feet below the surface, are the anchor plates, firmly secured in the masonry. To these are attached tie-bolts of the required length to secure the base of the guide column to the pier.

The framing of the holder consists of a number of vertical columns placed equidistant from one another in a circle concentric with the tank wall, but of slightly greater radius. Cast iron was formerly used for these columns, but in most recent structures wrought-iron lattice standards have been used. These generally taper uniformly from bottom to top, and each standard is united by lattice girders to the adjacent standards at the top, and at one or more points below, the number of these horizontal girders increasing with the height of the framing. The framing thus forms a number of approximately rectangular spaces, which are generally each traversed by diagonal tension rods. In some cases other plans of tying the frame are adopted. The framing forms a cylindrical piece of trellis-work, within which the bell of the holder is placed. The bell consists of iron plates built on to a light framing, forming a hollow cylinder, the diameter of which is rather less than that of the tank, with one end closed by a domed roof of plates. The open end of the cylinder dips into the water in the tank. The framing of the bell, if of considerable size, may be trussed both at the top and sides, and both the bottom and top curbs must be well strengthened, the plates adjoining them being of greater thickness than elsewhere. Opinions differ considerably as to the relative merits of trussed and untrussed roofs of holders. Opposite the standards of the framing are affixed to the sides of the bell, near the upper curb, carriages for the guide rollers, which traverse rails on the inner face of each standard of the framing. The arms of the carriages bearing the rollers are of such length that there is very little play between the rollers and the rails on the standards. The lower curb of the bell is also furnished with rollers, which traverse rails fixed on the tank wall. Where a trussed roof with central king-post is used, a pier is carried up in the centre of the tank for the bottom of the king-post to rest on when the bell is in its lowest position, and the roof is unsupported by the gas within. In other holders a substantial wooden framing is erected in the tank for the support of the top or crown of the bell when the latter is in its lowest position.

Mode of Using the Holder.—When the holder is in use, the tank contains water nearly to the top, and the gas within is under the pressure due to the weight of the bell. The pressure of the gas, of course, depresses the water within the holder, and the sides of the bell must always be immersed in the water of the tank to a depth greater than the depression so caused, or the gas will escape from under the sides of the bell. The pressure on the gas within a holder varies from 1 inch to 12 inches of water, according to the weight and dimensions of the holder bell. To pass gas into the holder, it must be pumped at a greater pressure than that thrown by the holder. The holder pressure may, with or without the intervention of a governor, serve for the distribution of the gas, though in large works the gas is generally withdrawn from the holders by the aid of an exhauster.

Telescopic Holders.—It is evident that the capacity of the holder, as here described, is limited for a given diameter by the depth of the tank. In some localities the difficulties of making a deep tank are very great, owing to the nature of the soil, and, in any case, the limit to which its depth can be profitably carried may be put at about 60 feet. In positions where ground is very valuable, the multiplication of holders becomes very expensive merely from the space which they occupy. Consequently holders, if of at all considerable dimensions, are now constructed on the telescopic principle, whereby the capacity may be practically doubled, trebled, quadrupled, or even still further increased for a given tank. The bell of the holder is formed of two or more concentric hollow cylinders, one sliding within the next larger. The smallest or inmost cylinder is alone roofed, the upper edge of the sides of the other cylinders being turned over inwards, and carried down parallel to the cylinder side to a depth of about 3 feet. The lower edge of the next smaller cylinder is turned outwards and upwards to the same height, forming an annular trough, which is filled with water. Into this water the turned-over edge of the larger cylinder dips, and a gas-tight seal is thereby formed. The upper curb of each lift, so constructed, of the bell is furnished with arms as carriages for rollers traversing the guide-framing rails. The carriages of the inner lifts are necessarily longer, and must be proportionately stronger than those of the outer lifts. The cup or seal of each lift need be only 1 to 2 feet in diameter; consequently, the capacity of the inner lift is not very much less than that of the outer. Rollers are attached to the outside of the lower curb of each lift, and traverse rails attached to the inside of the next larger lift, in the same manner as the lower guide rollers of a single holder, or of the outer lift of a telescopic gasholder, run on rails on the side of the tank. When down, the lifts of the holder rest on bed plates at the bottom of the tank, the crown of the inmost lift being supported as in single holders. Lack of space prevents the details of the construction of large telescopic gasholders being here given, but the general principles on which they act may be gathered from the illustration—part in section, part in elevation—of a four-lift holder (Fig. 31). For the sake of clearness, minor details are omitted. In the illustration guide-framing is shown for the whole of the lifts, but some holders have been constructed in which external guide-framing has been dispensed with for the inner lifts. As soon as cupping takes place, the weight of the next lower lift is thrown on to the cup of the upper one, and effectually keeps the latter in a position of stability. Rope guides have also been considerably used in

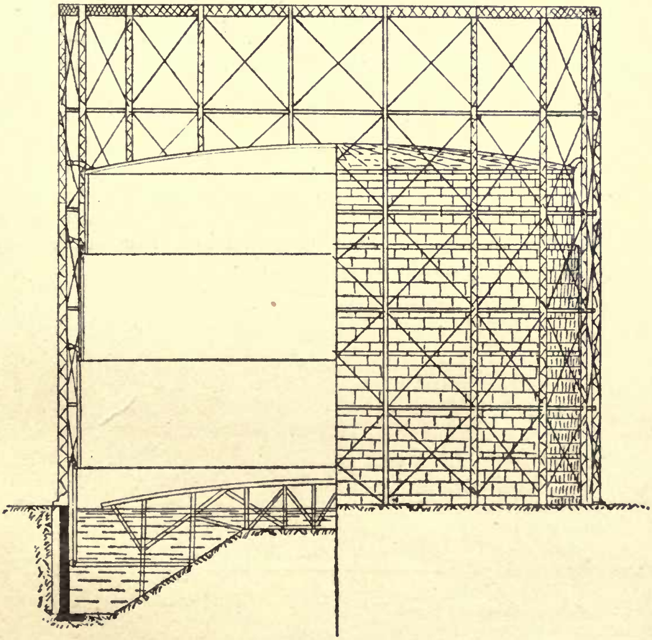


Fig. 31.—Four-lift gasholder.

recent years. For particulars of these later developments in gasholder construction, about which controversy still rages, the current technical journals should be consulted. Gasholders have now been made of 300 feet diameter, and with as many as six lifts, and several exist having capacities of from 7,000,000 to 12,000,000 cubic feet.

With telescopic gasholders, interference with, and even danger in, working occurs, from the freezing of the water in the lutes. Though not so much felt in this country as elsewhere, the annoyance and risk are sufficiently grave to make the adoption of some preventive means general. The most convenient is the passage of steam into the lutes by means of flexible tubing, which is supported on a series of pulleys attached to the guide-framing. This method has been patented by S. Cutler & Sons. One eminent engineer has proposed to warm the water in the lute by means of a series of Bunsen burners.

From the gasholders the gas is generally pumped into the distributing mains, and with its departure from the works the chemist may be said to have done with it, except in so far as he may have to examine it at some point in the distributing system, to see that the amounts of certain impurities in it are not excessive. For the details of such examination, the succeeding volume of this work should be consulted.

INDEX.

A

Abel, Sir F., flashing point apparatus, 48.
Absorption tubes, 154.
Acetic acid from wood, 5.
Acetone from wood, 5.
Acetylene, 2, 121, 236.
  ,, series of hydrocarbons, 57.
Actions in retort furnaces, 69.
Air required for combustion of carbon, 71, 72.
  ,, supply to furnace, 72, 74, 75, 79, 82.
  ,, ,, producer, 83, 87.
  ,, ,, water-gas generator, 202, 210.
  ,, use in purification, 176, 186.
Air gas, 1, 229.
Albo-carbon system of enriching gas, 65.
Alexander & Paterson, oil-gas plant, 222.
Algierian petroleum, 45.
Allen & Leffmann, bromine absorption of oils, 58.
Allen, R. W., vapour tension of naphthalene, 65.
America, Carburetted water gas in, 190.
American Chemical Society's Committee on Coal Analysis—
  Method of estimating ash in coal, 23.
  ,, ,, moisture in coal, 29.
  ,, ,, sulphur in coal, 19.
  ,, ,, ,, coke, 41.
  ,, ,, volatile matter in coal, 31.
American petroleum oil (see also *Petroleum*), 44, 56, 62.
Ammonia from distillation of coal, 124.
Ammonia in coal gas, 135, 136, 139, 140.
  ,, ,, Extraction of, 141-148.
  ,, ,, Increasing yield of, 125.
  ,, ,, traces after washing and purification, 148, 183.
  ,, in gas, Tests for, 149, 183, 184.
  ,, Temperature of decomposition of, 125.
Angle of repose of coal, 102.
Animal oils for gas making, 59.
Anthracene, Formation of, 122.
Anthracite, 4, 39, 40, 42, 198.
Anti-dips, 97.
Antimony in coal, 13.
Arsenic in coal and coke, 13, 25, 26.
  ,, ,, gas liquor, 28.
Ascension pipe, 67, 96.
Ash, Anthracite, 40.
  ,, Cannel, 14.
  ,, Coal and coke, 3, 4, 21, 23, 24, 26, 38, 41.
  ,, Peat, 7.
  ,, Wood, 5.
Ashpan of furnace, Water evaporation from, 77, 84, 87, 93, 94.
  ,, ,, water-gas generator, 202.
Astatki, 54.
Atmospheric condensers, 97, 99, 208.
Attix, J. C., volatile matter in coal, 32.
Austrian brown coal, 10.
Avery, R. B., oil-gas plant, 223.

B

Baku petroleum, 44.
Balakhani petroleum, 44, 45.
Balzer, theory of composition of coal, 116.

Batoum, Petroleum shipping at, 44.
Beale's exhauster, 100.
Beilby, G., ammonia from shale, 124.
Bell, J. F., enriching values of benzol and petroleum spirit, 232, 233.
Benzene for cold carburetting, 63, 232.
,, in gas, Formation of, 120, 121.
,, series of hydrocarbons, Reactions of, 57.
,, Vapour tension of, 64, 232.
Benzine, 54.
Benzol, Cost of enriching by, 233.
,, for cold carburetting, 63, 232.
,, ,, enriching mixed gas, 131.
Besemfelder, E. R., mixed gas, 218.
Bibi Eibat petroleum, 46.
Bichromate of potash, Standard solution of, 159.
Biggs, Wall & Co., charging machine, 106.
Blast for water gas manufacture, 202.
Blast furnace oil for gas making, 59.
Blount, B., absorption tube, 155.
Blow of water-gas process, 196, 208, 209.
Boghead cannel, 14.
Bog ore, 158.
Bohemian gas oil, 47.
,, peat, 8.
Borneo petroleum, 45, 46, 56.
Bradford petroleum, 44.
Brentford, Inclined retorts at, 104.
Bridge-pipe, 96.
Brin's oxygen producing process, 187, 224.
British Association Committee (1896) on coal, 117.
Bromine absorption of gas oils, 57, 59.
Brooks, H. W., oil-gas plant, 223.
Brown coal (see also *Lignite*), 9, 10.
,, oil for gas making, 47, 56.
Bueb's vertical retort, 116.
Bunte, H., enriching value of benzol, 232.
,, light oils for cold carburetting, 64.
,, peat, 8.
Buoys, Oil gas for, 221.
Burmese petroleum, 45.
Burning oil, 54.
Butane, 63.

C

CAKING coal, see *Coal, Caking.*
,, property of coals, 12.
Calcimeter, 156.
Calcium hydrate, hydroxide, and oxide, see *Lime.*
,, hydroxyhydrosulphide, 181.
,, thiocarbonate, 180.
,, thiocyanate, 184.
Californian petroleum, 44, 46.
Calorific balance of carbonization of coal, 131.
,, power of coal gas, 130, 132.
,, ,, self - carburetted gas, 130, 131.
Canadian petroleum, 45.
Candles per gallon of gas oils, 62.
,, per ton of coal or oil, 35, 37, 39, 129.
,, Standard spermaceti, 35, 37.
Cannel, Characteristics and composition of, 13, 14.
,, Coke from, 14.
,, Enrichment by, 191.
,, standard variety for comparative testings, 36.
,, Temperature for carbonization of, 137.
Cannel-gas, Composition of, 136.
Carbides as sources of gaseous hydrocarbons, 2.
Carbon, Air required for combustion of, 71, 72, 74.
,, and water vapour, Conditions of action between, 84, 192.
,, bisulphide, see *Carbon disulphide.*
,, Combustion of, 71, 72, 74.
,, dioxide, see *Carbonic acid.*
,, disulphide from coal, 126.
,, ,, in coal gas, and its removal therefrom, 135, 139, 140, 150, 174, 178, 186.
,, Heat of combustion of, 71, 73.
,, in coal, Estimation of, 16, 31.
,, monoxide, see *Carbonic oxide.*
,, Oxygen required for combustion of, 71, 72.
,, Specific heat of, 194.

Carbonates, Analysis of, 153, 155.
Carbonic acid, Conditions and heat of formation of, 71, 72.
,, ,, in blow gases from water-gas generator, 209.
,, ,, in carburetted water gas, 212, 214.
,, ,, in coal gas, and its removal therefrom, 135, 136, 137, 140, 149, 172.
,, ,, in gas, Estimation of, 213.
,, ,, in gas liquor, 141.
,, ,, in producer gas, 85, 86.
,, ,, in water gas, 199, 205, 212.
,, ,, Specific heat of, 195.
,, oxide, Conditions and heat of formation of, 71, 72.
,, ,, in blow gases from water-gas generator, 209, 211.
,, ,, in carburetted water gas, 214.
,, ,, in coal gas, 135, 136.
,, ,, in gas supplied, Proposed limitation of amount of, 217.
,, ,, in producer gas, 72, 85.
,, ,, in water gas, 190, 193, 198, 216.
,, ,, Specific heat of, 195.
Carbonization of coal, 116, 118.
,, ,, Calorific balance of the, 131.
,, ,, Conditions for proper, 113.
,, ,, Fuel consumed in the, 69.
,, ,, Heat liberated by the, 132.
,, ,, in a current of steam or gas, 125, 129.
,, ,, Products of the, 116.
,, ,, Temperature for the proper, 39, 71, 128.
Carbonization of Coal, Time required for the, 95.
,, of hydrocarbons, Products of the, 116.
,, of peat, 8.
,, of wood, 5, 6.
Carbonizers, Continuous, 114.
Carburetted water gas (see also *Water gas*), 190, 227.
,, ,, Carbonic acid in, 205.
,, ,, Composition of, 213.
,, ,, Condensation of, 207.
,, ,, Impurities in, 212.
,, ,, plant, 201.
,, ,, plant, Influence of conditions of working of, 60, 201.
,, ,, process, Description of, 204.
,, ,, Purification of, 212.
,, ,, tar, 64, 208.
,, ,, Toxic action of, 216.
Carburetting (cold) of air and gas, 62, 219, 229.
,, ,, Materials available for, 64, 231.
,, ,, Plant for, 229, 232.
Carburettor of carburetted water-gas plant, 200, 202.
Carburine for enriching gas, 62, 231, 232.
Carius, estimation of sulphur and phosphorus, 17.
Carnot, A., amount of phosphorus in coal, 17.
Carpenter, C., scrubbers for coal gas, 143.
,, partitioned purifiers, 171.
Carr, J., Dinsmore process, 235.
Caucasian petroleum, see *Russian petroleum.*
Cellulose and its carbonization products, 4, 5, 116.
Chalk for lime burning, 153.
Chapman, A. C., arsenic in coal and coke, 25, 26.

