Smoke prevention and fuel economy : (based on the German work of E. Schmatolla) / by Wm. H. Booth and John B.C. Kershaw, F.I.C ; with seventy-five illustrations.

Booth, William H.
Kershaw, John B. C. 1862-
Schmatolla, Ernst.

London : A. Constable & co., ltd., 1904.

SMOKE PREVENTION AND FUEL ECONOMY

BOOTH AND KERSHAW

SMOKE PREVENTION AND FUEL ECONOMY

SMOKE PREVENTION AND FUEL ECONOMY

(Based on the German Work of E. Schmatolla)

BY

Wm. H. BOOTH M.Amer.Soc.C.E.
(Formerly of the Manchester Steam Users' Association)

AND

JOHN B. C. KERSHAW F.I.C.

WITH SEVENTY-FIVE ILLUSTRATIONS

LONDON
ARCHIBALD CONSTABLE & CO LTD
16, JAMES STREET, HAYMARKET
1904

Butler & Tanner,
The Selwood Printing Works,
Frome, and London.

Contents.

Appendix

List of Illustrations.

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

Preface.

OUR object in writing this book has been to bring before the fuel-using public, in as brief a manner as possible, the principles of fuel combustion, and the means by which the practice of fuel combustion has been carried out, too often with little or no consideration of the physical and chemical conditions involved. The book has grown round our original idea of presenting a simple translation of the German book of Ernst Schmatolla,[1] to which however we have found it necessary to add much to fit our book to English practice, and to subtract other less suitable matter.

We have illustrated also a few examples of English and American appliances, and mechanical stokers, but wish to say that we have employed these merely as illustrations or as representatives of a class or type; desiring not to recommend any appliance further than it appears to fulfil the necessary requirements of thorough mixture of gases and air at a high temperature, the two essentials in our opinion of complete and perfect combustion. We believe

---

[1] *Rauchplage u. Brennstoffverschwendung*, Gebrüder Jänecke, Hanover, 1902.

that coal of bituminous quality is capable of perfect combustion, and that black smoke is merely so much evidence of improper design. This defect may be due, either to insufficient knowledge of the scientific principles of combustion on the part of the designer, or to parsimony on the part of the buyer and owner of the plant. The former evil we hope to remove by the present book. The latter can only be overcome by a greater insistence that the health and welfare of the general public are of paramount importance, and that they shall not be sacrificed to slight pecuniary gains on the side of the smoke-producer. Smoke prevention is at present possible—in time, it will, we believe, become general.

THE AUTHORS.

Westminster, London, *September* 1, 1904.

Introduction.

FROM the very earliest days of the use of coal the smoke question has been prominent, and laws were enacted to forbid the use of "sea-cole" in London, coal being so named because it was brought by sea from the Tyne Ports. The necessity for fuel and the growing scarcity of wood made all such enactments more or less a dead letter in the sixteenth century, and the nineteenth century legislation against smoke has been practically rendered nugatory by the ignorance of the public, who have come to believe that bituminous coal cannot be burned without producing smoke, and that where, by grace, it can so be burned, there will necessarily be loss.

In the latter part of the eighteenth century it may be supposed that James Watt, when he entered upon practical steam engineering, found the combustion of coal very crudely carried on. The county of Cornwall was the chief steam-using district, owing to its extensive and well-developed mines, which required to be pumped free of water.

The boilers used to generate steam for the pumps were large circular affairs under which many tons of coal were burning at one time. Trevithick speaks of one such boiler at the Dolcoath Mine, the firegrate of which had a grate 22 × 9 feet, and carried thirty tons of coal on a fire 7 feet thick.

Wales was the source of coal, and it is probable that the coal was of the so-called smokeless variety, so that there was perhaps little to urge on any better furnace arrangements. In the use of steam, however, the Cornish engineers appear to have been specially clever, and it is likely that Watt, when introducing his condensing engine, did all he could to secure better boiler conditions, in order that the fullest possible credit might redound to his new system of condensing.

Thus Watt is found to give directions for the proper firing of bituminous coal, and his advice, apart from the form of furnace, is as sound to-day as anything can be.

He recommended that coal be piled upon the dead-plate. There were no fire-doors: the pile of coal served as the door. The heat of the fire beyond caused the more volatile parts of the coal to be driven gradually off.

The pile being porous, some air would be drawn through it and would mingle with the escaping gas and burn with it. In time the pile became wholly or partially coked. The attendant then pushed the fuel onwards over the now decaying fuel on the grate, spreading it evenly over the grate surface, where it would certainly at first give off freely more gas which would be copiously fed with air from the unclosed furnace opening. The attendant then closed this opening by rapidly shovelling a fresh pile of coal upon the dead-plate, and the same cycle of operations was repeated. The boiler to which this furnace was adjunct was the first wagon boiler, so called because of its general form, and later the plain cylinder with hemispherical ends, usually termed the egg-ended boiler. This rested by means of ears or brackets, riveted near its upper part, upon side walls of brick, between which was the firegrate of considerable breadth, which terminated in a roomy dead-plate on which the green coal was piled. The present day dead-plate is a mere rudimentary survival of that of one hundred years ago.

The bottom of the boiler was brought down to within about eighteen inches of the grate surface, a distance that would have been better doubled.