Charcoal, 5.
Charge of coal, 95.
Charging coal-gas retorts, 94, 104, 114.
,, machines, 104.
Check purifiers, 182.
Chimney gases, Analysis of, 79, 80, 81.
,, Composition of, 73, 79, 80, 82.
,, Heat absorbed by, 73, 82.
,, Sampling of, 81.
Claus, C. F., purification of coal gas by liquor, 188.
Cleland's exhauster, 101.
Clinker in furnaces and generators, 87, 199.
Coal, Age of, 2, 4.
,, Analysis of, 16.
,, and cellulose, Relation between, 5.
,, Angle of repose of, 102.
,, Antimony in, 13.
,, Arsenic in, 13, 25, 26.
,, Ash of, 3, 4, 21, 38.
,, Caking, 11, 12, 13.
,, Cannel, see *Cannel.*
,, Carbon in, 16, 31.
,, Carbonization of, 69, 116, 118.
,, Characteristics of, 2.
,, Classes of, 11.
,, Composition of, 2, 3, 4, 16.
,, formation, Chemistry of, 3.
,, Hardness of, 4.
,, Hydrocarbons in, 120.
,, Hydrogen in, 3, 4, 16.
,, Hygroscopicity of, 3, 4.
,, Iron in, and its effect on distribution of sulphur, 24.
,, Mineral matter in, 3, 4, 21, 38.
,, Moisture in, 3, 4, 38.
,, Nitrogen in, 3, 4, 17, 124.
,, Non-caking, 13.
,, Origin of, 2.
,, Oxidation of, 28, 29, 117.
,, Oxygen in, 3, 4.
,, Paraffins in, 3.
,, Phosphorus in, 13, 17.
,, Pyrites in, 3.
,, Sampling of, 14.
,, Specific gravity of, 30, 38.
,, Spontaneous combustion of, 3.
,, Standard for comparative testings, 35.
,, substance, Composition of, 117.
Coal, Sulphur in, 3, 4, 17, 19, 24, 38, 126.
,, tar, see *Tar, Coal.*
,, testing, and results, 32, 35, 36, 37, 38.
,, Volatile matter in, 29, 31.
,, washing, 24.
Coal gas, 1, 66-189.
,, Ammonia in, 135, 136, 139, 140, 183.
,, Calorific power of, 132.
,, Carbon disulphide in, and its removal, 135, 139, 140, 150, 174, 178, 186.
,, Carbonic acid in, 135, 136, 137, 140, 149, 172.
,, Composition of, at different stages of manufacture, 116, 134, 135, 140, 183.
,, Cyanogen in, 124, 135, 136, 139, 140, 150, 163, 174, 184.
,, Hydrocarbons in, 135.
,, Hydrogen in, 135.
,, Illuminating power of, 38, 95.
,, Impurities in, 135, 137, 140, 183.
,, Nitrogen in, 124, 135.
,, Purification of, 140-189.
,, Quality and quantity from coal, 127.
,, retorts (see also *Retorts*), 66.
,, Scrubbing of, 140, 148.
,, Sulphur compounds in, 35, 135, 140, 149, 178, 183.
,, Sulphuretted hydrogen in, 135, 140, 149.
,, Washing of, 140.
,, Yield from coal, 38, 128.
Coefficient of expansion of petroleum, 48.
Coke (from coal), 25, 39.
,, ,, Arsenic in, 25, 26.
,, ,, Ash from, 23, 38, 41, 42.
,, ,, Conveyors for, 96, 102, 103.
,, ,, for firing retort furnaces, Quality of, 69, 89.
,, ,, for water gas manufacture, Quality of, 198.
,, ,, Moisture in, 38.
,, ,, Nitrogen, 17.

Coke (from coal), Quenching, 94, 96.
  ,, ,, Specific gravity of, 42.
  ,, ,, Sulphur in, 38, 41.
  ,, ,, Varieties of, 40.
  ,, ,, Yield from coal, 38.
  ,, (from cannel), 14, 137.
  ,, (from mineral oil), 224, 226.
  ,, (from peat), 8.
Coke-ovens, 40, 116.
Cold carburetting, see *Carburetting (cold)*.
Combustion, Analysis by, 16.
  ,, of Carbon, conditions and data, 71, 72, 74, 82.
Committees, Reports of, see *American Chemical Society, British Association, Home Office, Society of Chemical Industry, Society of Public Analysts.*
Compressed air power transmission for stoking machines, 106.
Condensation of carburetted water gas, 208.
  ,, of coal gas, 135.
Condenser, carburetted water-gas plant, 202, 207.
  ,, coal-gas plant, 97, 99.
Condenser-scrubber, 99.
Condensing surface, allowance for coal gas, 98.
Continuous carbonizers, 114.
  ,, water-gas system, 191.
Conveying trough for coke, 96.
Conveyors for coal and coke, 102, 103.
Cooper's coal-liming process, 125.
Coze, setting for inclined retorts, 102.
Crobaugh, F. L., phosphorus in coal and coke, 18.
Croissant, self-carburetting process, 131.
Cross and Bevan, cellulose and coal, 5, 116.
Crude coal gas, Composition of, 134.
Cutler & Sons, S., anti-freezing system for lutes, 244.
  ,, ,, carburetted water-gas plant, 215.
  ,, ,, condenser, 99.
Cyanogen in coal gas, and its extraction, 124, 135, 136, 139, 140, 150, 163, 174, 184.
Cyanogen produced on distillation of coal, 124.
Cyclohexanes, 56.
Cyclohexenes, 57.
Cymogene, 56.

D

Dartmoor lignite, 9.
Dead tar oils for gas making, 59.
De Brouwer charging machine, 111.
Dellwik-Fleischer water-gas plant, 211, 218.
Density, see *Specific gravity.*
Didier retort furnace, 68.
Dinas fireclays and bricks, 93.
Dinsmore, J., process for carbonizing tar, 235.
Diphenyl, Formation of, 122.
Dip-pipe, 96.
Direct combustion retort furnaces, 71, 73, 74, 75, 79, 81, 82.
Discharging machines, 104, 106, 110, 111, 113.
Distillation testings of petroleum, 49, 61.
Distributing pressure, 238.
Donath, E., caking coal, 12.
  ,, manganese dioxide, 164.
Donkin, E. B., exhausters, 101.
Drawing machines, 104, 106, 110, 111.
  ,, rake, 95.
  ,, retorts, 94, 95, 104, 106, 110.
Drown, I. S., iron in coal, 127.
Durham coal, 13, 38.
Dutch bog ore, 158.

E

Earth-oil, see *Petroleum.*
Economical Gas Apparatus Construction Co., water-gas plant, 215.
Efficiency of retort furnaces, 71, 81.
Egyptian petroleum, 45.
Eisenlohr, gas-making oils, 55.
Electrical power transmission for stoking machines, 111.
Empyreumatic oils from wood, 5.
Endothermicity of carbonization of coal, 132, 133.
Enriching materials and processes, 1, 13, 43, 62, 190, 220, 229, 235.

Eschka, sulphur in coal, 19.
Exeter gas works, Vertical retorts at, 115.
Exhausters, 100, 101.
  ,, Control of, 238.
Experimental plant for coal testing, 33.
Euchêne, calorific balance of carbonization of coal, 132.
  ,, retort furnaces, producers and settings, 81, 84, 85, 87, 90.

F

Fender for retort house stage, 96.
Ferric oxide and hydroxide, see *Oxide of iron.*
Ferrocyanide from coal gas, 163.
Fire-bars, Cooling, 78, 84, 87, 93, 202.
Firebricks and clays, 93.
Fixed carbon in coal, 31.
Flashing point of petroleum, 48.
Foster, W., carburine enrichment, 231.
  ,, nitrogen in products of distillation of coal, 124.
Foul main, 97.
Fouling of oxide, 161.
  ,, Weldon mud, 167.
Foulis-Arrol stoking machines, 110.
Fractionation of oil, 61.
Frankland, P., disilluminating effect of carbonic acid, 138.
Freezing of gasholder lutes, Prevention of, 244.
Fresenius, estimation of carbonate in lime, 153.
Furnace, see *Retort furnace.*

G

Galician petroleum, 45, 46, 56.
Gas analysis apparatus, 81.
  ,, Carburetted water, see *Carburetted water gas.*
  ,, coke, see *Coke.*
  ,, Coal, see *Coal gas.*
  ,, Lighting Improvement Co., carburetting plant, 229.
  ,, Lignite (see also *Lignite*), 10.
  ,, liquor, see *Liquor.*
Gas, Natural, see *Natural gas.*
  ,, Oil, see *Oil gas.*
  ,, Peat, see *Peat gas.*
  ,, Wood, see *Wood gas.*
Gaseous fuel, advantages for retort firing, 91.
Gasholder, and its structural parts, 240-243.
Gasolene, 54.
German brown coals, 10.
  ,, petroleum, 44, 46.
Generator, see *Carburetted water-gas plant, Producer.*
Glover, S., mixed coal-oil gas, 227.
Governors, 238.
Green coal-tar oil for gas making, 59.
Grein, charging machine, 111.
Greville, H. L., enriching value of petroleum spirit, 232.
Grids for purifiers, 168, 170, 171.
Grosny petroleum, 46.
Guides of gasholders, 241, 243.

H

Haber, decomposition of hexane, 120.
Haldane, J. S., absorption tube, 154.
  ,, toxicity of carbonic oxide, 216.
Hanover petroleum, 45.
Hasse-Didier retort furnace, 69.
Heat balance for producer, 88.
  ,, ,, carbonization of coal, 131.
  ,, for carbonization of coal, 39, 128.
  ,, loss of (see also *Loss of heat*), 82.
Heathfield natural gas, 44.
Heinrich, volatile matter and fixed carbon in coal, 31.
Heptane, 63, 231.
Herring, W. H., oxy-oil gas, 225.
Hexane, 63, 231.
  ,, Decomposition of, 120, 121.
Hirzel, standard gas oil, 60.
Hislop, reburning spent lime, 151.
  ,, retort setting, 69.
  ,, test of washer-scrubber, 148.
Holmes & Co., W. C., carburetted water-gas plant, 215.
  ,, ,, Pelouze tar extractor, 142.

Holmes & Co., W. C., washer-scrubber, 146.
Home Office Committee on water gas, 217.
Hood and Salamon, lime in purification, 186.
  ,, Weldon mud, 164.
Hopper for water-gas generators, 206.
Horizontal retorts, see *Retorts, Horizontal.*
Humphreys & Glasgow, carburetted water-gas plant, 215.
Hungarian lignite, 10.
  ,, petroleum, 45.
Hunt, C., enriching value of benzene and carburine, 234.
  ,, purification of coal gas by liquor, 188.
Hydraulic main, 95-97.
Hydrocarbon from oil gas, 63, 221.
  ,, vapours for enriching gas, 227.
Hydrocarbons, 1, 56, 120, 122.
  ,, in carburetted water gas, 214.
  ,, in coal, 120.
  ,, in coal gas, 135, 136.
  ,, in oil gas, 54.
  ,, in petroleum, 55-57.
Hydrocyanic acid (see also *Cyanogen*), 156.
Hydrogen, effect on yield of ammonia from coal, 125.
  ,, in carburetted water gas, 214.
  ,, in coal, 3, 4, 16.
  ,, in coal gas, 135, 136.
Hydrogenized water gas, 215.

I

Illuminating Power"—
  Depreciation by carbonic acid, 138.
    ,, condensation, 99, 100.
    ,, nitrogen, 138.
    ,, washing, 143.
  Of carburetted water gas, 213, 214.
  Of coal gas, 38, 95.
  Of oil gas, 221-226.
  Of "self-carburetted" gas, 130.
Illinois petroleum, 44.
Impurities in carburetted water gas, 212.
Impurities in coal gas, 137, 183.
Inclined retorts, 101-104.
Indian petroleum, 45.
Indiana petroleum, 44.
Intermittent water-gas system, 191, 192.
Irish bog ore, 158.
  ,, peat, 8.
Iron carbonyl in water gas, 217.
  ,, in coal, 24.
  ,, in oxide of iron, 158.
Irminger, wood gas, 4.
Isbell, vertical retort, 116.

J

Jager's purifiers, 171.
Japanese petroleum, 45, 46.
Jouanne, carbonization of coal in current of steam, 130.
Jute, 5.

K

Keith, oil-gas plant, 222.
Kendal, Washer-scrubber at, 148.
Kentucky petroleum, 44.
Kirkham, Hulett & Chandler, washer-scrubber, 144.
Kjeldahl, estimation of nitrogen, 17.
Klönne, retort furnace, 69.
Körting, exhauster, 101.
Kramers, water-gas plant, 212.

L

Lacey, T. S., on light oils for carburetting, 64.
Laming, retort furnace, 68.
La Villette (Paris), stoking machines, 113.
Lead (acetate of) test paper, 183.
Le Chatelier pyrometer, 52.
Lecomte, self-carburetting process, 130.
Lesmahagow cannel, 36, 38.
Levelling plate for inclined retorts, 103.
Lewes, V. B., effect of carbonic acid and nitrogen on illuminating power of gas, 138.
  ,, self-carburetting process, 130.

Lid, see *Retort lid.*
Liegel retort furnace, 68.
Light oils deposited from carburetted water gas, 64, 208.
,, for cold carburetting, 62.
Lightships, Oil gas for, 221.
Lignite, Characteristics and constituents of, 3, 4, 9, 10.
,, Gas from, 10.
,, Tar from, 10.
Ligroin, 63.
Lima petroleum, 44, 47.
Lime, Analysis and testing of, 150, 153, 156.
,, burning, 150.
,, Data relating to, 151.
,, Impurities absorbed by, 174.
,, Mixing, with coal for carbonization, 125.
,, Purification by, 149, 150, 173, 182.
,, Slaking of, 151.
,, Spent, see *Spent lime.*
,, Storage of, 151.
,, Testing reburnt, 154.
Liquor (gas or ammoniacal), Constituents of, 28, 140.
,, Purification of gas by, 187.
,, Standard strength of, 36, 38.
,, Yield from coal, 38.
Lishman, G. P., testing of coal, 20, 35.
Loss of heat from furnaces, &c., Sources of, 73, 76, 82, 87.
,, petroleum on distillation, 50, 61.
Lowe carburetted water-gas plant, 192, 201.
Lubricating oils, 55, 101.
Lutes of purifiers, gasholders, &c., 169, 172, 242, 244.

M

Machine stokers, see *Stoking machinery.*
Mahler, P., calorific balance of carbonization of coal, 132.
Manchester, Stoking machines at, 107.
Manganese dioxide, 164, 165.
Mantle illumination, 138, 217, 218.
Manual stoking machines, 106.
Mariendorf gas works, Inclined retorts at, 104.
Markownikoff, Russian petroleum, 45, 46.
Masut, 54.
Maxim carburetting plant, 229.
Meade, R. K., volatile matter in coal, 32.
Mechanical stokers, see *Stoking machinery.*
Meeze, A. G., oil-gas plant, 223.
Merrifield-Westcott-Pearson carburetted water-gas plant, 215.
Meters, Gas, 236.
Methane in gas, 135, 136, 214.
Mexican petroleum, 45.
M'Ilhiney, bromine absorption, 58.
Mills, E. J., theory of coal distillation, 123.
Mills and Snodgrass, bromine absorption, 58.
Mineral matter in coal (see also *Ash*), 3.
,, oil, see *Petroleum.*
Mixed gas (coal gas + water gas), 130, 131, 218.
Moisture in air supply to furnaces, producers, &c., 76, 79, 84.
,, anthracite, 4.
,, coal and coke, 3, 4, 28, 29, 38.
,, lignite, 4, 10.
,, oxide of iron, 160, 161.
,, peat, 7.
,, petroleum, 51.
,, Weldon mud, 165, 167.
,, wood, 5.
Mond gas producer, Yield of ammonia in, 125.
Morton, self-sealing retort lid, 67.
Motor spirit, 63.
Mouthpiece (see also *Retort mouthpiece*), 67.
Muck, Coal, 117.
Munich cold carburetting plant, 233.

N

Nakamura, sulphur in coal, 19.
Naphthenes, 56.
Naphthalene, Data concerning, 64, 65.
,, in gas, 99, 121, 122, 135, 136, 140.
Naphthylenes, 57.
Natural gas, 44.
"New" washer-scrubber, 146.

Newcastle fireclays, 93.
Nitrogen in carburetted water gas, 214.
,, coal, 3, 4, 17, 123, 124.
,, coal gas, 124, 135, 136, 137.
,, coke, 17, 124.
Non-caking coal, see *Coal, Non-caking.*

O

Ohio petroleum, 44, 45.
Oil (mineral), see *Petroleum.*
,, coke, 224, 226.
,, gas, 1, 54, 220-228.
,, ,, burners, 221, 223,
,, ,, Hydrocarbons in, 54, 227.
,, heater of carburetted water-gas plant, 202, 207.
,, (shale), see *Shale oil.*
,, tar, 59, 62, 221.
Olefine hydrocarbons, 57, 122.
Ontario petroleum, 45.
Oxide of iron, absorbent of hydrocyanic acid, 185.
,, ,, sulphuretted hydrogen, 156, 157.
,, Analysis of, 158, 160, 161.
,, characteristics and use for purification, 149, 161, 175, 182.
,, Fouling of, 161.
,, Fouled, 162.
,, Hydrated, 157.
,, Purification by, 149, 161, 175, 182.
,, Quality of, 158.
,, Revivification of, 161, 162, 175, 176.
,, Spent, 163.
Oxygen, admixture with coal gas, 224.
,, ,, oil gas, 223.
,, for making non-nitrogenous semi-water gas, 192.
,, in coal, 3, 4.
,, use in purification, 177, 186.
Oxygenated bodies in coal, 122.
Oxy-oil gas, 223.
Oven, see *Retort oven.*
Oven coke, 40.

P

Paisley, Washer-scrubber at, 148.
Paraffin hydrocarbons, Behaviour of, 56, 120.
,, ,, in coal, 3.
Peat briquettes, 7.
,, Carbonization of, 8.
,, Characteristics and constituents of, 4, 7, 8.
,, Coke from, 8.
,, gas, 8, 9.
,, Tar from, 8, 9.
Peebles oil-gas plant and process, 225.
Pelouze and Audouin tar extractor, 142.
Pennsylvanian anthracite, 40.
,, petroleum, 44, 45, 46, 56, 62.
Pensky-Martens flashing point apparatus, 49.
Pentane, 63.
Persian petroleum, 45.
Peruvian petroleum, 45, 46.
Petrol, 63.
Petroleum, Bromine absorption of, 59.
,, Characteristics and constituents of, 43, 44, 45.
,, Coefficient of expansion of, 48.
,, ether, 63.
,, Flashing point of, 48.
,, Gas making varieties of, 47, 51, 54, 55, 56, 61.
,, Sources of, 43, 44, 58.
,, Specific gravity determination of, 47.
,, spirit, 62, 231.
,, standard type of gas-making oil, 54, 60.
,, Sulphur in, 51.
,, testing and its results, 47, 49, 50, 51, 53, 54, 60, 61, 62.
,, Water in, 51.
Phenanthrene, 122.
Phosphorus in coal, 13, 17.
Pintsch, oil-gas plant, 220.
Pope, oil-gas plant, 222.
Potassium ferricyanide as an indicator, 159.

"Pounds of sperm," 35, 38, 62.
Pressure changer, Automatic, 240.
Pressure of gas, holder, 242.
 ,, in purifiers, 171.
 ,, in retorts, 95, 129.
 ,, Regulation of, 238.
Price, cold carburetting plant, 232.
Producer for retort firing, 69, 83, 84.
 ,, ,, Heat balance for, 88.
 ,, ,, Moisture in air supply to, 84, 87.
 ,, gas, 72, 83, 85, 86, 208.
Products of combustion, 71-73, 79-82.
Projecting charging machines, 111, 113.
Prussian blue, 163.
Purification of carburetted water gas, 212.
 ,, coal gas, Systems of, 140, 172, 183, 186, 187.
 ,, coal gas, wet process, 168, 187.
Purifier-house, 170.
Purifiers, 168, 169.
 ,, area required, 172.
 ,, Pressure within, 171.
 ,, Rate of flow of gas through, 172.
 ,, Smell from, 186.
Purifying materials, 168.
 ,, vessels, see *Purifiers*.
Pyrites in coal, 3.
Pyroligneous acid from wood, 5.
Pyrometers, 52.

Q

QUENCHING coke, 94, 96.

R

RAILWAY carriages, Oil gas for lighting, 221.
Rake for drawing retorts, 95.
Ram discharging machine, 113.
Ramella, rotary engine, 100.
Ramsay, decomposition of ammonia, 125.
"Rapid" manual charging machine, 106.
Raw materials of gas manufacture, 1.
Recuperation applied to retort furnaces, 68, 73, 89, 91.
 ,, Alternating system of, 68, 89.
 ,, Continuous system of, 68, 90.
Recuperative furnaces and settings, 68, 93.
Regeneration, see *Recuperation*.
Regenerative, see *Recuperative*.
Remscheid, Self-carburetting process at, 130.
Residue, petroleum, 50, 61.
Resinous constituents of coal, 117.
Retort (coal gas), 66, 68.
 ,, carbon, 133.
 ,, furnace, 68, 69, 82, 86, 104.
 ,, ,, direct combustion, 71, 73, 74, 75, 79, 81, 82.
 ,, ,, Efficiency of, 71, 81.
 ,, ,, Recuperative, 68, 73, 89.
 ,, ,, Semi-producer, 82.
 ,, heating, Conditions and temperature of, 91, 119.
 ,, Horizontal, charging and drawing, 94.
 ,, Inclined, 101.
 ,, lid, 67.
 ,, mouthpiece, 67.
 ,, oven, 68.
 ,, Revolving, 115.
 ,, stack, 93.
 ,, Vertical, 115.
 ,, (oil gas), 220.
Revivification of oxide of iron, 161, 162, 175.
 ,, Weldon mud, 177.
Revolving retort, 115.
Rhigolene, 62.
Riché wood gas, 6.
Ries and Schilling, enriching by benzol, 233.
Rope-guided gasholders, 243.
Roumanian petroleum, 45, 46.
"Runs" in water-gas process, 196.
Ruscoe, charging machine, 110.
Russian petroleum, 44, 45, 47, 54, 55, 61, 220.

S

SADDLE used in charging retorts, 94.
Sampling chimney gases, 81.

Sampling coal, 14.
  ,, water gas, 205.
Saturation limit of gas with hydrocarbon vapours, 64.
Sawdust mixed with oxide, 161.
Saxony gas oils, 47, 55.
Scheibler, calcimeter, 156.
Schilling, E., ammonia in coal gas, 124.
Schilling and Bunte, retort furnace, 69.
Schmidt, nitrogen in coal and coke, 17.
Scoop, Charging, 94.
  ,, driver, 95.
Scotch shale oil, 47, 55, 220.
Scrubber, Carburetted water-gas, 202, 207.
  ,, Coal-gas, 140, 142, 144.
  ,, ,, area required, 143.
Scurf (Retort-), 43, 133.
Seal in hydraulic main, Depth of, 95, 97.
  ,, of purifiers, 169, 172.
Self-carburetting process, 130, 218, 219, 236.
Semi-producer retort furnaces, 82.
  ,, water gas, 126.
  ,, ,, Non-nitrogenous, 192.
Settle and Padfield retort, 115.
Shale oils, 47, 55, 59, 62.
Siemens' regenerative retort furnace, 68, 84.
Sight cocks on water-gas plant, 207.
Silkstone coal, 38.
Smith, Watson, nitrogen in coal tar, 124.
  ,, paraffins in coal, 3.
Smythe, J. A., substance of coal, 117.
Society of Chemical Industry, Committee on arsenic in coal and coke, 25.
  ,, Public Analysts, Committee on arsenic in coal and coke, 25.
Solar oil, 54, 55, 56, 61, 62.
Southall, Water gas at, 206.
Specific gravity of coal, 30, 38.
  ,, ,, coke, 42.
  ,, ,, peat, 7.
  ,, ,, petroleum, 47.
  ,, heat of carbon, 194.
  ,, ,, carbonic acid, 138, 195.
  ,, ,, carbonic oxide, 195.
  ,, ,, nitrogen, 138.
  ,, ,, water, 194.
Spent lime, 151, 174.
Spent oxide, 163.
"Sperm, Pounds of," 35, 37, 38, 39.
  ,, standard candle, 35, 37.
Spontaneous combustion of coal, 3.
Springer carburetted water-gas plant, 214.
Stack valve of carburetted water-gas plant, 202.
Standard candle, 35, 37.
  ,, coal for comparative testings, 35.
  ,, gas oil (petroleum), 54, 60.
  ,, washer-scrubber, 144.
Steam in carbonization of coal, 125, 130.
  ,, furnace, Undecomposed, 86.
  ,, oil gas manufacture, 222.
  ,, water gas manufacture, 196, 205.
Steam interaction with carbon, 84.
Stelfox, J., purification of coal gas by liquor, 188.
Stock, W. F. K., phosphorus in coal and coke, 18.
  ,, sulphur in coke, 41.
Stokes, reburning spent lime, 152.
Stoking machinery, 101, 104, 110.
Stolba, F., sulphur in coal and coke, 21, 41.
Stops for inclined retorts, 103.
Stourbridge fireclays and bricks, 93.
Strache, H., purification of water gas, 218.
Styrian lignite, 10.
Sulphate of ammonia, 126.
Sulphide purifiers, 177, 180, 181.
Sulphided lime, 179.
Sulphocyanide from coal gas, 163.
Sulphur dioxide, Estimation of, 42.
  ,, compounds in carburetted water gas, 212.
  ,, in coal, 3, 4, 12, 17, 19, 24, 38.
  ,, ,, gas, 35, 127, 135, 136, 139, 140, 149, 178, 183.
  ,, in coke, 38, 41.
  ,, ,, coke-ash, 42.
  ,, ,, fouled and spent oxide of iron, 162, 163.
  ,, ,, Weldon mud, 168.
  ,, ,, petroleum, 51.
  ,, products from distillation of coal, 126.

Sulphuretted hydrogen, absorption by lime, 149, 182, 184.
,, ,, absorption by oxide of iron, 155.
,, ,, absorption by Weldon mud, 168.
,, ,, from coal, 126.
,, ,, in carburetted water gas, 212.
,, ,, in coal gas, 135, 136, 139, 140, 149, 175, 184.
,, ,, in gas, Testing of, 183, 213.
,, ,, in gas liquor, 141.
Superheater of carburetted water-gas plant, 202.

T

Tar, Cannel, 137.
,, Carburetted water gas, 202, 208.
,, Coal, 97, 132, 136, 142, 148.
,, ,, Carbonization of, 59, 235.
,, extractor, Coal-gas plant, 141.
,, ,, Carburetted water-gas plant, 202.
,, Lignite, 10.
,, Oil, 221.
,, Peat, 8, 9.
Tatham oil-gas plant and process, 223.
Telescopic gasholder, 244.
Temperature of coal-gas retorts, Proper, 119, 128.
Tessié du Motay water-gas plant, 192.
Testing, see the material concerned, e.g., *Coal*, *Petroleum*, &c.
Texas petroleum, 44, 45, 46, 56.
Thénius on carbonization of coal in steam, 130.
Thermometers for oil testing, 51.
Thomas, J. W., coal, 3, 4.
Thuringian gas oil, 47, 55.
Time required for carbonizing coal, 95.
Toluene, 63.
Tower scrubbers, 142.

U

United States, Natural gas in, 44.
,, Petroleum in, 44, 46, 56.

V

Valon, retort furnace, 68.
,, oxygen in purification, 187.
Van Steenburg carburetted water-gas plant, 215.
Vapour tensions of hydrocarbons, 64.
Veevers, oxygen in purification, 177.
Vegetable oils for gas making, 59.
Veley, V. H., active material of sulphide purifiers, 180.
Vertical retorts, 115.
Vienna gas works, Inclined retorts at, 103, 104.
Virginian petroleum, 44.
Volatile matter in coal, 29, 31.

W

Walker, C. & W., tar extractor, 143.
Washer, 143.
,, scrubber, 142-146, 148.
Washing coal gas, 140, 143.
Water in materials, see *Moisture*.
,, amount used in scrubbers, 148.
,, -cooled condenser, 99.
,, Specific heat of, 194.
Water gas, carburetted, see *Carburetted water gas*.
,, simple (or uncarburetted), 1, 190, 193, 197.
,, ,, Cold carburetting of, 219.
,, ,, generator, 198.
,, ,, manufacture, Fuel for, 1, 39, 41, 198.
,, ,, manufacture, operations, and processes, 191, 196, 205, 208.
,, ,, passage through coal-gas retorts, 130.
,, ,, reactions, 39, 191, 192, 193, 195, 197.
,, ,, toxic action of, 216.

LIBRARY OF THE UNIVERSITY OF CALIFORNIA

Water gas, simple, Uses of, 216, 217.

Watts, C. W., purification of coal gas by liquor, 188.

Weldon mud, composition and preparation, 160, 164, 165, 166, 177, 178.
  ,, Purification by use of, 150, 167, 168, 177, 182.
  ,, Sampling of, 165.
  ,, spent, Sulphur in, 168.

Welsh anthracite, 40.

West's stoking machinery, 106, 107.

Widnes, Dinsmore process at, 235.

Winckler, C., ammonia in coke oven gas, 125.

Wood, Composition and characteristics of, 4, 5.
  ,, Destructive distillation of, 5.
  ,, gas, 5, 6.
  ,, spirit, 5.

Woodward and Crossley, stoking machinery, 110.

Wright, L. T., active material of sulphide purifiers, 180.
  ,, ammonia in coal gas, 124.
  ,, enriching value of benzol, 234.
  ,, "New" washer-scrubber, 148.
  ,, purification of coal gas by liquor, 188.
  ,, sulphur in coal gas, 127.
  ,, tar for gas making, 236.
  ,, volatile matter in coal, 31.

Wyoming petroleum, 44.

Wyss, O., toxicity of water gas, 216.

X

Xylenes, 63.

Y

Yeadon and Adgie, revolving tort, 115.
  ,, reburning spent lime, 153.

Young and Bell, oil gas manufacture, 225.
  ,, carburetted water gas, 227.

Z

Zinc as a reducing agent, 158.

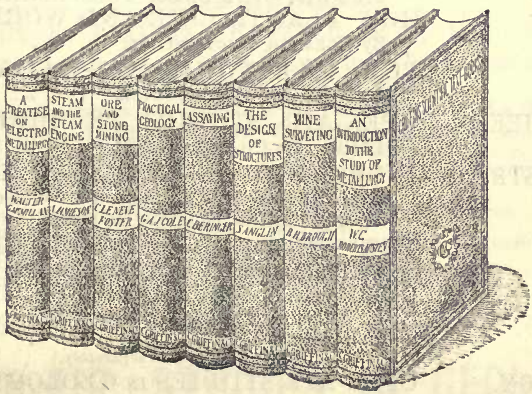
BELL AND BAIN, LIMITED, PRINTERS, GLASGOW.

A SELECTION FROM

CHARLES GRIFFIN & CO.'S PUBLICATIONS

OF

SCIENTIFIC AND TECHNICAL WORKS.



MESSRS. CHARLES GRIFFIN & COMPANY'S PUBLICATIONS may be obtained through any Bookseller in the United Kingdom, or will be sent Post-free on receipt of a remittance to cover published price. To prevent delay, Orders should be accompanied by a Cheque or Postal Order crossed "UNION OF LONDON AND SMITH'S BANK, Chancery Lane Branch."

☞ **COMPLETE TECHNICAL, MEDICAL, and GENERAL CATALOGUES forwarded Post-free on Application.**

LONDON:
EXETER STREET, STRAND.

1/2/05.
C. 32.

GRIFFIN'S INTRODUCTORY SCIENCE SERIES.

FULLY ILLUSTRATED.

BOTANY.	OPEN-AIR STUDIES IN BOTANY. By R. Lloyd Praeger, B.A., M.R.I.A.,	7/6
	THE FLOWERING PLANT. By Prof. Ainsworth Davis. Third Edition,	3/6
	HOW PLANTS LIVE AND WORK. By Eleanor Hughes-Gibb,	2/6
	THE MAKING OF A DAISY. By Eleanor Hughes-Gibb,	2/6
BIRD-LIFE.	OPEN-AIR STUDIES IN BIRD-LIFE. By Charles Dixon,	7/6
CHEMISTRY.	INORGANIC CHEMISTRY. By Prof. Dupré, F.R.S., and Dr. Wilson Hake. Third Edition, Re-issued,	6/ net.
	THE THRESHOLD OF SCIENCE. By Dr. Alder Wright. Second Edition,	6/
	CHEMICAL RECREATIONS. By J. J. Griffin, F.C.S. Tenth Edition, Complete, (Or in 2 parts, sold separately.)	12/6
GEOLOGY.	OPEN-AIR STUDIES IN GEOLOGY. By Prof. G. A. J. Cole, F.G.S., M.R.I.A. Second Edition,	8/6
ENGINEERING DRAWING.	I. PRACTICAL GEOMETRY, Fourth Edition,	4/6
	II. MACHINE DESIGN, Fourth Edition. By Principal S. H. Wells, A.M.Inst.C.E.	4/6
MAGNETISM & ELECTRICITY.	By Prof. Jamieson, late of the Glasgow and West of Scotland Technical College. Fifth Edition,	3/6
MECHANICS.	By Prof. Jamieson. Sixth Edition,	3/6
THE STEAM ENGINE.	By Prof. Jamieson. Tenth Edition,	3/6
METALLURGY.	By Prof. Humboldt Sexton, Glasgow and West of Scotland Technical College. Third Edition, Revised,	6/
PHYSICS.	A TEXT-BOOK OF PHYSICS: By J. H. Poynting, Sc.D., F.R.S., and J. J. Thomson, M.A., F.R.S. Vol. I.—Properties of Matter. Second Edition,	10/6
	Vol. II.—Sound (Third Edition),	8/6
PHOTOGRAPHY.	By A. Brothers, F.R.A.S. Second Edition,	21/

"Boys COULD NOT HAVE A MORE ALLURING INTRODUCTION to scientific pursuits than these charming-looking volumes."—Letter to the Publishers from the Headmaster of one of our great Public Schools.