The hot gases enveloped the boiler up to the water level, and usually there was a flash flue, or the gases passed once under the boiler in a single flue with no return side flues.

It will be noted that Watt advocated the " coking " system of firing ; that is the gases mixed with air travelled over the length of the bright hot fire and were afforded ample room for combustion in the wide flue beyond, which was bounded on three sides by brickwork. Apart from the cooling effect of the fourth boundary, or boiler bottom, everything was favourable to smokeless combustion. The under-fired boiler endured for some time ; indeed, it still serves in the original form at certain collieries and ironworks, and the writer has seen this boiler within the past few years still fired as described, and without any other door than the heap of green coal.

An improvement was introduced in the shape of an internal tube passing through the boiler from end to end, and affording so much more heating surface. This tube, by bringing the gases back to the front end of the boiler, necessitated a modified brick-setting, and probably this led up to the two side flues. Another step was to enlarge the inner tube and place the firegrate inside. This produced the Cornish boiler, which was brought out by Trevithick. From it Fairbairn developed the double tube, or Lancashire boiler. In all these modifications the arrangement of the fires and the course of the gases relative thereto, remained the same. It was found, however, that more power could be produced from a boiler, that is to say, it would generate more steam, when the coal was spread over the fire, in place of being coked on the dead-plate. Combustion was more rapid, and smoke was the result. This was partially due to the gradual neglect of steam plant as it became common and familiar, and fell into the hands of less scientific men to attend. Indeed, when Fairbairn founded the Manchester Steam Users' Association in 1854, steam engineering had fallen to a low ebb, coal consumption was excessive, boiler explosions were of alarming frequency, and minor accidents due to broken blow-off pipes were of daily occurrence. Boiler making was the roughest and crudest of arts, and boiler plate was of poor quality; whilst rivet holes were punched, and that badly and irregularly, and the worst and most barbaric "drifting" was employed to make openings sufficient to enable a rivet to be entered. In twenty-five years the Association and the Boiler Insurance Companies, which sprang up later, had raised boiler making to a high-class art, and much credit is due, in this connexion, to the late Daniel Adamson, who had the courage to use steel plate, and invented the flanged furnace seam, which made it possible for the Lancashire boiler to maintain its position at the head of all boilers, in respect of all-round safety up to and at the present day. The Lancashire boiler has the correct arrangement of furnace to fit it to burn coal smokelessly, and, if not overpressed, it can be fired smokelessly by a good fireman. To this end it is necessary to provide air grids in the furnace doors, with an opening of about four square inches for each square foot of grate surface. These openings should be fully open when each fresh charge of fuel has been fired, and they should remain fully open for a short time, and should then gradually close.

As is always the case in a growing business, the original provision of boilers became too small in most works, and, when over-worked, smokeless firing became more difficult. Adding boilers often demonstrates the smallness of the chimney, and with poor draught the requisite volume of air cannot flow in through the air-grids in the fire-doors.

There was continual rivalry in producing boilers to do a maximum of evaporation, and, one unfortunate day, the cross-water tube made its appearance. These are parallel or taper pipes five or six inches diameter, or four or five to eight or ten inches if tapering, welded or riveted at various inclinations across the furnace tubes of the boiler behind the fire-bridge. They vary from three to fifteen in number. They were claimed to increase the heating surface of a boiler and to promote circulation. Actual experiment has disproved the latter claim, and if there is anything in the former it was more than counterweighted in actual working.

The water-pipes formed lodging for scale, but did the most harm by their bad effect on combustion. They extinguished nascent flame and produced large amounts of soot, and the cross-water tube was fatal to smokelessness. Still worse was the mechanical and physical error of non-circular flue tubes. In this type an oval flue, incapable of self-support, was propped up by a thickly-spaced forest of cross-water pipes which were most provocative of soot, and were always so covered with it, that their surface was of small value as heating surface.

Fortunately this variety of boiler flue is unsuitable for modern pressures, and it has given way to the more practical and scientifically correct circular furnace tube Lancashire boiler, without any cross pipes. The same lack of knowledge of the principles of combustion, however, which gave birth to the cross-water tube, has extended to the present day, and has gained the upper hand. Before the advent of the latter-day water-tube boiler, the question of smoke was gradually being brought into line. Water-tube boilers had been tried and found wanting in the matter of smoke. In the United States, however, where the making of boilers is very far behind the practice of this country (and it was still further behind a quarter of a century ago), the water-tube boiler was persevered with, and the well-known type of to-day was evolved, with its inclined tubes, and, when moderately worked, some degree of safety, or at least a danger much less than attached to the discarded Howard safety boiler. But the water-tube boiler in America was the product of the hard coal region. It was made to burn Pennsylvanian anthracite, which is absolutely smokeless, and so far as coal combustion is concerned, the water-tube boiler is all right except for the fact, that even smokeless anthracite should give better results if the furnace gases are all mixed up, so that there may not be too much air at one part and too little at another.