Handsome Cloth, 7s. 6d. Gilt, for Presentation, 8s. 6d.

OPEN-AIR STUDIES IN BOTANY:

SKETCHES OF BRITISH WILD FLOWERS IN THEIR HOMES.

BY R. LLOYD PRAEGER, B.A., M.R.I.A.

Illustrated by Drawings from Nature by S. Rosamond Praeger, and Photographs by R. Welch.

GENERAL CONTENTS.—A Daisy-Starred Pasture—Under the Hawthorns—By the River—Along the Shingle—A Fragrant Hedgerow—A Connemara Bog—Where the Samphire grows—A Flowery Meadow—Among the Corn (a Study in Weeds)—In the Home of the Alpines—A City Rubbish-Heap—Glossary.

"A FRESH AND STIMULATING book . . . should take a high place . . . The Illustrations are drawn with much skill."—*The Times.*

"BEAUTIFULLY ILLUSTRATED. . . . One of the MOST ACCURATE as well as INTERESTING books of the kind we have seen."—*Athenæum.*

"Redolent with the scent of woodland and meadow."—*The Standard.*

With 12 Full-Page Illustrations from Photographs. Cloth.
Second Edition, Revised. 8s. 6d.

OPEN-AIR STUDIES IN GEOLOGY:

An Introduction to Geology Out-of-doors.

BY GRENVILLE A. J. COLE, F.G.S., M.R.I.A.,

Professor of Geology in the Royal College of Science for Ireland,
and Examiner in the University of London.

GENERAL CONTENTS.—The Materials of the Earth—A Mountain Hollow—Down the Valley—Along the Shore—Across the Plains—Dead Volcanoes—A Granite Highland—The Annals of the Earth—The Surrey Hills—The Folds of the Mountains.

"The FASCINATING 'OPEN-AIR STUDIES' of PROF. COLE give the subject a GLOW OF ANIMATION . . . cannot fail to arouse keen interest in geology."—*Geological Magazine.*

"A CHARMING BOOK, beautifully illustrated."—*Athenæum.*

Beautifully Illustrated. With a Frontispiece in Colours, and Numerous Specially Drawn Plates by Charles Whymper. 7s. 6d.

OPEN-AIR STUDIES IN BIRD-LIFE:

SKETCHES OF BRITISH BIRDS IN THEIR HAUNTS.

BY CHARLES DIXON.

The Spacious Air.—The Open Fields and Downs.—In the Hedgerows.—On Open Heath and Moor.—On the Mountains.—Amongst the Evergreens.—Copse and Woodland.—By Stream and Pool.—The Sandy Wastes and Mud-flats.—Sea-laved Rocks.—Birds of the Cities.—INDEX.

'Enriched with excellent illustrations. A welcome addition to all libraries."—*Westminster Review.*

THIRD EDITION, Revised and Enlarged. Large Crown 8vo, with numerous Illustrations. 3s. 6d.

THE FLOWERING PLANT,

WITH A SUPPLEMENTARY CHAPTER ON FERNS AND MOSSES,

As Illustrating the First Principles of Botany.

BY J. R. AINSWORTH DAVIS, M.A., F.Z.S.,

Prof. of Biology, University College. Aberystwyth; Examiner in Zoology, University of Aberdeen.

"It would be hard to find a Text-book which would better guide the student to an accurate knowledge of modern discoveries in Botany. . . . The SCIENTIFIC ACCURACY of statement, and the concise exposition of FIRST PRINCIPLES make it valuable for educational purposes. In the chapter on the Physiology of Flowers, an *admirable résumé*, drawn from Darwin, Hermann Müller, Kerner, and Lubbock, of what is known of the Fertilization of Flowers, is given."—*Journal of Botany*.

POPULAR WORKS ON BOTANY BY MRS. HUGHES-GIBB.

With Illustrations. Crown 8vo. Cloth. 2s. 6d.

HOW PLANTS LIVE AND WORK:

A Simple Introduction to Real Life in the Plant-world, Based on Lessons originally given to Country Children.

BY ELEANOR HUGHES-GIBB.

⁂ The attention of all interested in the Scientific Training of the Young is requested to this DELIGHTFULLY FRESH and CHARMING LITTLE BOOK. It ought to be in the hands of every Mother and Teacher throughout the land.

"The child's attention is first secured, and then, in language SIMPLE, YET SCIENTIFICALLY ACCURATE, the first lessons in plant-life are set before it."—*Natural Science.*

"In every way well calculated to make the study of Botany ATTRACTIVE to the young."—*Scotsman*

With Illustrations. Crown 8vo. Gilt, 2s. 6d.

THE MAKING OF A DAISY;

"WHEAT OUT OF LILIES;"

And other Studies from the Plant World.

A Popular Introduction to Botany.

BY ELEANOR HUGHES-GIBB,

Author of *How Plants Live and Work.*

"A BRIGHT little introduction to the study of Flowers."—*Journal of Botany.*

"The book will afford real assistance to those who can derive pleasure from the study of Nature in the open. . . . The literary style is commendable."—*Knowledge.*

LONDON: CHARLES GRIFFIN & CO., LIMITED, EXETER STREET, STRAND.

Griffin's Standard Publications

FOR

ENGINEERS, ELECTRICIANS, ARCHITECTS, BUILDERS, NAVAL CONSTRUCTORS, AND SURVEYORS.

		PAGE
Applied Mechanics, .	RANKINE, BROWNE, JAMIESON, 35, 47,	34
Civil Engineering, . .	PROF. RANKINE, .	35
Design of Structures, .	S. ANGLIN, . . .	26
Bridge-Construction, .	PROF. FIDLER, . .	26
Dock Engineering, .	B. CUNNINGHAM, .	27
Engineering Drawing, .	S. H. WELLS, . .	27
Central Electrical Stations,	C. H. WORDINGHAM, .	49
Electricity Control, .	L. ANDREWS, . .	49
Light Railways, . .	W. H. COLE, . .	30
Sewage Disposal Works,	SANTO CRIMP, . .	48
Traverse Tables, . .	R. L. GURDEN, . .	33
Electrical Tramways, .	PROF. A. JAMIESON, .	34
Locomotive Engineering,	W. F. PETTIGREW, .	30
Valves and Valve-Gearing,	CHAS. HURST, . .	31
Hints on Design, . .	CHAS. HURST, . .	31
Marine Engineering, .	A. E. SEATON, . .	45
Engine-Room Practice,	J. G. LIVERSIDGE, .	29
Pocket-Book, . . .	SEATON AND ROUNTHWAITE,	45
Design of Ships, . .	PROF. HARVARD BILES,	38
Steel Vessels, . .	T. WALTON, . .	38
Stability of Ships, .	SIR E. J. REED, .	38
Nautical Series, . .	Ed. by CAPT. BLACKMORE,	39
The Steam-Engine, .	RANKINE, JAMIESON, . 35,	34
Gas, Oil, and Air-Engines,	BRYAN DONKIN,	28
Gas and Oil Engines, .	PROF. WATKINSON,	29
Boilers: Land and Marine,	T. W. TRAILL, . .	29
,, Steam, . .	R. D. MUNRO, . .	32
,, Kitchen, . .	R. D. MUNRO, . .	32
,, Heat Efficiency of,	BRYAN DONKIN, . .	28
Oil Fuel, ...	SIDNEY H. NORTH, .	29
Fuel and Water, . .	W. R. BROWNE, . .	47
Machinery and Millwork,	PROF. RANKINE, .	35
Pumping Machinery, .	H. DAVEY, . . .	37
Hydraulic Machinery, .	PROF. ROBINSON, .	37
Grinding Machinery, .	R. B. HODGSON, . .	33
Lubrication and Lubricants,	ARCHBUTT & DEELEY,	32
Rules and Tables, . .	RANKINE AND JAMIESON,	36
Bonus Tables, . .	H. A. GOLDING, . .	31
Electrical Pocket-Book,	MUNRO AND JAMIESON,	49
Electrical Price-Book, .	H. J. DOWSING, . .	31
The Calculus for Engineers,	PROF. ROBT. H. SMITH,	46
Measurement Conversions,	PROF. ROBT. H. SMITH,	46
Chemistry for Engineers,	BLOUNT & BLOXAM,	47

THIRD EDITION, *Revised, with an Additional Chapter on Foundations. Numerous Diagrams, Examples, and Tables. Large 8vo. Cloth.* 16*s.*

THE DESIGN OF STRUCTURES:

A Practical Treatise on the Building of Bridges, Roofs, &c.

BY S. ANGLIN, C.E.,

Master of Engineering, Royal University of Ireland, late Whitworth Scholar, &c.

"Students of Engineering will find this Text-Book INVALUABLE."—*Architect.*

"The author has certainly succeeded in producing a THOROUGHLY PRACTICAL Text-Book."—*Builder.*

"We can unhesitatingly recommend this work not only to the Student, as the BEST TEXT-BOOK on the subject, but also to the professional engineer as an EXCEEDINGLY VALUABLE book of reference."—*Mechanical World.*

THIRD EDITION, *Thoroughly Revised. Royal 8vo. With numerous Illustrations and* 13 *Lithographic Plates. Handsome Cloth. Price* 30*s.*

A PRACTICAL TREATISE ON BRIDGE-CONSTRUCTION:

Being a Text-Book on the Construction of Bridges in Iron and Steel.

FOR THE USE OF STUDENTS, DRAUGHTSMEN, AND ENGINEERS.

BY T. CLAXTON FIDLER, M. INST. C. E.,

Prof. of Engineering, University College, Dundee.

GENERAL CONTENTS.—PART I.—Elementary Statics. PART II.—General Principles of Bridge-Construction. PART III.—The Strength of Materials. PART IV.—The Design of Bridges in Detail.

"The new edition of Mr. Fidler's work will again occupy the same CONSPICUOUS POSITION among professional text-books and treatises as has been accorded to its predecessors. The instruction imparted is SOUND, SIMPLE, AND FULL. The volume will be found valuable and useful alike to those who may wish to study only the theoretical principles enunciated, and . . . to others whose object and business is . . . practical."—*The Engineer.*

In Large 8vo. Handsome Cloth, Gilt, Uniform with *Stability of Ships* and *Steel Ships* (p. 38). With 34 Folding Plates and 468 Illustrations in the Text. 30s. net.

The Principles and Practice of
DOCK ENGINEERING.

By BRYSSON CUNNINGHAM, B.E., Assoc.M.Inst.C.E.,
Of the Engineers' Department, Mersey Docks and Harbour Board.

GENERAL CONTENTS.

Historical and Discursive.—Dock Design.—Constructive Appliances.—Materials.—Dock and Quay Walls.—Entrance Passages and Locks.—Jetties, Wharves, and Piers.—Dock Gates and Caissons.—Transit Sheds and Warehouses.—Dock Bridges.—Graving and Repairing Docks.—Working Equipment of Docks.—Index.

"Will be found indispensable to all whose business leads them to deal with docks or dock matters. The Author has spared no pains to treat the subject exhaustively. We have never seen a more profusely-illustrated treatise. It is a most important standard work, and should be in the hands of all dock and harbour engineers."—*Steamship.*

"Will be of the greatest service to the expert as a book of reference."—*Engineer.*

Fourth Edition. In Two Parts, Published Separately.

A TEXT-BOOK OF
Engineering Drawing and Design

Vol. I.—Practical Geometry, Plane, and Solid. 4s. 6d.

Vol. II.—Machine and Engine Drawing and Design. 4s. 6d.

BY
SIDNEY H. WELLS, Wh.Sc.,
A.M.Inst.C.E., A.M.Inst.Mech.E.,
Principal of the Battersea Polytechnic Institute, and Head of the Engineering Department therein; formerly of the Engineering Departments of the Yorkshire College, Leeds; and Dulwich College, London.

With many Illustrations, specially prepared for the Work, and numerous Examples, for the Use of Students in Technical Schools and Colleges.

"A capital text-book, arranged on an excellent system, calculated to give an intelligent grasp of the subject, and not the mere faculty of mechanical copying. . . . Mr. Wells shows how to make complete working-drawings, discussing fully each step in the design."—*Electrical Review*

"The first book leads easily and naturally towards the second, where the technical pupil is brought into contact with large and more complex designs."—*The Schoolmaster.*

Works by BRYAN DONKIN, M.Inst.C.E., M.Inst.Mech.E., &c.

Fourth Edition, Revised and Enlarged. With additional Illustrations. Large 8vo, Handsome Cloth. [*At Press.*

GAS, OIL, AND AIR ENGINES:

A Practical Text-Book on Internal Combustion Motors without Boiler.

By BRYAN DONKIN, M.Inst.C.E., M.Inst.Mech.E.

General Contents.—**Gas Engines**:—General Description—History and Development—British, French, and German Gas Engines—Gas Production for Motive Power—Theory of the Gas Engine—Chemical Composition of Gas in Gas Engines—Utilisation of Heat—Explosion and Combustion. **Oil Motors**:—History and Development—Various Types—Priestman's and other Oil Engines. **Hot-Air Engines**:—History and Development—Various Types: Stirling's, Ericsson's, &c., &c.

"The best book now published on Gas, Oil, and Air Engines. . . . Will be of very great interest to the numerous practical engineers who have to make themselves familiar with the motor of the day. . . . Mr. Donkin has the advantage of long practical experience, combined with high scientific and experimental knowledge, and an accurate perception of the requirements of Engineers."—*The Engineer.*

"We heartily recommend Mr. Donkin's work. . . . A monument of careful labour. . . . Luminous and comprehensive."—*Journal of Gas Lighting*

"A thoroughly reliable and exhaustive Treatise."—*Engineering.*

In Quarto, Handsome Cloth. With Numerous Plates. 25s.

THE HEAT EFFICIENCY OF STEAM BOILERS

(LAND, MARINE, AND LOCOMOTIVE).

With many Tests and Experiments on different Types of Boilers, as to the Heating Value of Fuels, &c., with Analyses of Gases and Amount of Evaporation, and Suggestions for the Testing of Boilers.

By BRYAN DONKIN, M.Inst.C.E.

General Contents.—Classification of different Types of Boilers—425 Experiments on English and Foreign Boilers with their Heat Efficiencies shown in Fifty Tables—Fire Grates of Various Types—Mechanical Stokers—Combustion of Fuel in Boilers—Transmission of Heat through Boiler Plates, and their Temperature—Feed Water Heaters, Superheaters, Feed Pumps, &c.—Smoke and its Prevention—Instruments used in Testing Boilers—Marine and Locomotive Boilers—Fuel Testing Stations—Discussion of the Trials and Conclusions—On the Choice of a Boiler, and Testing of Land, Marine, and Locomotive Boilers—Appendices—Bibliography—Index.

With Plates illustrating Progress made during recent years, and the best Modern Practice.

"Probably the most exhaustive *resumé* that has ever been collected. A practical Book by a thoroughly practical man."—*Iron and Coal Trades Review.*

Third Edition, *Revised and Enlarged. Pocket-Size, Leather*, 12s. 6d.; *also Larger Size for Office Use, Cloth*, 12s. 6d.

Boilers, Marine and Land:

THEIR CONSTRUCTION AND STRENGTH.

A Handbook of Rules, Formulæ, Tables, &c., relative to Material, Scantlings, and Pressures, Safety Valves, Springs, Fittings and Mountings, &c.

FOR THE USE OF ENGINEERS, SURVEYORS, BOILER-MAKERS, AND STEAM USERS.

By T. W. TRAILL, M. Inst. C. E., F. E. R. N.,

Late Engineer Surveyor-in-Chief to the Board of Trade.

⁂ To the Second and Third Editions many New Tables for Pressure, up to 200 Lbs. per Square Inch have been added.

"The most valuable work on Boilers published in England."—*Shipping World.*

"Contains an Enormous Quantity of Information arrranged in a very convenient form. . . A most useful volume . . . supplying information to be had nowhere else."—*The Engineer.*

Fourth Impression. Large Crown 8vo. With numerous Illustrations. 6s.

ENGINE-ROOM PRACTICE:

A Handbook for Engineers and Officers in the Royal Navy and Mercantile Marine, Including the Management of the Main and Auxiliary Engines on Board Ship.

By JOHN G. LIVERSIDGE, Engineer R.N., A.M.I.C.E.

Contents.—General Description of Marine Machinery.—The Conditions of Service and Duties of Engineers of the Royal Navy—Entry and Conditions of Service of Engineers of the Leading S.S. Companies.—Raising Steam—Duties of a Steaming Watch on Engines and Boilers.—Shutting off Steam.—Harbour Duties and Watches.—Adjustments and Repairs of Engines.—Preservation and Repairs of "Tank" Boilers.—The Hull and its Fittings.—Cleaning and Painting Machinery.—Reciprocating Pumps, Feed Heaters, and Automatic Feed-Water Regulators.—Evaporators.—Steam Boats.—Electric Light Machinery.—Hydraulic Machinery.—Air-Compressing Pumps—Refrigerating Machines.—Machinery of Destroyers.—The Management of Water-Tube Boilers.—Regulations for Entry of Assistant Engineers, R.N.—Questions given in Examinations for Promotion of Engineers, R.N.—Regulations respecting Board of Trade Examinations for Engineers, &c.