A hard coal furnace, produces carbon dioxide, CO_2, which is colourless. With insufficient air it also produces carbon monoxide, also colourless. With a correct furnace, the latter should be burned by means of the excess of air which may come through bare or thinner parts of the fire. Howbeit, this boiler, which could not make smoke when fired with Pennsylvanian anthracite, was sent over to Great Britain to use bituminous coal, and being set exactly as in America, the results have been hopelessly bad, and the present smoke of London is due to this boiler more than to anything else. It has resulted in fines and other difficulties, and, to secure peace, frequently in the use of the best Welsh smokeless coal at double cost. But even with Welsh coal the water-tube boiler will produce bad smoke if badly set. We hope to show in the sequel why this is so, and what is necessary to prevent such results. We shall show something of what has been attempted in the way of preventing smoke, and shall have to deal more or less with questions of furnace forms, draught, systems of mechanical stoking, and other matters which closely interconnect with the subject. Schmatolla in the book upon which our work is based, has put together something of the principles and practice of fuel combustion in Germany. In that country certainly the scarcity of fuel and the severity of the law, and the scientific training of the men who hold the purse-strings, may account for the better status of the coal combustion question than with ourselves.

It remains, however, a fact that the ordering of coal combustion arrangements in electric light stations and power houses has been sometimes in the hands of men who are electrical engineers chiefly, that they have been at the mercy of boiler makers, and have simply installed steam plant irrespective of all scientific principles or value. Controlled by committees of no scientific or technical knowledge, or by boards whose ideas have not extended beyond questions of barest first cost, those who have known better have perhaps found themselves hampered for want of sufficient appropriations to put in really correct plant. Yet what is possible in Germany should be more easily possible here. With every admiration for certain phases of American practice however, this admiration cannot be extended to American steam practice in this country, for it is to this that we owe our "skies plastered with soot," a not, perhaps, unnatural result of work done by men who are alien to the country, and look only to a few years' residence here, before returning to America. Still, it is not unreasonable to demand of such the same respect which we ourselves give to life outside mere dollars. We say emphatically, there is no need for smoke. Its production is evidence of neglect of simple laws of chemistry. Smoke can be prevented, and every one should help to enforce the law which says, "thou shalt not smoke." The scriptural hospitality to the stranger within our gates has been freely given. Let us demand of that stranger that at least he shall not break the laws under which he comes unbidden.

Experience shows that smoke can often be prevented by the admission of a very large excess of air. This has been done by admitting it under the grate and through the lower part of the bridge. It appears that the large volume of air enables every particle of gas to secure its requisite of oxygen, but the method is uneconomical and causes undue reduction of temperature in the flues. This brings into prominence the great importance of thorough mixture of the air with the gas. If perfectly mingled in the correct chemical proportion, combustion would be perfect without excess of air. This desirable admixture is never attained, but it is approximated in the furnaces of Lancashire boilers, and with good draught and good firing, smokelessness is secured without serious difficulty in boilers without cross tubes. It also appears that combustion is not so rapid when the smaller amounts of air are employed, and it is therefore extended along the flues, and the gases are all the time exposed to cooling by the boiler. Here the importance of temperature appears. It is necessary to conserve the temperature of the gases, until they are in a state of combustion sufficiently active, to maintain such temperature against the cooling effect of the boiler plates. How this has been arrived at in German practice will appear later.

Though the burning of coal in wholly refractory furnaces has been advocated by one of the Authors for years, as the only means whereby smokelessness could be absolutely assured, it appears that the small additional initial expense has been too much for most engineers to face. The external furnace has not always been built with a view to saving the radiant heat, and the *Engineer* in October, 1903, laid it down as a fact that all such attempts have proved a failure, and that no one even knew what became of the heat lost. We need hardly say that this view does not accord with reason or experience, and we are supported by Mr. F. Grover, of Leeds, who conducted an investigation of Bengal coals for the Indian Government, and found that such furnaces gave good results. In America they have been