"The contents cannot fail to be appreciated."—*The Steamship.*

"This very useful book. . . . Illustrations are of great importance in a work of this kind, and it is satisfactory to find that special attention has been given in this respect."—*Engineers' Gazette.*

Just Out. In Large Crown 8vo, Cloth. Fully Illustrated. 5s. net.

OIL FUEL:

ITS SUPPLY, COMPOSITION, AND APPLICATION.

By SIDNEY H. NORTH,

late editor of the "petroleum review."

Contents.—The Sources of Supply.—Economic Aspect of Liquid Fuel.—Chemical Composition of Fuel Oils—Conditions of Combustion in Oil Fuel Furnaces.—Early Methods and Experiments.—Modern Burners and Methods.—Oil Fuel for Marine Purposes.—For Naval Purposes.—On Locomotives.—For Metallurgical and other Purposes.—Appendices.—Index.

Second Edition, Revised. With numerous Plates reduced from Working Drawings and 280 Illustrations in the Text. 21s.

A MANUAL OF
LOCOMOTIVE ENGINEERING:
A Practical Text-Book for the Use of Engine Builders, Designers and Draughtsmen, Railway Engineers, and Students.

BY

WILLIAM FRANK PETTIGREW, M.Inst.C.E.

With a Section on American and Continental Engines.

By **ALBERT F. RAVENSHEAR, B.Sc.,**
Of His Majesty's Patent Office.

Contents.—Historical Introduction, 1763-1863.—Modern Locomotives: Simple.—Modern Locomotives: Compound.—Primary Consideration in Locomotive Design.—Cylinders, Steam Chests, and Stuffing Boxes.—Pistons, Piston Rods, Crossheads, and Slide Bars.—Connecting and Coupling Rods.—Wheels and Axles, Axle Boxes, Hornblocks, and Bearing Springs.—Balancing.—Valve Gear.—Slide Valves and Valve Gear Details.—Framing, Bogies and Axle Trucks, Radial Axle Boxes.—Boilers.—Smokebox, Blast Pipe, Firebox Fittings.—Boiler Mountings.—Tenders.—Railway Brakes.—Lubrication.—Consumption of Fuel, Evaporation and Engine Efficiency.—American Locomotives.—Continental Locomotives.—Repairs, Running, Inspection, and Renewals.—Three Appendices.—Index.

"Likely to remain for many years the Standard Work for those wishing to learn Design."—*Engineer.*

"A most interesting and valuable addition to the bibliography of the Locomotive."—*Railway Official Gazette.*

"We recommend the book as THOROUGHLY PRACTICAL in its character, and MERITING A PLACE IN ANY COLLECTION of . . . works on Locomotive Engineering."—*Railway News.*

"The work CONTAINS ALL THAT CAN BE LEARNT from a book upon such a subject. It will at once rank as THE STANDARD WORK UPON THIS IMPORTANT SUBJECT."—*Railway Magazine.*

In Large 8vo. Handsome Cloth. With Plates and Illustrations. 16s.

LIGHT RAILWAYS
AT HOME AND ABROAD.

By **WILLIAM HENRY COLE, M.Inst.C.E.,**
Late Deputy-Manager, North-Western Railway, India.

Contents.—Discussion of the Term "Light Railways."—English Railways, Rates, and Farmers.—Light Railways in Belgium, France, Italy, other European Countries, America and the Colonies, India, Ireland.—Road Transport as an alternative.—The Light Railways Act, 1896.—The Question of Gauge.—Construction and Working.—Locomotives and Rolling-Stock.—Light Railways in England, Scotland, and Wales.—Appendices and Index.

"Mr. W. H. Cole has brought together . . . a LARGE AMOUNT of VALUABLE INFORMATION . . . hitherto practically inaccessible to the ordinary reader."—*Times.*

"Will remain, for some time yet a Standard Work in everything relating to Light Railways."—*Engineer.*

"The author has extended practical experience that makes the book lucid and useful. It is EXCEEDINGLY well done."—*Engineering.*

"The whole subject is EXHAUSTIVELY and PRACTICALLY considered. The work can be cordially recommended as INDISPENSABLE to those whose duty it is to become acquainted with one of the prime necessities of the immediate future."—*Railway Official Gazette.*

"There could be no better book of first reference on its subject. All classes of Engineers will welcome its appearance."—*Scotsman.*

FOURTH EDITION, Thoroughly Revised and Greatly Enlarged.
With Numerous Illustrations. Price 10s. 6d.

VALVES AND VALVE-GEARING:

A PRACTICAL TEXT-BOOK FOR THE USE OF ENGINEERS, DRAUGHTSMEN, AND STUDENTS.

BY CHARLES HURST, Practical Draughtsman.

PART I.—Steam Engine Valves.
PART II.—Gas Engine Valves and Gears.
PART III.—Air Compressor Valves and Gearing.
PART IV.—Pump Valves.

"MR. HURST'S VALVES and VALVE-GEARING will prove a very valuable aid, and tend to the production of Engines of SCIENTIFIC DESIGN and ECONOMICAL WORKING. . . . Will be largely sought after by Students and Designers."—*Marine Engineer.*

"Almost EVERY TYPE of VALVE and its gearing is clearly set forth, and illustrated in such a way as to be READILY UNDERSTOOD and PRACTICALLY APPLIED by either the Engineer, Draughtsman, or Student. . . . Should prove both USEFUL and VALUABLE to all Engineers seeking for RELIABLE and CLEAR information on the subject. Its moderate price brings it within the reach of all."—*Industries and Iron.*

Hints on Steam Engine Design and Construction. By CHARLES HURST, "Author of Valves and Valve Gearing." SECOND EDITION, Revised. In Paper Boards, 8vo., Cloth Back. Illustrated. Price 1s. 6d. net.

CONTENTS.—I. Steam Pipes.—II. Valves.—III. Cylinders.—IV. Air Pumps and Condensers.—V. Motion Work.—VI. Crank Shafts and Pedestals.—VII. Valve Gear.—VIII. Lubrication.—IX. Miscellaneous Details.—INDEX.

"A handy volume which every practical young engineer should possess."—*The Model Engineer.*

Strongly Bound in Super Royal 8vo. Cloth Boards. 7s. 6d. net.

BONUS TABLES:

For Calculating Wages on the Bonus or Premium Systems.

For Engineering, Technical and Allied Trades.

BY HENRY A. GOLDING, A.M.INST.M.E.,

Technical Assistant to Messrs. Bryan Donkin and Clench, Ltd., and Assistant Lecturer in Mechanical Engineering at the Northampton Institute, London, E.C.

"Cannot fail to prove practically serviceable to those for whom they have been designed."—*Scotsman.*

SECOND EDITION, Cloth, 8s. 6d. Leather, for the Pocket, 8s. 6d.

GRIFFIN'S ELECTRICAL PRICE-BOOK: For Electrical, Civil, Marine, and Borough Engineers, Local Authorities, Architects, Railway Contractors, &c., &c. Edited by H. J. DOWSING.

"The ELECTRICAL PRICE-BOOK REMOVES ALL MYSTERY about the cost of Electrical Power. By its aid the EXPENSE that will be entailed by utilising electricity on a large or small scale can be discovered."—*Architect.*

Large 8vo, Handsome Cloth. With Illustrations, Tables, &c. 21s.

Lubrication & Lubricants:

A TREATISE ON THE THEORY AND PRACTICE OF LUBRICATION

AND ON THE

NATURE, PROPERTIES, AND TESTING OF LUBRICANTS.

By LEONARD ARCHBUTT, F.I.C., F.C.S.,
Chemist to the Midland Railway Company,

AND

R. MOUNTFORD DEELEY, M.I.M.E., F.G.S.,
Chief Locomotive Superintendent, Midland Railway Company.

CONTENTS.—I. Friction of Solids.—II. Liquid Friction or Viscosity, and Plastic Friction.—III. Superficial Tension.—IV. The Theory of Lubrication.—V. Lubricants, their Sources, Preparation, and Properties.—VI. Physical Properties and Methods of Examination of Lubricants.—VII. Chemical Properties and Methods of Examination of Lubricants.—VIII. The Systematic Testing of Lubricants by Physical and Chemical Methods.—IX. The Mechanical Testing of Lubricants.—X. The Design and Lubrication of Bearings.—XI. The Lubrication of Machinery.—INDEX.

"Destined to become a CLASSIC on the subject."—*Industries and Iron.*

"Contains practically ALL THAT IS KNOWN on the subject. Deserves the careful attention of all Engineers."—*Railway Official Guide.*

FOURTH EDITION. *Very fully Illustrated.* *Cloth*, 4s. 6d.

STEAM-BOILERS:

THEIR DEFECTS, MANAGEMENT, AND CONSTRUCTION.

By R. D. MUNRO,
Chief Engineer of the Scottish Boiler Insurance and Engine Inspection Company.

GENERAL CONTENTS.—I. EXPLOSIONS caused (1) by Overheating of Plates—(2) By Defective and Overloaded Safety Valves—(3) By Corrosion, Internal or External—(4) By Defective Design and Construction (Unsupported Flue Tubes; Unstrengthened Manholes; Defective Staying; Strength of Rivetted Joints; Factor of Safety)—II. CONSTRUCTION OF VERTICAL BOILERS: Shells—Crown Plates and Uptake Tubes—Man-Holes, Mud-Holes, and Fire-Holes—Fireboxes—Mountings—Management—Cleaning—Table of Bursting Pressures of Steel Boilers—Table of Rivetted Joints—Specifications and Drawings of Lancashire Boiler for Working Pressures (*a*) 80 lbs.; (*b*) 200 lbs. per square inch respectively.

"A valuable companion for workmen and engineers engaged about Steam Boilers, ought to be carefully studied, and ALWAYS AT HAND."—*Coll. Guardian.*

"The book is VERY USEFUL, especially to steam users, artisans, and young Engineers."—*Engineer.*

BY THE SAME AUTHOR.

KITCHEN BOILER EXPLOSIONS: Why they Occur, and How to Prevent their Occurrence. A Practical Handbook based on Actual Experiment. With Diagram and Coloured Plate. Price 3s.

In Crown 8vo, Handsome Cloth. With Numerous Illustrations. 5s. net.

EMERY GRINDING MACHINERY.

A Text-Book of Workshop Practice in General Tool Grinding, and the Design, Construction, and Application of the Machines Employed.

BY

R. B. HODGSON, A.M.INST.MECH.E.,

Author of "Machines and Tools Employed in the Working of Sheet Metals."

INTRODUCTION.—Tool Grinding.—Emery Wheels.—Mounting Emery Wheels.—Emery Rings and Cylinders.—Conditions to Ensure Efficient Working.—Leading Types of Machines.—Concave and Convex Grinding.—Cup and Cone Machines.—Multiple Grinding.—"Guest" Universal and Cutter Grinding Machines.—Ward Universal Cutter Grinder.—Press.—Tool Grinding.—Lathe Centre Grinder.—Polishing.—INDEX.

Deals practically with every phase of his subject."—*Ironmonger*

"Eminently practical . . . cannot fail to attract the notice of the users of this class of machinery, and to meet with careful perusal."—*Chem. Trade Journal.*

SIXTH EDITION. Folio, strongly half-bound, 21s.

TRAVERSE TABLES:

Computed to Four Places of Decimals for every Minute of Angle up to 100 of Distance.

For the use of Surveyors and Engineers.

BY

RICHARD LLOYD GURDEN,

Authorised Surveyor for the Governments of New South Wales and Victoria.

*** *Published with the Concurrence of the Surveyors-General for New South Wales and Victoria.*

"Those who have experience in exact SURVEY-WORK will best know how to appreciate the enormous amount of labour represented by this valuable book. The computations enable the user to ascertain the sines and cosines for a distance of twelve miles to within half an inch, and this BY REFERENCE TO BUT ONE TABLE, in place of the usual Fifteen minute computations required. This alone is evidence of the assistance which the Tables ensure to every user, and as every Surveyor in active practice has felt the want of such assistance FEW KNOWING OF THEIR PUBLICATION WILL REMAIN WITHOUT THEM."
—*Engineer.*

WORKS BY
ANDREW JAMIESON, M.INST.C.E., M.I.E.E., F.R.S.E.,

Formerly Professor of Electrical Engineering, The Glasgow and West of Scotland Technical College.

PROFESSOR JAMIESON'S ADVANCED TEXT-BOOKS.

In Large Crown 8vo. Fully Illustrated.

STEAM AND STEAM-ENGINES, INCLUDING TURBINES AND BOILERS. For the Use of Students preparing for Competitive Examinations. With over 700 pp., over 350 Illustrations, 10 Folding Plates, and very numerous Examination Papers. FOURTEENTH EDITION. Revised throughout. 10s. 6d.

"Professor Jamieson fascinates the reader by his CLEARNESS OF CONCEPTION AND SIMPLICITY OF EXPRESSION. His treatment recalls the lecturing of Faraday."—*Athenæum.*

"The BEST BOOK yet published for the use of Students."—*Engineer.*

MAGNETISM AND ELECTRICITY. For Advanced and "Honours" Students. By Prof. Jamieson, assisted by David Robertson, B.Sc., Professor of Electrical Engineering in the Merchant Venturers' Technical College, Bristol. [*Shortly.*

APPLIED MECHANICS & MECHANICAL ENGINEERING.

Vol. I.—Comprising Part I., with 540 pages, 300 Illustrations, and 540 Examination Questions: The Principle of Work and its applications; Part II.: Friction; Gearing, &c. FOURTH EDITION. 8s. 6d.

"FULLY MAINTAINS the reputation of the Author."—*Pract. Engineer.*

Vol. II.—Comprising Parts III. to VI., with 608 pages, 371 Illustrations, and copious Examination Questions: Motion and Energy; Graphic Statics; Strength of Materials; Hydraulics and Hydraulic Machinery. FOURTH EDITION, Greatly Enlarged.

"WELL AND LUCIDLY WRITTEN."—*The Engineer.*

*** *Each of the above volumes is complete in itself, and sold separately.*

PROFESSOR JAMIESON'S INTRODUCTORY MANUALS

Crown 8vo. With Illustrations and Examination Papers.

STEAM AND THE STEAM-ENGINE (Elementary Manual of). For First-Year Students. TENTH EDITION, Revised. 3/6.

"Should be in the hands of EVERY engineering apprentice."—*Practical Engineer.*

MAGNETISM AND ELECTRICITY (Elementary Manual of). For First-Year Students. FIFTH EDITION. 3/6.

"A CAPITAL TEXT-BOOK . . . The diagrams are an important feature."—*Schoolmaster.*

"A THOROUGHLY TRUSTWORTHY Text-book. PRACTICAL and clear."—*Nature.*

APPLIED MECHANICS (Elementary Manual of). Specially arranged for First-Year Students. SIXTH EDITION, Revised and Greatly Enlarged. 3/6.

"The work has VERY HIGH QUALITIES, which may be condensed into the one word 'CLEAR.'"—*Science and Art.*

IN PREPARATION. 300 *pages. Crown 8vo. Profusely Illustrated.*

MODERN ELECTRIC TRAMWAY TRACTION:

A Text-Book of Present-Day Practice.

For the Use of Electrical Engineering Students and those interested in Electric Transmission of Power.

BY PROF. ANDREW JAMIESON.

A POCKET-BOOK of ELECTRICAL RULES and TABLES. For the Use of Electricians and Engineers. By JOHN MUNRO, C.E., and Prof. JAMIESON. Pocket Size. Leather, 8s. 6d. SEVENTEENTH EDITION. [See p. 49.

WORKS BY

W. J. MACQUORN RANKINE, LL.D., F.R.S.,

Late Regius Professor of Civil Engineering in the University of Glasgow.

THOROUGHLY REVISED BY

W. J. MILLAR, C.E.,

Late Secretary to the Institute of Engineers and Shipbuilders in Scotland.

A MANUAL OF APPLIED MECHANICS:

Comprising the Principles of Statics and Cinematics, and Theory of Structures, Mechanism, and Machines. With Numerous Diagrams. Crown 8vo, cloth. SEVENTEENTH EDITION. 12s. 6d.

A MANUAL OF CIVIL ENGINEERING:

Comprising Engineering Surveys, Earthwork, Foundations, Masonry, Carpentry, Metal Work, Roads, Railways, Canals, Rivers, Waterworks, Harbours, &c. With Numerous Tables and Illustrations. Crown 8vo. cloth. TWENTY-SECOND EDITION. 16s.

A MANUAL OF MACHINERY AND MILLWORK:

Comprising the Geometry, Motions, Work, Strength, Construction, and Objects of Machines, &c. Illustrated with nearly 300 Woodcuts, Crown 8vo, cloth. SEVENTH EDITION. 12s. 6d.

A MANUAL OF THE STEAM-ENGINE AND OTHER PRIME MOVERS:

With a Section on GAS, OIL, and AIR ENGINES, by BRYAN DONKIN, M.Inst.C.E. With Folding Plates and Numerous Illustrations. Crown 8vo, cloth. FIFTEENTH EDITION. 12s. 6d.

PROF. RANKINE'S WORKS—(*Continued*).

USEFUL RULES AND TABLES:

For Architects, Builders, Engineers, Founders, Mechanics, Shipbuilders, Surveyors, &c. With APPENDIX for the use of ELECTRICAL ENGINEERS. By Professor JAMIESON, F.R.S.E. SEVENTH EDITION. 10s. 6d.

A MECHANICAL TEXT-BOOK:

A Practical and Simple Introduction to the Study of Mechanics. By Professor RANKINE and E. F. BAMBER, C.E. With Numerous Illustrations. Crown 8vo, cloth. FIFTH EDITION. 9s.

*** *The* "MECHANICAL TEXT-BOOK" *was designed by* Professor RANKINE *as an* INTRODUCTION *to the above Series of Manuals.*

MISCELLANEOUS SCIENTIFIC PAPERS.

Royal 8vo. Cloth, 31s. 6d

Part I. Papers relating to Temperature, Elasticity, and Expansion of Vapours, Liquids, and Solids. Part II. Papers on Energy and its Transformations. Part III. Papers on Wave-Forms, Propulsion of Vessels, &c.

With Memoir by Professor TAIT, M.A. Edited by W. J. MILLAR, C.E. With fine Portrait on Steel, Plates, and Diagrams.

"No more enduring Memorial of Professor Rankine could be devised than the publication of these papers in an accessible form. . . . The Collection is most valuable on account of the nature of his discoveries, and the beauty and completeness of his analysis. . . . The Volume exceeds in importance any work in the same department published in our time."—*Architect.*

SHELTON-BEY (W. Vincent, Foreman to the Imperial Ottoman Gun Factories, Constantinople):

THE MECHANIC'S GUIDE: A Hand-Book for Engineers and Artizans. With Copious Tables and Valuable Recipes for Practical Use. Illustrated. *Second Edition.* Crown 8vo. Cloth, 7/6.

THIRD EDITION, *Thoroughly Revised and Enlarged. With 60 Plates and Numerous Illustrations. Handsome Cloth. 34s.*

HYDRAULIC POWER
AND
HYDRAULIC MACHINERY.

BY

HENRY ROBINSON, M. INST. C.E., F.G.S.,

FELLOW OF KING'S COLLEGE, LONDON; PROF. EMERITUS OF CIVIL ENGINEERING, KING'S COLLEGE, ETC., ETC.

CONTENTS.—Discharge through Orifices.—Flow of Water through Pipes.—Accumulators.—Presses and Lifts.—Hoists.—Rams.—Hydraulic Engines.—Pumping Engines.—Capstans.—Traversers.—Jacks.—Weighing Machines.—Riveters and Shop Tools.—Punching, Shearing, and Flanging Machines.—Cranes.—Coal Discharging Machines.—Drills and Cutters.—Pile Drivers, Excavators, &c.—Hydraulic Machinery applied to Bridges, Dock Gates, Wheels and Turbines.—Shields.—Various Systems and Power Installations—Meters, &c.—INDEX.

"As a compendious guide to the subjects with which it treats, 'Hydraulic Power and Hydraulic Machinery' still stands without a rival."—*Water.*

In Large 8vo, Handsome Cloth. With Frontispiece, several Plates, and over 250 Illustrations. 21s.

THE PRINCIPLES AND CONSTRUCTION OF PUMPING MACHINERY

(STEAM AND WATER PRESSURE).

With Practical Illustrations of ENGINES and PUMPS applied to MINING, TOWN WATER SUPPLY, DRAINAGE of Lands, &c., also Economy and Efficiency Trials of Pumping Machinery.

BY HENRY DAVEY,

Member of the Institution of Civil Engineers, Member of the Institution of Mechanical Engineers, F.G.S., &c.

CONTENTS.—Early History of Pumping Engines—Steam Pumping Engines—Pumps and Pump Valves—General Principles of Non-Rotative Pumping Engines—The Cornish Engine, Simple and Compound—Types of Mining Engines—Pit Work—Shaft Sinking—Hydraulic Transmission of Power in Mines—Valve Gears of Pumping Engines—Water Pressure Pumping Engines—Water Works Engines—Pumping Engine Economy and Trials of Pumping Machinery—Centrifugal and other Low-Lift Pumps—Hydraulic Rams, Pumping Mains, &c.—INDEX.

"By the 'one English Engineer who probably knows more about Pumping Machinery than ANY OTHER.' . . . A VOLUME RECORDING THE RESULTS OF LONG EXPERIENCE AND STUDY."—*The Engineer.*

"Undoubtedly THE BEST AND MOST PRACTICAL TREATISE on Pumping Machinery THAT HAS YET BEEN PUBLISHED."—*Mining Journal.*

Royal 8vo. Handsome Cloth. With numerous Illustrations and Tables. 25s.

THE STABILITY OF SHIPS.

BY

SIR EDWARD J. REED, K.C.B., F.R.S., M.P.,

KNIGHT OF THE IMPERIAL ORDERS OF ST. STANILAUS OF RUSSIA; FRANCIS JOSEPH OF AUSTRIA; MEDJIDIE OF TURKEY; AND RISING SUN OF JAPAN; VICE-PRESIDENT OF THE INSTITUTION OF NAVAL ARCHITECTS.

In order to render the work complete for the purposes of the Shipbuilder, whether at home or abroad, the Methods of Calculation introduced by Mr. F. K. BARNES, Mr. GRAY, M. REECH, M. DAYMARD, and Mr. BENJAMIN, are all given separately, illustrated by Tables and worked-out examples. The book contains more than 200 Diagrams, and is illustrated by a large number of actual cases, derived from ships of all descriptions.

"Sir EDWARD REED'S 'STABILITY OF SHIPS' IS INVALUABLE. The NAVAL ARCHITECT will find brought together and ready to his hand, a mass of information which he would otherwise have to seek in an almost endless variety of publications, and some of which he would possibly not be able to obtain at all elsewhere."—*Steamship.*

THE DESIGN AND CONSTRUCTION OF SHIPS. By JOHN HARVARD BILES, M.INST.N.A., Professor of Naval Architecture in the University of Glasgow. [*In Preparation.*

THIRD EDITION. Illustrated with Plates, Numerous Diagrams, and Figures in the Text. 18s. net.

STEEL SHIPS:

THEIR CONSTRUCTION AND MAINTENANCE.

A Manual for Shipbuilders, Ship Superintendents, Students, and Marine Engineers.

BY THOMAS WALTON, NAVAL ARCHITECT,

AUTHOR OF "KNOW YOUR OWN SHIP."

CONTENTS.—I. Manufacture of Cast Iron, Wrought Iron, and Steel.—Composition of Iron and Steel, Quality, Strength, Tests, &c. II. Classification of Steel Ships. III. Considerations in making choice of Type of Vessel.—Framing of Ships. IV. Strains experienced by Ships.—Methods of Computing and Comparing Strengths of Ships. V. Construction of Ships.—Alternative Modes of Construction.—Types of Vessels.—Turret, Self Trimming, and Trunk Steamers, &c.—Rivets and Rivetting, Workmanship. VI. Pumping Arrangements. VII. Maintenance.—Prevention of Deterioration in the Hulls of Ships.—Cement, Paint, &c.—INDEX.

"So thorough and well written is every chapter in the book that it is difficult to select any of them as being worthy of exceptional praise. Altogether, the work is excellent, and will prove of great value to those for whom it is intended."—*The Engineer.*

"Mr. Walton has written for the profession of which he is an ornament. His work will be read and appreciated, no doubt, by every M.I.N.A., and with great benefit by the majority of them."—*Journal of Commerce.*

UNIFORM WITH THE ABOVE.

THE PRINCIPLES AND PRACTICE OF

DOCK ENGINEERING.

BY BRYSSON CUNNINGHAM, B.E., M.INST.C.E.

See p. 27.

GRIFFIN'S NAUTICAL SERIES.

EDITED BY EDW. BLACKMORE,
Master Mariner, First Class Trinity House Certificate, Assoc. Inst. N.A.;
AND WRITTEN, MAINLY, by SAILORS for SAILORS.

"THIS ADMIRABLE SERIES."—*Fairplay.* "A VERY USEFUL SERIES."—*Nature.*

"The volumes of MESSRS. GRIFFIN'S NAUTICAL SERIES may well and profitably be read by ALL interested in our NATIONAL MARITIME PROGRESS."—*Marine Engineer.*

"EVERY SHIP should have the WHOLE SERIES as a REFERENCE LIBRARY. HANDSOMELY BOUND, CLEARLY PRINTED and ILLUSTRATED."—*Liverpool Journ. of Commerce.*

The British Mercantile Marine: An Historical Sketch of its Rise and Development. By the EDITOR, CAPT. BLACKMORE. 3s. 6d.

"Captain Blackmore's SPLENDID BOOK . . . contains paragraphs on every point of interest to the Merchant Marine. The 243 pages of this book are THE MOST VALUABLE to the sea captain that have EVER been COMPILED."—*Merchant Service Review.*

Elementary Seamanship. By D. WILSON-BARKER, Master Mariner, F.R.S.E., F.R.G.S. With numerous Plates, two in Colours, and Frontispiece. THIRD EDITION, Thoroughly Revised, Enlarged, and Re-set. With additional Illustrations. 6s.

"This ADMIRABLE MANUAL, by CAPT. WILSON BARKER, of the 'Worcester,' seems to us PERFECTLY DESIGNED."—*Athenæum.*

Know Your Own Ship: A Simple Explanation of the Stability, Construction, Tonnage, and Freeboard of Ships. By THOS. WALTON, Naval Architect. With numerous Illustrations and additional Chapters on Buoyancy, Trim, and Calculations. EIGHTH EDITION. 7s. 6d.

'MR. WALTON'S book will be found VERY USEFUL."—*The Engineer.*

Navigation: Theoretical and Practical. By D. WILSON-BARKER and WILLIAM ALLINGHAM. SECOND EDITION, Revised. 3s. 6d.

"PRECISELY the kind of work required for the New Certificates of competency. Candidates will find it INVALUABLE."—*Dundee Advertiser.*

Marine Meteorology: For Officers of the Merchant Navy. By WILLIAM ALLINGHAM, First Class Honours, Navigation, Science and Art Department. With Illustrations, Maps, and Diagrams, and *facsimile* reproduction of log page. 7s. 6d.

"Quite the BEST PUBLICATION on this subject."—*Shipping Gazette.*

Latitude and Longitude: How to find them. By W. J. MILLAR, C.E. SECOND EDITION, Revised. 2s.

"Cannot but prove an acquisition to those studying Navigation."—*Marine Engineer.*

Practical Mechanics: Applied to the requirements of the Sailor. By THOS. MACKENZIE, Master Mariner, F.R.A.S. SECOND EDITION, Revised. 3s. 6d.

"WELL WORTH the money . . . EXCEEDINGLY HELPFUL."—*Shipping World.*

Trigonometry: For the Young Sailor, &c. By RICH. C. BUCK, of the Thames Nautical Training College, H.M.S. "Worcester." SECOND EDITION, Revised. Price 3s. 6d.

"This EMINENTLY PRACTICAL and reliable volume."—*Schoolmaster.*

Practical Algebra. By RICH. C. BUCK. Companion Volume to the above, for Sailors and others. Price 3s. 6d.

"It is JUST THE BOOK for the young sailor mindful of progress. —*Nautical Magazine.*

The Legal Duties of Shipmasters. By BENEDICT WM. GINSBURG, M.A., LL.D., of the Inner Temple and Northern Circuit: Barrister-at-Law. SECOND EDITION, Thoroughly Revised and Enlarged. Price 4s. 6d.

"INVALUABLE to masters. . . . We can fully recommend it."—*Shipping Gazette.*

A Medical and Surgical Help for Shipmasters. Including First Aid at Sea. By WM. JOHNSON SMITH, F.R.C.S., Principal Medical Officer, Seamen's Hospital, Greenwich. SECOND EDITION, Thoroughly Revised. 6s.

"SOUND, JUDICIOUS, REALLY HELPFUL."—*The Lancet.*

GRIFFIN'S NAUTICAL SERIES.

Introductory Volume. Price 3s. 6d.

THE
British Mercantile Marine.

BY EDWARD BLACKMORE,

MASTER MARINER; ASSOCIATE OF THE INSTITUTION OF NAVAL ARCHITECTS; MEMBER OF THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND; EDITOR OF GRIFFIN'S "NAUTICAL SERIES."

GENERAL CONTENTS.—HISTORICAL: From Early Times to 1486—Progress under Henry VIII.—To Death of Mary—During Elizabeth's Reign—Up to the Reign of William III.—The 18th and 19th Centuries—Institution of Examinations — Rise and Progress of Steam Propulsion — Development of Free Trade—Shipping Legislation, 1862 to 1875—"Locksley Hall" Case—Shipmasters' Societies—Loading of Ships—Shipping Legislation, 1884 to 1894—Statistics of Shipping. THE PERSONNEL: Shipowners—Officers—Mariners—Duties and Present Position. EDUCATION: A Seaman's Education: what it should be—Present Means of Education—Hints. DISCIPLINE AND DUTY—Postscript—The Serious Decrease in the Number of British Seamen, a Matter demanding the Attention of the Nation.

"INTERESTING and INSTRUCTIVE . . . may be read WITH PROFIT and ENJOYMENT."—*Glasgow Herald.*

"EVERY BRANCH of the subject is dealt with in a way which shows that the writer 'knows the ropes' familiarly."—*Scotsman.*

"This ADMIRABLE book . . . TEEMS with useful information—Should be in the hands of every Sailor."—*Western Morning News.*

THIRD EDITION, *Thoroughly Revised, Enlarged, and Re-set.*
With Additional Illustrations. Price 6s.

A MANUAL OF
ELEMENTARY SEAMANSHIP.

BY

D. WILSON-BARKER, MASTER MARINER; F.R.S.E., F.R.G.S., &c., &c.
YOUNGER BROTHER OF THE TRINITY HOUSE.

With Frontispiece, Numerous Plates (Two in Colours), and Illustrations in the Text.

GENERAL CONTENTS.—The Building of a Ship; Parts of Hull, Masts, &c.—Ropes, Knots, Splicing, &c. — Gear, Lead and Log, &c. — Rigging, Anchors — Sailmaking — The Sails, &c. — Handling of Boats under Sail — Signals and Signalling—Rule of the Road—Keeping and Relieving Watch—Points of Etiquette—Glossary of Sea Terms and Phrases—Index.

*** The volume contains the NEW RULES OF THE ROAD.

"This ADMIRABLE MANUAL, by CAPT. WILSON-BARKER of the 'Worcester,' seems to us PERFECTLY DESIGNED, and holds its place excellently in 'GRIFFIN'S NAUTICAL SERIES.' . . . Although intended for those who are to become Officers of the Merchant Navy, it will be found useful by ALL YACHTSMEN."—*Athenæum.*

*** For complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

GRIFFIN'S NAUTICAL SERIES.

SECOND EDITION, *Revised and Illustrated. Price 3s. 6d.*

NAVIGATION:

PRACTICAL AND THEORETICAL.

BY DAVID WILSON-BARKER, R.N.R., F.R.S.E., &c., &c.,

AND

WILLIAM ALLINGHAM,

FIRST-CLASS HONOURS, NAVIGATION, SCIENCE AND ART DEPARTMENT.

With Numerous Illustrations and Examination Questions.

GENERAL CONTENTS.—Definitions—Latitude and Longitude—Instruments of Navigation—Correction of Courses—Plane Sailing—Traverse Sailing—Day's Work — Parallel Sailing — Middle Latitude Sailing — Mercator's Chart—Mercator Sailing—Current Sailing—Position by Bearings—Great Circle Sailing —The Tides—Questions—Appendix: Compass Error—Numerous Useful Hints. &c.—Index.