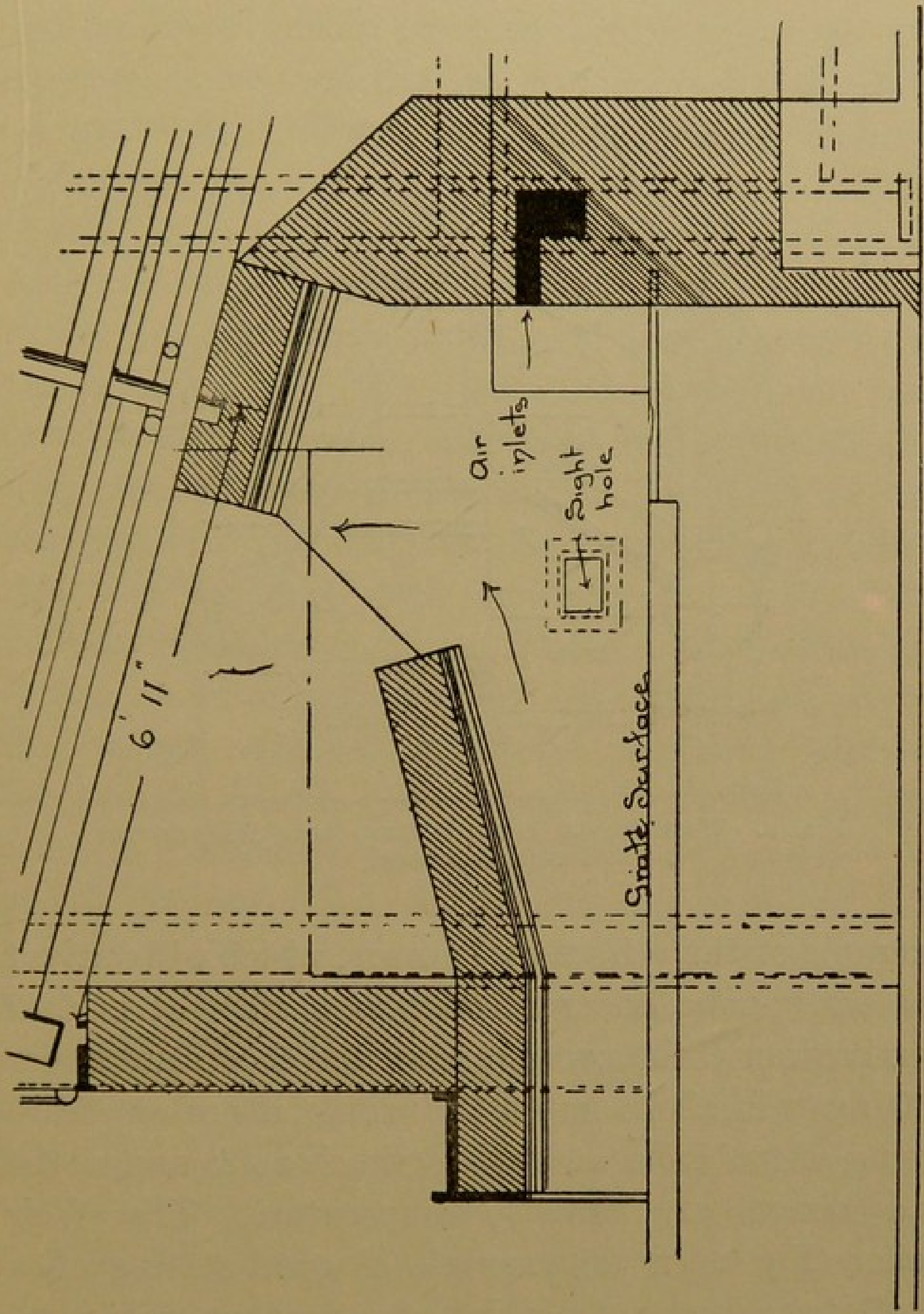

FIG. 1. REFRACTORY FURNACE FOR WATER TUBE BOILER.

employed under the name of the Dutch oven, and over twenty years ago Mr. Adams, of the Safety

Valve Works of West Gorton, built a large external furnace to a tubular boiler, with satisfactory results.

The water-tube boiler setting of Fig. 1 is an

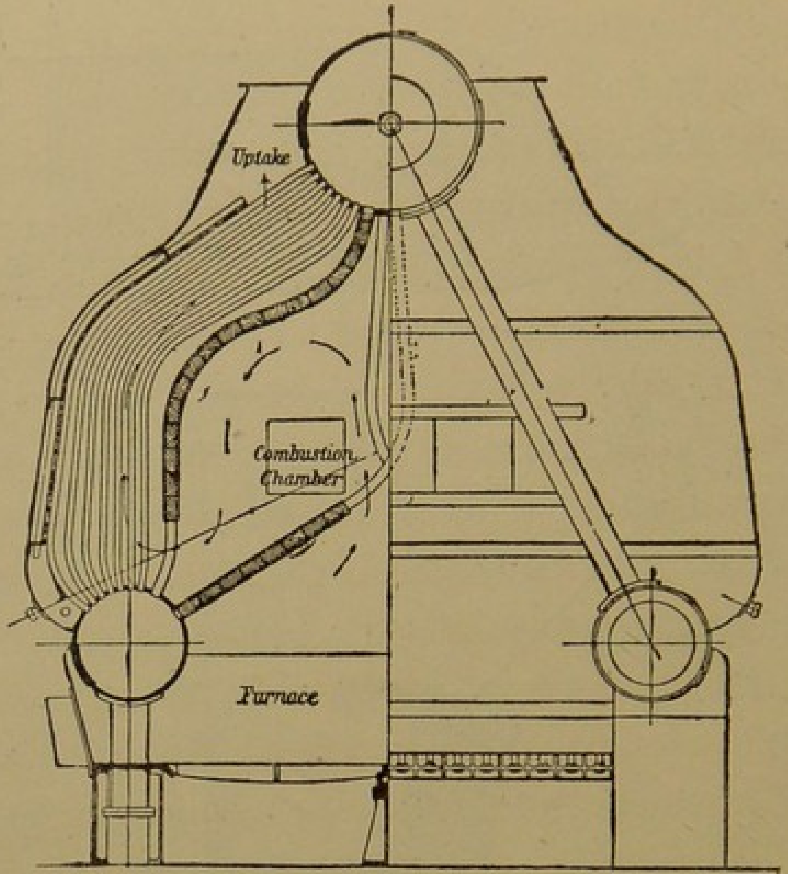

Fig. 2. Weir Small Tube Boiler, with Refractory Lined Furnace.

example of the refractory furnace, which will convert the water-tube boiler furnace to a state of perfect combustion with economy, and the successful boiler settings will all be noted to include, if not an entire lining of firebrick, at least so much as to secure the end aimed at, namely, temperature. The Weir boiler (Fig. 2) is an example of good setting of a small tube boiler, in which the furnace and combustion chamber are lined with firebrick, and perfect combustion is secured.

DOMESTIC SMOKE

The solution of the domestic smoke problem hardly comes within the province of this book, but it seems to us that the solution lies in the direction of gas firing. There appears no reason why the suggestion of Mr. B. H. Thwaite should not be carried out. He proposes to carbonize coal in retorts to the extreme point, by means of exhaustion of the retort carried to the point of depletion of all the volatile gases. He would then convert the coke in separate producers into poor gas, and mix this with the retorted product. In this way all the heating effect of domestic fires would be secured, with the discharge into the atmosphere of water vapour and clean carbon dioxide. The same gas mains would supply gas for heat, light, or power, the second application being rendered possible by means of the incandescent mantle. Some rougher modification of this, however, appears to us to be necessary for a certain class of the population, who would not go to the trouble or expense of renewing the ordinary tender incandescent mantle. The difficulties in the way of altering every fireplace to burn bituminous coal without smoke would be so great, that even a cheap and perfect smoke-preventing fireplace would be impossible of realization as a popular article. The stove as used in America and Germany is not attractive to the Englishman, and demands special anthracite coal. Gas fuel will give a bright and cheerful fire, and can be arranged for purchase on the penny-in-the-slot system, which has already proved a success with the poorer classes, and offers them a means of purchasing their fuel in small quantities at a fixed price, and thereby protecting them against the extortionate rates charged for fuel sold by the nominal hundred-weight of, too frequently, ninety or even eighty pounds weight. Smokeless combustion on the domestic hearth, at present, is only to be obtained where a brisk fire is maintained and fresh fuel is brought up from below on the hopper system, whereby the evolved hydrocarbon gases are compelled to travel upwards through a thick fire of red-hot coked fuel. With these few remarks, therefore, the subject of domestic smoke must be dismissed as outside the scope of this volume, and only to be treated along special lines. These will be readily understood by those who have grasped the fundamental ideas of air mixture and temperature, without the inclusion of which any scheme of smokeless combustion is impossible. The open grate does not possess these essentials, and even the arrangement foreshadowed above demands a deep red fire and an expensive under hopper of fuel, with an upwinding device that places it beyond the reach of the poor man, who cannot weigh the disadvantages of an immediate first cost against an ultimate advantage in cleanliness and economy.

CHAPTER I

The Chemistry of the Combustion Process.

THE prevention of smoke and fuel waste in connexion with industrial heating appliances, either for steam-raising or for other purposes, is dependent upon a clear understanding of the chemical and physical changes which occur during the combustion process, and upon a proper provision for these changes to take place within the combustion area. The smoke and unconsumed gases, which form the most deleterious portions of chimney gases, are due to arrested combustion; that is, to a partial in place of a complete oxidation of the carbon and hydrocarbons of the fuel.

The most important factors in the combustion process are the carbon or carbonaceous constituents of the fuel, and the oxygen of the air.

Carbon, which is represented chemically by the symbol C, is one of the bodies classified by chemists as Elements, and has an atomic weight of 12. In nature, it is only found in the free state, as diamond and graphite. When heated in oxygen or in air, it unites with the former, producing two compound gases known as carbon monoxide and carbon dioxide respectively, and in the course of this change it gives out much heat. The process is really one of rapid oxidation. Carbon forms the most important combustible constituent of all natural fuels, and taking these in the order of their age we have the following list: wood, turf, lignite, brown coal, soft or bituminous coal, hard or steam coal, and anthracite. Petroleum and natural gas may also be regarded as fuels, but the exact relation of these to each other and to the solid fuels named above, from the geologist's point of view, has not yet been settled. The distinguished French chemist, Moissan, has put forward a theory that petroleum is formed in the earth's crust by the decomposition of metallic carbides.

In wood, or woody fibres, the carbon occurs combined in the form of *Cellulose*. This is represented chemically by the symbol $C_6H_{10}O_5$, and contains carbon, hydrogen and oxygen in the atomic proportions denoted by the figures. Expressed as a percentage, carbon forms 44 per cent. of the total weight in pure cellulose.

The fuels that are produced by the decay of wood and woody fibres, under conditions which hinder the access of air, contain a higher percentage of carbon than the original wood. This percentage of carbon increases as the process of fossilization and decay advances, and it reaches its maximum in the fuels which geologists class as the oldest occurring or found in the earth's crust.

In addition to carbon, the natural fossilized fuels contain oxygen and hydrogen, in chemical combination with the carbon, and with each other.

Oxygen (chemical symbol O, atomic weight 16) is a gaseous element, and forms one of the constituent gases of the atmosphere.

In the free state, it is a gas without colour and without smell. Combined with hydrogen, it forms eight-ninths of the total weight of water on this earth, and in addition it is found in combination in all natural fuels.

Hydrogen (chemical symbol H, atomic weight 1) is also a gaseous element, and is the lightest gas known. It occurs only rarely in nature in the free state. It resembles carbon in being a combustible element; and its combination with oxygen is marked by the liberation of 29,150 calories of heat, and by the production of water.

Nitrogen (chemical symbol N, atomic weight 14) has importance for the combustion process, only as a diluting constituent of the air. This gaseous element is not a supporter of combustion; that is, at moderate temperatures it does not combine with carbon or with oxygen. But under special conditions, it can be made to unite with both of these elements.