"PRECISELY the kind of work required for the New Certificates of competency in grades from Second Mate to extra Master. . . . Candidates will find it INVALUABLE."—*Dundee Advertiser.*

"A CAPITAL LITTLE BOOK . . . specially adapted to the New Examinations. The Authors are CAPT. WILSON-BARKER (Captain-Superintendent of the Nautical College, H.M.S. 'Worcester,' who has had great experience in the highest problems of Navigation), and MR. ALLINGHAM, a well-known writer on the Science of Navigation and Nautical Astronomy." —*Shipping World.*

Handsome Cloth. Fully Illustrated. Price 7s. 6d.

MARINE METEOROLOGY,

FOR OFFICERS OF THE MERCHANT NAVY.

BY WILLIAM ALLINGHAM,

Joint Author of "Navigation, Theoretical and Practical."

With numerous Plates, Maps, Diagrams, and Illustrations, and a facsimile Reproduction of a Page from an actual Meteorological Log-Book.

SUMMARY OF CONTENTS.

INTRODUCTORY.—Instruments Used at Sea for Meteorological Purposes.—Meteorological Log-Books.—Atmospheric Pressure.—Air Temperatures.—Sea Temperatures.—Winds.—Wind Force Scales.—History of the Law of Storms.—Hurricanes, Seasons, and Storm Tracks.—Solution of the Cyclone Problem.—Ocean Currents.—Icebergs.—Synchronous Charts.—Dew, Mists, Fogs, and Haze.—Clouds.—Rain, Snow, and Hail.—Mirage, Rainbows, Coronas, Halos, and Meteors.—Lightning, Corposants, and Auroras.—QUESTIONS.—APPENDIX.—INDEX.

"Quite the BEST publication, AND certainly the MOST INTERESTING, on this subject ever presented to Nautical men."—*Shipping Gazette.*

*** For Complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

LONDON: CHARLES GRIFFIN & CO., LIMITED, EXETER STREET, STRAND.

GRIFFIN'S NAUTICAL SERIES.

SECOND EDITION, REVISED. With Numerous Illustrations. Price 3s. 6d.

Practical Mechanics:

Applied to the Requirements of the Sailor.

BY THOS. MACKENZIE,

Master Mariner, F.R.A.S.

GENERAL CONTENTS.—Resolution and Composition of Forces—Work done by Machines and Living Agents—The Mechanical Powers: The Lever; Derricks as Bent Levers—The Wheel and Axle: Windlass; Ship's Capstan; Crab Winch—Tackles: the "Old Man"—The Inclined Plane; the Screw—The Centre of Gravity of a Ship and Cargo—Relative Strength of Rope: Steel Wire, Manilla, Hemp, Coir—Derricks and Shears—Calculation of the Cross-breaking Strain of Fir Spar—Centre of Effort of Sails—Hydrostatics: the Diving-bell; Stability of Floating Bodies; the Ship's Pump, &c.

"THIS EXCELLENT BOOK . . . contains a LARGE AMOUNT of information."—*Nature.*

"WELL WORTH the money . . . will be found EXCEEDINGLY HELPFUL."—*Shipping World.*

"NO SHIPS' OFFICERS' BOOKCASE will henceforth be complete without CAPTAIN MACKENZIE'S 'PRACTICAL MECHANICS.' Notwithstanding my many years' experience at sea, it has told me *how much more there is to acquire.*"—(Letter to the Publishers from a Master Mariner).

"I must express my thanks to you for the labour and care you have taken in 'PRACTICAL MECHANICS.' . . . IT IS A LIFE'S EXPERIENCE. . . . What an amount we frequently see wasted by rigging purchases without reason and accidents to spars, &c., &c.! 'PRACTICAL MECHANICS' WOULD SAVE ALL THIS."—(Letter to the Author from another Master Mariner).

WORKS BY RICHARD C. BUCK,

of the Thames Nautical Training College, H.M.S. 'Worcester.'

A Manual of Trigonometry:

With Diagrams, Examples, and Exercises. *Price 3s. 6d.*

SECOND EDITION, Revised and Corrected.

⁂ Mr. Buck's Text-Book has been SPECIALLY PREPARED with a view to the New Examinations of the Board of Trade, in which Trigonometry is an obligatory subject.

"This EMINENTLY PRACTICAL and RELIABLE VOLUME."—*Schoolmaster.*

A Manual of Algebra.

Designed to meet the Requirements of Sailors and others. *Price 3s. 6d.*

⁂ These elementary works on ALGEBRA and TRIGONOMETRY are written specially for those who will have little opportunity of consulting a Teacher. They are books for "SELF-HELP." All but the simplest explanations have, therefore, been avoided, and ANSWERS to the Exercises are given. Any person may readily, by careful study, become master of their contents, and thus lay the foundation for a further mathematical course, if desired. It is hoped that to the younger Officers of our Mercantile Marine they will be found decidedly serviceable. The Examples and Exercises are taken from the Examination Papers set for the Cadets of the "Worcester."

"Clearly arranged, and well got up. . . . A first-rate Elementary Algebra.—*Nautical Magazine.*

⁂ For complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

GRIFFIN'S NAUTICAL SERIES.

SECOND EDITION, Thoroughly Revised and Extended. In Crown 8vo.
Handsome Cloth. Price 4s. 6d.

THE LEGAL DUTIES OF SHIPMASTERS.

BY

BENEDICT WM. GINSBURG, M.A., LL.D. (CANTAB.),
Of the Inner Temple and Northern Circuit; Barrister-at-Law.

General Contents.—The Qualification for the Position of Shipmaster—The Contract with the Shipowner—The Master's Duty in respect of the Crew: Engagement; Apprentices; Discipline; Provisions, Accommodation, and Medical Comforts; Payment of Wages and Discharge—The Master's Duty in respect of the Passengers—The Master's Financial Responsibilities—The Master's Duty in respect of the Cargo—The Master's Duty in Case of Casualty—The Master's Duty to certain Public Authorities—The Master's Duty in relation to Pilots, Signals, Flags, and Light Dues—The Master's Duty upon Arrival at the Port of Discharge—Appendices relative to certain Legal Matters: Board of Trade Certificates, Dietary Scales, Stowage of Grain Cargoes, Load Line Regulations, Life-saving Appliances, Carriage of Cattle at Sea, &c., &c.—Copious Index.

"No intelligent Master should fail to add this to his list of necessary books. A few lines of it may SAVE A LAWYER'S FEE, BESIDES ENDLESS WORRY."—*Liverpool Journal of Commerce.*

"SENSIBLE, plainly written, in CLEAR and NON-TECHNICAL LANGUAGE, and will be found of MUCH SERVICE by the Shipmaster."—*British Trade Review.*

SECOND EDITION, Revised. With Diagrams. Price 2s.

Latitude and Longitude:

How to Find them.

BY W. J. MILLAR, C.E.,
Late Secretary to the Inst. of Engineers and Shipbuilders in Scotland.

"CONCISELY and CLEARLY WRITTEN . . . cannot but prove an acquisition to those studying Navigation."—*Marine Engineer.*

"Young Seamen will find it HANDY and USEFUL, SIMPLE and CLEAR."—*The Engineer.*

FIRST AID AT SEA.

SECOND EDITION, Revised. With Coloured Plates and Numerous Illustrations, and comprising the latest Regulations Respecting the Carriage of Medical Stores on Board Ship. Price 6s.

A MEDICAL AND SURGICAL HELP

FOR SHIPMASTERS AND OFFICERS *IN THE MERCHANT NAVY.*

BY

WM. JOHNSON SMITH, F.R.C.S.,
Principal Medical Officer, Seamen's Hospital, Greenwich.

*** The attention of all interested in our Merchant Navy is requested to this exceedingly useful and valuable work. It is needless to say that it is the outcome of many years PRACTICAL EXPERIENCE amongst Seamen.

"SOUND, JUDICIOUS, REALLY HELPFUL."—*The Lancet.*

*** For Complete List of GRIFFIN'S NAUTICAL SERIES, see p. 39.

GRIFFIN'S NAUTICAL SERIES.

EIGHTH EDITION. *Revised, with Chapters on Trim, Buoyancy, and Calculations. Numerous Illustrations. Handsome Cloth, Crown 8vo. Price 7s. 6d.*

KNOW YOUR OWN SHIP.

BY THOMAS WALTON, NAVAL ARCHITECT.

SPECIALLY ARRANGED TO SUIT THE REQUIREMENTS OF SHIPS' OFFICERS, SHIPOWNERS, SUPERINTENDENTS, DRAUGHTSMEN, ENGINEERS, AND OTHERS.

This work explains, in a simple manner, such important subjects as:—

Displacement,
Deadweight,
Tonnage,
Freeboard,
Moments,
Buoyancy,
Strain,
Structure,
Stability,
Rolling,
Ballasting,
Loading,
Shifting Cargoes,
Admission of Water,
Sail Area,
&c., &c.

"The little book will be found EXCEEDINGLY HANDY by most officers and officials connected with shipping. . . . Mr. Walton's work will obtain LASTING SUCCESS, because of its unique fitness for those for whom it has been written."—*Shipping World.*

"An EXCELLENT WORK, full of solid instruction and INVALUABLE to every officer of the Mercantile Marine who has his profession at heart."—*Shipping.*

"Not one of the 242 pages could well be spared. It will admirably fulfil its purpose . . . useful to ship owners, ship superintendents, ship draughtsmen, and all interested in shipping."—*Liverpool Journal of Commerce.*

"A mass of VERY USEFUL INFORMATION, accompanied by diagrams and illustrations, is given in a compact form."—*Fairplay.*

"We have found no one statement that we could have wished differently expressed. The matter has, so far as clearness allows, been admirably condensed, and is simple enough to be understood by every seaman."—*Marine Engineer.*

BY THE SAME AUTHOR.

Steel Ships: Their Construction and Maintenance.

(See page 38.)

FIFTEENTH EDITION, *Thoroughly Revised, Greatly Enlarged, and Reset Throughout. Large 8vo, Cloth. pp.* i-xxiv+708. *With* 280 *Illustrations, reduced from Working Drawings, and* 8 *Plates.* 21*s. net.*

A MANUAL OF
MARINE ENGINEERING:
COMPRISING THE DESIGNING, CONSTRUCTION, AND WORKING OF MARINE MACHINERY.

By A. E. SEATON, M. Inst. C. E., M. Inst. Mech. E., M.Inst.N.A.

GENERAL CONTENTS. — PART I.—Principles of Marine Propulsion. PART II.—Principles of Steam Engineering. PART III.—Details of Marine Engines: Design and Calculations for Cylinders, Pistons, Valves, Expansion Valves, &c. PART IV.—Propellers. PART V.—Boilers. PART IV.—Miscellaneous.

⁂ This EDITION includes a Chapter on WATER-TUBE BOILERS, with Illustrations of the leading Types and the Revised Rules of the *Bureau Veritas.*

"In the three-fold capacity of enabling a Student to learn how to design, construct, and work a Marine Steam-Engine, Mr. Seaton's Manual has NO RIVAL."—*Times.*

"By far the BEST MANUAL in existence. . . . Gives a complete account of the methods of solving, with the utmost possible economy, the problems before the Marine Engineer."—*Athenæum.*

"The Student, Draughtsman, and Engineer will find this work the MOST VALUABLE HANDBOOK of Reference on the Marine Engine now in existence."—*Marine Engineer*

EIGHTH EDITION, Thoroughly Revised. Pocket-Size, Leather. 8s. 6d.

A POCKET-BOOK OF
MARINE ENGINEERING RULES AND TABLES,
FOR THE USE OF

Marine Engineers, Naval Architects, Designers, Draughtsmen, Superintendents and Others.

BY

A. E. SEATON, M.I.C.E., M.I.Mech.E., M.I.N.A.,

AND

H. M. ROUNTHWAITE, M.I.Mech.E., M.I.N.A.

"ADMIRABLY FULFILS its purpose."—*Marine Engineer.*

By B. CUNNINGHAM.

DOCKS: THEIR CONSTRUCTION & MAINTENANCE.
(See page 27.)

WORKS BY PROF. ROBERT H. SMITH, Assoc.M.I.C.E.,

M.I.M.E., M.I.El.E., M.I.Min.E., Whit. Sch., M.Ord.Meiji.

THE CALCULUS FOR ENGINEERS AND PHYSICISTS,

Applied to Technical Problems.

WITH EXTENSIVE

CLASSIFIED REFERENCE LIST OF INTEGRALS.

By PROF. ROBERT H. SMITH.

ASSISTED BY

R. F. MUIRHEAD, M.A., B.Sc.,

Formerly Clark Fellow of Glasgow University, and Lecturer on Mathematics at Mason College.

In Crown 8vo, extra, with Diagrams and Folding-Plate. **8s. 6d.**

"Prof. R. H. Smith's book will be serviceable in rendering a hard road AS EASY AS PRACTICABLE for the non-mathematical Student and Engineer."—*Athenæum.*

"Interesting diagrams, with practical illustrations of actual occurrence, are to be found here in abundance. THE VERY COMPLETE CLASSIFIED REFERENCE TABLE will prove very useful in saving the time of those who want an integral in a hurry."—*The Engineer.*

MEASUREMENT CONVERSIONS

(English and French):

28 GRAPHIC TABLES OR DIAGRAMS.

Showing at a glance the Mutual Conversion of Measurements in Different Units

Of Lengths, Areas, Volumes, Weights, Stresses, Densities, Quantities of Work, Horse Powers, Temperatures, &c.

For the use of Engineers, Surveyors, Architects, and Contractors.

In 4to, Boards. 7s. 6d.

*** Prof. Smith's Conversion-Tables form the most unique and comprehensive collection ever placed before the profession. By their use much time and labour will be saved, and the chances of error in calculation diminished. It is believed that henceforth no Engineer's Office will be considered complete without them.

"The work is INVALUABLE."—*Colliery Guardian.*

"Ought to be in EVERY office where even occasional conversions are required. . . . Prof. Smith's Tables form very EXCELLENT CHECKS on results."—*Electrical Review.*

"Prof. Smith deserves the hearty thanks, not only of the Engineer, but of the Commercial World, for having smoothed the way for the ADOPTION of the Metric System of Measurement, a subject which is now assuming great importance as a factor in maintaining our HOLD upon FOREIGN TRADE."—*The Machinery Market.*

SECOND EDITION in Preparation. In Large 8vo. Handsome Cloth. 10s. 6d.

CHEMISTRY FOR ENGINEERS.

BY

BERTRAM BLOUNT, F.I.C., F.C.S., A.I.C.E., Consulting Chemist to the Crown Agents for the Colonies.

AND

A. G. BLOXAM, F.I.C., F.C.S., Consulting Chemist, Head of the Chemistry Department, Goldsmiths' Inst., New Cross.

GENERAL CONTENTS.—Introduction—Chemistry of the Chief Materials of Construction—Sources of Energy—Chemistry of Steam-raising—Chemistry of Lubrication and Lubricants—Metallurgical Processes used in the Winning and Manufacture of Metals.

"The authors have SUCCEEDED beyond all expectation, and have produced a work which should give FRESH POWER to the Engineer and Manufacturer."—*The Times.*

"PRACTICAL THROUGHOUT . . . an ADMIRABLE TEXT-BOOK, useful not only to Students, but to ENGINEERS and MANAGERS OF WORKS in PREVENTING WASTE and IMPROVING PROCESSES."—*Scotsman.*

"A book worthy to take HIGH RANK . . . treatment of the subject of GASEOUS FUEL particularly good. . . . WATER GAS and its production clearly worked out. . . . We WARMLY RECOMMEND the work."—*Journal of Gas Lighting.*

For Companion Volume by the same Authors, see "CHEMISTRY FOR MANUFACTURERS," p. 71 *General Catalogue.*

Pocket Size, Leather Limp, with Gilt Edges and Rounded Corners, printed on Special Thin Paper, with Illustrations, pp. I.—XII. + 834. Price 18s. net.

(THE NEW "NYSTROM")

THE MECHANICAL ENGINEER'S REFERENCE BOOK

A Handbook of Tables, Formulas and Methods for Engineers, Students and Draughtsmen.

BY HENRY HARRISON SUPLEE, B.Sc., M.E.

Tables, Formulas, and Reference Data for Mechanical Engineers, comprising machine design and information relating to the drawing office and the designing department; intended as a successor to the well-known Pocket-Book written many years ago by the late JOHN W. NYSTROM.—*Publishers' Note.*

"The work should prove exceedingly useful not only to Students but to Practical Engineers as well."—*Railways.*

WORKS BY WALTER R. BROWNE, M.A., M.INST.C.E.,

Late Fellow of Trinity College, Cambridge.

THE STUDENT'S MECHANICS:

An Introduction to the Study of Force and Motion.

With Diagrams. Crown 8vo. Cloth, 4s. 6d.