The Air is a *mixture*, not a chemical combination, of oxygen and nitrogen, in the volumetric proportions denoted in round numbers by 21 and 79. One litre of air weighs 1·293 grammes, and it contains roughly 23 per cent. of oxygen and 77 per cent. nitrogen by weight.

Sulphur occurs as an impurity in most natural fuels, and in coal it is due to the presence of pyrites or "brasses" in the coal seams. It is an elementary substance (chemical symbol S, atomic weight 32), and it burns in oxygen with production of a stifling gas called sulphurous acid, represented by the chemical symbol, SO_2.

The elementary bodies mentioned above yield, in combination with one another, compounds which may be either solid, liquid, or gaseous, at the ordinary temperature. The combustible element, carbon, when burnt in oxygen or air, yields two compounds, namely carbon mon-oxide and carbon di-oxide; both gases without colour or distinctive smell. Carbon monoxide is formed by the union of one atom of carbon with one atom of oxygen, and is represented by the symbol CO; while carbon dioxide is formed by the union of one atom of carbon, with two atoms of oxygen, and is represented chemically by the symbol CO_2. The first of these gases is combustible; that is, it can unite with another atom of oxygen, and then yields CO_2. Carbon monoxide is a directly poisonous gas; while carbon dioxide is only dangerous as an asphyxiant.

Hydrogen, as already stated, when burnt in oxygen or air, combines with one-half its volume of oxygen and yields water; generally in the gaseous state, or as steam.

The combinations of carbon and hydrogen yield an important series of chemical compounds known as the hydro-carbons, and play an important part in the combustion process. These hydro-carbons are some of them solid, some liquid, and some of them gaseous, at the normal temperature.

The following are the more important of these compounds, in relation to the combustion of fuel—

Methane or Marsh Gas	Chemical symbol	CH_4
Ethylene or Olefiant Gas	,, ,,	C_2H_4
Acetylene	,, ,,	C_2H_2

The heats of combustion of these hydro-carbons, according to Berthelot, are—

Methane	13,343	calories[1]
Ethylene	12,182	,,
Acetylene	12,142	,,

In each case, carbonic acid gas and water vapour are produced by their complete combustion in oxygen or air.

Sulphur also forms a gaseous compound with hydrogen, known as sulphuretted hydrogen, when the combustion of a fuel containing much sulphur and hydrogen occurs, without a sufficiency of oxygen (or air) being admitted to the grate. This gas has a distinctive odour, and its presence in the waste gases, is always a sign of imperfect combustion.

---

[1] One calorie, or unit of heat, is that amount which is required to raise the temperature of the unit weight of water through 1°C. The unit weight is the gram for the small calorie, and the kilogram for the large calorie. In English practice the pound and the degree F. are usually employed; and the resultant heat unit is known as the B.Th.U., or British Thermal Unit.

When an excess of oxygen or air is present at the requisite temperature, sulphuretted hydrogen gas burns to sulphur dioxide and water.

Turning now to a consideration of the chemical changes involved in the combustion of natural or artificial fuels, it is advisable to commence with that of the purest form of carbon. This is found in wood-charcoal and in coke, these products being obtained by the dry distillation (that is, distillation in the absence of air or oxygen) of wood and coal respectively. When either wood charcoal or coke is raised to a temperature of 700°C., known as the ignition temperature, in an excess of oxygen or of air, combination occurs between the carbon and oxygen, with production of light and heat, and the wood charcoal or coke is reduced to ash, with change of all the carbon into gaseous carbon dioxide. The following represents the change, in chemical symbols, and the weight and volume of gases evolved, when oxygen is employed—

Chemical equation . . .	$C + 2O = CO_2$
Weights in kilograms . . .	$1 + 2\cdot667 = 3\cdot667$
Volumes in cubic metres . .	$\cdot932$[1] $+ 1\cdot865 = 1\cdot865$

When air is employed the changes are as follows—

Chemical equation . .	$C + \text{Air} = CO_2 + xN$
Weights in kilograms . .	$1 + 11\cdot508 = 3\cdot667 + 8\cdot841$
Volumes in cubic metres .	$\cdot932$[1] $+ 8\cdot897 = 1\cdot865 + 7\cdot032$

---

[1] ·932 is the calculated volume of 1 kg. of carbon, when it has assumed the gaseous state. The kilograms can be changed into pounds avoirdupois by multiplying by 2·204, and the cubic metres can be changed into cubic feet by multiplying by 35·3.

When an insufficient supply of oxygen or air is present, the carbon is only converted into carbon monoxide gas, and the chemical and physical results are as follows—

In Oxygen—

Chemical equation . . .	$C+O=CO$
Weights in kilograms . . .	$1+1\cdot333=2\cdot333$
Volumes in cubic metres . .	$\cdot932$[1] $+\cdot932=1\cdot865$

In Air—

Chemical equation . .	$C+\mathrm{Air}=CO+xN$
Weights in kilograms . .	$1+5\cdot754=2\cdot333+4\cdot421$
Volumes in cubic metres .	$\cdot932$[1] $+4\cdot448=1\cdot865+3\cdot516$

The volumes of combustible in the above tables are for carbon in the gaseous state. One kilogram of carbon when burnt to carbon dioxide yields 8,137 calories of heat, while only 2,453 calories are liberated, when carbon monoxide is produced. It is customary now to ascribe this deficiency in heat-production, for the union with the first atom of oxygen, to the heat absorption due to the conversion of the carbon from the solid into the gaseous state. The heat which disappears in the performance of this work is 3,231 centigrade units.

Should the carbon monoxide first formed be mixed with the requisite amount of air or oxygen and burnt to CO_2, the following changes occur—

In Oxygen—

Chemical equation . .	$CO+O=CO_2$
Weights in kilograms . .	$1+\cdot571=1\cdot571$
Volumes in cubic metres .	$\cdot80+\cdot40=\cdot80$

---

[1] See Footnote on previous page.

In Air—

Chemical equation . .	$CO + Air = CO_2 + xN$
Weights in kilograms . .	1 + 2·463 = 1·571 + 1·892
Volumes in cubic metres .	·80 + 1·908 = ·80 + 1·508

Carbon monoxide gas can also be formed, by the reduction of carbon dioxide in the presence of red-hot carbon, according to the following equation—

$$CO_2 + C = 2\ CO.$$

While the formation of carbon monoxide by the direct union of carbon and oxygen produces 2,453 calories of heat, as stated above, the formation of this gas by reduction of carbon dioxide already formed, is a heat *absorbing* reaction, and 3,159 calories of heat disappear in the change. This reduction of carbon dioxide in the presence of heated carbon to carbon monoxide, occurs frequently under certain conditions of fuel utilization; and the reaction is purposely brought about in the various methods of manufacturing "Producer gas" from raw fuel.

It is now necessary to consider the changes involved when water-vapour or steam comes into contact with carbon at a red heat, since this is always present in smaller or larger amounts in the air and fuel; and in many appliances for smoke prevention it is purposely admitted to the furnaces. The chemical equations show that either carbon monoxide, or carbon dioxide, and free hydrogen are produced, carbon dioxide being formed when two molecules of water-vapour react with one atom of carbon. The temperature at which this decomposition of water-vapour occurs is between 800° and 1000°C.; carbon monoxide being formed at the higher temperature. These reactions play an important rôle in the Dowson and Mond gas producers, and in the production of water gas.

In addition to the carbon which is the chief constituent of all natural fuels, these contain considerable percentages of oxygen and hydrogen, which remain after the fossilization of the cellulose of the original woody fibre has proceeded through its various stages. The percentage of oxygen, however, diminishes with the age of the fuel, being greatest in peat and lignite, and lowest in anthracite. The percentage of hydrogen does not show such great variation, and it is generally assumed to be present combined with carbon to form hydrocarbons. The most important of these for the fuel user are those already named:—methane, ethylene and acetylene. The exact state in which the oxygen and hydrogen exist in solid fuels has, however, not yet been settled by scientists; but there are some grounds for the belief that both gases exist free in the solid or liquid state. For a detailed discussion of this question, see *Oil Fuel*, by W. H. Booth, 1903, pp. 99–101. The percentage of these hydrocarbons evolved when heating raw fuel, is the measure of the difficulty experienced in burning the fuel without smoke. The greater the percentage of volatile hydrocarbons evolved on heating the fuel, the greater is the need for careful design of the furnace in which it is to be used. Table I in the Appendix contains some valuable information relating to typical English coals, and from this table it will be seen that the percentage of volatile matter varies from 10 per cent. in South Wales steam coal, to 35 per cent. in a North-country slack.

When the necessary conditions for perfect combustion are present, these gaseous hydrocarbons burn completely to carbon dioxide and water. The changes in the case of Methane (CH_4) are as follows—

Methane in Oxygen—

Chemical equation . .	$CH_4 + 4O = CO_2 + 2H_2O$
Weights in kilograms . .	$1 + 4{\cdot}000 = 2{\cdot}750 + 2{\cdot}250$
Volumes in cubic metres .	$1{\cdot}40 + 2{\cdot}800 = 1{\cdot}400 + 2{\cdot}800$

When air is employed to burn the methane in place of oxygen, the changes are set forth in the next tabular statement—

Methane in Air—

Chemical equation .	$CH_4 + \text{Air} = CO_2 + 2H_2O + xN$
Weights in kilograms	$1 + 17{\cdot}26 = 2{\cdot}750 + 2{\cdot}250 + 13{\cdot}26$
Volumes in cubic metres	$1{\cdot}40 + 13{\cdot}358 = 1{\cdot}400 + 2{\cdot}800 + 10{\cdot}61$

The combustion of Ethylene and Acetylene follow on similar lines, and it is hardly necessary to present a tabular statement of the changes for each of these gases. The heats of combustion produced by these hydrocarbons have already been given (see p. 31), the heat contained in the aqueous vapour being included in these results.

The ignition points for these gases, according to Mayer and Münch, are—

Methane, 667°C. Acetylene, 580°C.

The formation of visible smoke during the combustion of natural fuels is chiefly due to the liberation of these hydrocarbons, and to the lack of the oxygen or air, essential for their complete combustion to carbon dioxide and water.