"Clear in style and practical in method, 'THE STUDENT'S MECHANICS' is cordially to be recommended from all points of view."—*Athenæum.*

FOUNDATIONS OF MECHANICS.

Papers reprinted from the *Engineer.* In Crown 8vo, 1s.

Demy 8vo, with Numerous Illustrations, 9s.

FUEL AND WATER:

A Manual for Users of Steam and Water.

BY PROF. FRANZ SCHWACKHÖFER OF VIENNA, AND WALTER R. BROWNE, M.A., C.E.

GENERAL CONTENTS.—Heat and Combustion—Fuel, Varieties of—Firing Arrangements: Furnace, Flues, Chimney—The Boiler, Choice of—Varieties—Feed-water Heaters—Steam Pipes—Water: Composition, Purification—Prevention of Scale, &c., &c.

"The Section on Heat is one of the best and most lucid ever written."—*Engineer.*
"Cannot fail to be valuable to thousands using steam power."—*Railway Engineer.*

SECOND EDITION, REVISED AND ENLARGED.

With Tables, Illustrations in the Text, and 37 Lithographic Plates. Medium 8vo. Handsome Cloth. 30s.

SEWAGE DISPOSAL WORKS:

A Guide to the Construction of Works for the Prevention of the Pollution by Sewage of Rivers and Estuaries.

BY W. SANTO CRIMP, M.INST.C.E., F.G.S.,

Late Assistant-Engineer, London County Council.

PART I.—INTRODUCTORY. PART II.—SEWAGE DISPOSAL WORKS IN OPERATION—THEIR CONSTRUCTION, MAINTENANCE, AND COST.

⁂ From the fact of the Author's having, for some years, had charge of the Main Drainage Works of the Northern Section of the Metropolis, the chapter on LONDON will be found to contain many important details which would not otherwise have been available.

"All persons interested in Sanitary Science owe a debt of gratitude to Mr. Crimp. . . . His work will be especially useful to SANITARY AUTHORITIES and their advisers . . . EMINENTLY PRACTICAL AND USEFUL."—*Lancet.*

"Probably the MOST COMPLETE AND BEST TREATISE on the subject which has appeared in our language . . Will prove of the greatest use to all who have the problem of Sewage Disposal to face."—*Edinburgh Medical Journal.*

Beautifully Illustrated, with Numerous Plates, Diagrams, and Figures in the Text. 21s. net.

TRADES' WASTE:

ITS TREATMENT AND UTILISATION.

A Handbook for Borough Engineers, Surveyors, Architects, and Analysts.

BY W. NAYLOR, F.C.S., A.M.INST.C.E.,

Chief Inspector of Rivers, Ribble Joint Committee.

CONTENTS.—I. Introduction.—II. Chemical Engineering.—III.—Wool De-greasing and Grease Recovery.—IV. Textile Industries; Calico Bleaching and Dyeing.—V. Dyeing and Calico-Printing.—VI. Tanning and Fellmongery.—VII. Brewery and Distillery Waste.—VIII. Paper Mill Refuse.—IX. General Trades' Waste.—INDEX.

"There is probably no person in England to-day better fitted to deal rationally with such a subject."—*British Sanitarian.*

"The work is thoroughly practical, and will serve as a handbook in the future for those who have to encounter the problems discussed."—*Chemical Trade Journal.*

JUST OUT. SECOND EDITION, Thoroughly Revised and Re-Written. 15s. net.

CALCAREOUS CEMENTS:

THEIR NATURE, PREPARATION, AND USES.

With some Observations upon Cement Testing.

BY GILBERT R. REDGRAVE, ASSOC. INST. C.E.,

AND CHARLES SPACKMAN, F.C.S.

"INVALUABLE to the Student, Architect, and Engineer."—*Building News.*

"Will be useful to ALL interested in the MANUFACTURE, USE, and TESTING of Cements."—*Engineer.*

ELECTRICAL ENGINEERING.

SECOND EDITION, *Revised. In Large 8vo. Handsome Cloth. Profusely Illustrated with Plates, Diagrams, and Figures.* 24*s. net.*

CENTRAL ELECTRICAL STATIONS:

Their Design, Organisation, and Management.

BY CHAS. H. WORDINGHAM, A.K.C., M.INST.C.E., M.INST.MECH.E.,
Late Memb. of Council Inst. E. E., and Electrical Engineer to the City of Manchester;
Electrical Engineer-in-Chief to the Admiralty.

ABRIDGED CONTENTS.

Introductory.—Central Station Work as a Profession.—As an Investment.—The Establishment of a Central Station.—Systems of Supply.—Site.—Architecture.—Plant.—Boilers.—Systems of Draught and Waste Heat Economy.—Coal Handling, Weighing, and Storing.—The Transmission of Steam.—Generators.—Condensing Appliances.—Switching Gear, Instruments, and Connections.—Distributing Mains.—Insulation, Resistance, and Cost.—Distributing Networks.—Service Mains and Feeders.—Testing Mains.—Meters and Appliances.—Standardising and Testing Laboratory.—Secondary Batteries.—Street Lighting.—Cost.—General Organisation.—Mains Department.—Installation Department.—Standardising Department.—Drawing Office.—Clerical Department.—The Consumer.—Routine and Main Laying.—INDEX.

"One of the MOST VALUABLE CONTRIBUTIONS to Central Station literature we have had for some time."—*Electricity.*

In Large 8vo. Handsome Cloth. Profusely Illustrated. 12s. 6d. net.

ELECTRICITY CONTROL.

A Treatise on Electric Switchgear and Systems of Electric Transmission.

BY LEONARD ANDREWS,
Associate Member of the Institution of Civil Engineers, Member of the Institution of Electrical Engineers, Ex-Member of Council of Incorporated Municipal Electrical Association, &c.

General Principles of Switchgear Design.—Constructional Details.—Circuit Breakers or Arc Interrupting Devices.—Automatically Operated Circuit-Breakers.—Alternating Reverse Current Devices.—Arrangement of 'Bus Bars, and Apparatus for Parallel Running.—General Arrangement of Controlling Apparatus for High Tension Systems.—General Arrangement of Controlling Apparatus for Low Tension Systems.—Examples of Complete Installations.—Long Distance Transmission Schemes.

"Well written. . . . Admirably illustrated, both by photographs and diagrams. The diagrams in particular are remarkably good and clear."—*Scotsman.*

SEVENTEENTH EDITION, Thoroughly Revised and Enlarged. 8s. 6d.

A POCKET-BOOK OF ELECTRICAL RULES & TABLES

FOR THE USE OF ELECTRICIANS AND ENGINEERS.

BY JOHN MUNRO, C.E., & PROF. JAMIESON, M.INST.C.E., F.R.S.E.
With Numerous Diagrams. Pocket Size. Leather, 8s. 6d.

GENERAL CONTENTS.

Units of Measurement.—Measures.—Testing.—Conductors.—Dielectrics.—Submarine Cables.—Telegraphy.—Electro-Chemistry.—Electro-Metallurgy.—Batteries.—Dynamos and Motors.—Transformers.—Electric Lighting.—Miscellaneous.—Logarithms.—Appendices.

"WONDERFULLY PERFECT. . . . Worthy of the highest commendation we can give it."—*Electrician.*

"The STERLING VALUE of Messrs. MUNRO and JAMIESON'S POCKET-BOOK."—*Electrical Review.*

By PROFESSORS J. H. POYNTING & J. J. THOMSON.

In Five Volumes. Large 8vo. Sold Separately.

A TEXT-BOOK OF PHYSICS.

BY

J. H. POYNTING,
SC.D., F.R.S.,
Late Fellow of Trinity College, Cambridge;
Professor of Physics, Birmingham
University.

AND

J. J. THOMSON,
M.A., F.R.S.,
Fellow of Trinity College, Cambridge; Prof.
of Experimental Physics in the University
of Cambridge.

INTRODUCTORY VOLUME, fully Illustrated. SECOND EDITION, Revised.
Price 10s. 6d.

PROPERTIES OF MATTER.

CONTENTS. — Gravitation. — The Acceleration of Gravity. — Elasticity. — Stresses and Strains. — Torsion. — Bending of Rods. — Spiral Springs. — Collision. — Compressibility of Liquids. — Pressures and Volumes of Gases. — Thermal Effects Accompanying Strain. — Capillarity. — Surface Tension. — Laplace's Theory of Capillarity. — Diffusion of Liquids — Diffusion of Gases. — Viscosity of Liquids. — INDEX.

"Students of physics cannot fail to derive benefit from the book." — *Knowledge.*

"We regard this book as quite indispensable not merely to teachers but to physicists of ever grade above the lowest." — *University Correspondent.*

VOLUME II. THIRD EDITION. Fully Illustrated. Price 8s. 6d.

SOUND.

CONTENTS. — The Nature of Sound and its chief Characteristics. — The Velocity of Sound in Air and other Media. — Reflection and Refraction of Sound. — Frequency and Pitch of Notes. — Resonance and Forced Oscillations. — Analysis of Vibrations. — The Transverse Vibrations of Stretched Strings or Wires. — Pipes and other Air Cavities. — Rods. — Plates. — Membranes. — Vibrations maintained by Heat. — Sensitive Flames and Jets. — Musical Sand. — The Superposition of Waves. — INDEX.

"The work . . . may be recommended to anyone desirous of possessing an EASY, UP-TO-DATE STANDARD TREATISE on Acoustics." — *Literature.*

"Very clearly written. . . . The names of the authors are a guarantee of the SCIENTIFIC ACCURACY and UP-TO DATE CHARACTER of the work." — *Educational Times.*

JUST OUT. VOLUME III. Fully Illustrated. Price 15s.

HEAT.

CONTENTS. — Temperature. — Expansion of Solids. — Liquids. — Gases. — Circulation and Convection. — Quantity of Heat; Specific Heat. — Conductivity. — Forms of Energy; Conservation; Mechanical Equivalent of Heat. — The Kinetic Theory — Change of State; Liquid Vapour. — Critical Points. — Solids and Liquids. — Atmospheric Conditions. — Radiation — Theory of Exchanges. — Radiation and Temperature. — Thermodynamics. — Isothermal and Adiabatic Changes. — Thermodynamics of Changes of State, and Solutions. — Thermodynamics of Radiation. — INDEX.

Remaining Volumes in Preparation—

LIGHT; MAGNETISM AND ELECTRICITY.

THE MEAN DENSITY OF THE EARTH: An Essay to which the Adams Prize was adjudged in 1893 in the University of Cambridge. By J. H. POYNTING, Sc.D., F.R.S., Late Fellow of Trinity College, Cambridge; Professor of Physics, Birmingham University. In Large 8vo, with Bibliography, Illustrations in the Text, and Seven Lithographed Plates. 12s. 6d.

"An account of this subject cannot fail to be of GREAT and GENERAL INTEREST to the scientific mind. Especially is this the case when the account is given by one who has contributed so considerably as has Prof. Poynting to our present state of knowledge with respect to a very difficult subject. . . . Remarkably has Newton's estimate been verified by Prof. Poynting." — *Athenæum.*

THIRD EDITION, Revised, Enlarged, and Re-issued. Price 6s. net.

A SHORT MANUAL OF INORGANIC CHEMISTRY.

BY

A. DUPRÉ, Ph.D., F.R.S.,

AND

WILSON HAKE, Ph.D., F.I.C., F.C.S.,
Of the Westminster Hospital Medical School.

"A well-written, clear and accurate Elementary Manual of Inorganic Chemistry. . . We agree heartily with the system adopted by Drs. Dupré and Hake. WILL MAKE EXPERIMENTAL WORK TREBLY INTERESTING BECAUSE INTELLIGIBLE."—*Saturday Review.*

"There is no question that, given the PERFECT GROUNDING of the Student in his Science, the remainder comes afterwards to him in a manner much more simple and easily acquired. The work IS AN EXAMPLE OF THE ADVANTAGES OF THE SYSTEMATIC TREATMENT of a Science over the fragmentary style so generally followed. BY A LONG WAY THE BEST of the small Manuals for Students."—*Analyst.*

LABORATORY HANDBOOKS BY A. HUMBOLDT SEXTON,

Professor of Metallurgy in the Glasgow and West of Scotland Technical College.

OUTLINES OF QUANTITATIVE ANALYSIS.

FOR THE USE OF STUDENTS.

With Illustrations. FOURTH EDITION. Crown 8vo, Cloth, 3s.

"A COMPACT LABORATORY GUIDE for beginners was wanted, and the want has been WELL SUPPLIED. . . . A good and useful book."—*Lancet.*

OUTLINES OF QUALITATIVE ANALYSIS.

FOR THE USE OF STUDENTS.

With Illustrations. FOURTH EDITION, Revised. Crown 8vo, Cloth, 3s. 6d.

"The work of a thoroughly practical chemist."—*British Medical Journal.*
"Compiled with great care, and will supply a want."—*Journal of Education.*

ELEMENTARY METALLURGY:

Including the Author's Practical Laboratory Course. With many Illustrations. [See p. 66 *General Catalogue.*

THIRD EDITION, Revised. Crown 8vo. Cloth, 6s.

"Just the kind of work for students commencing the study of metallurgy."—*Practical Engineer.*

Griffin's Geological, Prospecting, Mining, and Metallurgical Publications.

		PAGE
Geology, Stratigraphical,	R. Etheridge, F.R.S.,	52
,, Physical,	Prof. H. G. Seeley,	52
,, Practical Aids,	Prof. Grenville Cole,	53
,, Open Air Studies,	,, ,,	85
Griffin's "New Land" Series,	Ed. by Prof. Cole,	54
Prospecting for Minerals,	S. Herbert Cox, A.R.S.M.,	55
Food Supply,	Robt. Bruce,	55
New Lands,	H. R. Mill, D.Sc., F.R.S.E.,	54
Building Construction,	Prof. James Lyon,	54
Ore and Stone Mining,	Sir C. Le Neve Foster,	56
Elements of Mining,	,, ,,	56
Coal Mining,	H. W. Hughes, F.G.S.,	56
Practical Coal Mining,	G. L. Kerr, M.Inst.M.E.,	58
Elementary ,,	,, ,,	58
Electrical Coal Mining,	D. Burns,	58
Mine-Surveying,	Bennett H. Brough, A.R.S.M.,	57
Blasting and Explosives,	O. Guttmann, A.M.I.C.E.,	57
Mine Accounts,	Prof. J. G. Lawn,	57
Mining Engineers' Pkt.-Bk.,	E. R. Field, M.Inst.M.M.,	57
Petroleum,	Redwood and Holloway,	61
A Handbook on Petroleum,	J. H. Thomson and Dr. Redwood,	61
The Petroleum Lamp,	,, ,,	61
Metallurgical Analysis,	Macleod and Walker,	60
Microscopic Analysis,	F. Osmond & J. E. Stead, F.R.S.,	60
Metallurgy (General),	Phillips and Bauerman,	60
,, (Elementary),	Prof. Humboldt Sexton,	66
Getting Gold,	J. C. F. Johnson, F.G.S.,	58
Gold Seeking in South Africa,	Theo Kassner,	59
Cyanide Process,	James Park, F.G.S.,	59
Cyaniding,	Julian and Smart,	59
Electric Smelting,	Borchers and McMillan,	67
Electro-Metallurgy,	W. G. McMillan, F.I.C.,	67
Assaying,	J. J. & C. Beringer,	66
Metallurgical Analysis,	J. J. Morgan, F.C.S.,	66
Griffin's Metallurgical Series	Ed. by Sir W. Roberts-Austen,	62
Introduction,	Sir W. Roberts-Austen, K.C.B.,	63
Gold, Metallurgy of,	Dr. Kirke Rose, A.R.S.M.,	63
Lead and Silver, ,,	H. F. Collins, A.R.S.M.,	64
Iron, Metallurgy of,	Thos. Turner, A.R.S.M.,	65
Steel, ,,	F. W. Harbord,	65
Metallurgical Machinery,	H. C. Jenkins, A.R.S.M.,	64
Iron-Founding,	Prof. Turner,	68
Goldsmith and Jeweller's Art,	Thos. B. Wigley,	68
Precious Stones,	Dr. Max Bauer,	68

JS14
V25 nes

RETURN TO the circulation desk of any
University of California Library
or to the
NORTHERN REGIONAL LIBRARY FACILITY
Bldg. 400, Richmond Field Station
University of California
Richmond, CA 94804-4698

ALL BOOKS MAY BE RECALLED AFTER 7 DAYS

- 2-month loans may be renewed by calling (510) 642-6753
- 1-year loans may be recharged by bringing books to NRLF
- Renewals and recharges may be made 4 days prior to due date.

DUE AS STAMPED BELOW

MAR 11 1998

JAN 04 1999

12,000 (11/95)

YC 94096

TP751
B8
1904
v.1
Butterfield
141343