At high temperatures these hydrocarbons decompose, and the carbon separates as soot or graphite. If insufficient oxygen or air be present, these particles remain unconsumed, although all the hydrogen may be converted into aqueous vapour; for hydrogen at a certain temperature is believed to have a greater affinity than carbon, for oxygen.[1] These particles of carbon, in the form of soot or graphite, may also remain unburnt even in presence of an excess of oxygen, should the temperature of the furnace be too low. The temperature required, in order to cause carbon to unite with oxygen to form carbon dioxide, is known as the temperature of ignition. For amorphous carbon, this is about 700°C.—for graphite it lies considerably higher. The hydrocarbons have also each their own ignition temperature; and no excess of air, or good admixture of the gases and air, can remedy the failure to maintain this minimum ignition temperature within the furnace.

The dissociation of hydrocarbons by heat, in "*absence*" of oxygen or of air, simply involves a

---

[1] The reducing action of heated carbon on aqueous vapour which occurs in gas-producers requires a high temperature for its completion. At lower temperatures the action may be reversed.

splitting-up of the molecule, into carbon and hydrogen molecules or atoms. Should only sufficient oxygen be present to combine with the hydrogen of the hydrocarbon, the following change will occur—

$$CH_4 + 2O = 2H_2O + C.$$

Methane and Oxygen yield Aqueous Vapour and Soot.

Increasing amounts of soot will be produced by the similar incomplete combustion of Ethane and Ethylene, since the proportion of carbon to hydrogen in these is greater than in marsh gas.[1]

It is customary to speak of smoke and the smoke nuisance as though black smoke were the only feature of imperfect combustion that demanded a remedy. But it cannot be too strongly emphasized that the visible impurities of the waste gases from factory chimneys are the least harmful part of their constituents ; and that the invisible gases, which too often escape as the result of imperfect combustion, are far more detrimental in their effects upon vegetation and upon the health of the community. These invisible gases consist of unaltered hydrocarbons and of carbon monoxide ; their presence is due either to deficiency of air, or to the lack of the requisite temperature in the combustion area. Smoke is the visible sign of the presence of these deleterious gases. It is, therefore, a useful signal of something wrong n the combustion process. Smoke ought to be

---

[1] Bone in a recent paper (see *Chemical News*, Dec. 12th, 1903), has, however, thrown doubts on this selective affinity of H for O, in presence of carbon.

attacked, not only because it brings dirt and depression in its train, but because its emission is accompanied by that of gases which are directly detrimental to the health of all living things, and at the same time carry away much heat from the plant of the fuel user.

Both on humanitarian and economic grounds its suppression is called for.

CHAPTER II

Present Methods of Burning Fuels and their Defect.

AS will appear later, the practice of fuel combustion for steam-raising purposes has been and still is, to place the relatively cold surface of the steam boiler, very near to the furnace in which the fuel is undergoing combustion. Thus, in the case of internally-fired boilers, the grate is covered by a semi-cylinder of water-cooled plate, which absorbs heat from the fire and from the unburned or burning gases, and deprives them of so much heat that they are cooled below the ignition point. Otherwise, the internal furnace possesses most of the requisites of perfect combustion, which have been laid down as follows—

1. A draught velocity of not less than thirty feet per second over the fire, to draw in air above the fire bed for combination with the gases distilled from the freshly charged fuel.

2. A thorough mixing of this air with the fuel gas, which can usually only be done by allowing the air and gas to flow together over the length of the

furnace. The air must be admitted in numerous fine jets, as through a perforated plate in the door.

3. A sufficient temperature to ensure ignition at the bridge end of the furnace.

4. Space in which the combustion can complete itself undisturbed.

The third requisite is usually more or less absent, owing to the effect of the water-cooled furnace plates.

The fourth requisite in Lancashire boilers is frequently destroyed by the cross pipes in the flue tubes, which have the effect of knocking out the nascent flame. Hence the sootiness when cross-pipes are present.

THE WATER-TUBE BOILER

Excepting No. 1, all the above requisites are absent from the usual setting of the water-tube boiler.

Air may enter at the doors, but it does not sweep over the fire surface. The gases rise vertically from the grate and pass unmixed with air between the tubes, which cool them below the point of ignition. The tubes, however, do mix up the gas and air, and these may ignite beyond the boiler, where they can effect no good. The small vertical boiler is obviously of this same faulty design. So also is the locomotive boiler, but this is more or less cured by the insertion of a fire-brick arch that compels the gases to travel round its projecting end and along its heated face, to meet fresh air near the door and burn in the dome of the fire box. Without the arch, the gases rise directly from the grate, and pass unburned to the cold tubes. In all cases, however, there is seen the close approximation of the boiler to the grate, with an absence of all consideration of the most important requisite, of temperature. Such neglect, with bituminous fuel, is productive of visible, more or less black smoke, which tells of early cooling. Black smoke may not in itself indicate a serious loss of actual carbon, but it is certain evidence of sooted heating surfaces, and points to inefficient transfer of heat. Colour alone is, however, not a necessary sign of imperfect combustion. The most imperfect combustion may give colourless furnace gases, the chimney top being quite clear.

In order to avoid smoke production, especially in towns, coke is often employed. Practically a compound of pure carbon and ash, containing no hydrocarbons, it is smokeless. But the use of coke, though it may avoid black smoke, does not necessarily imply perfect combustion. The waste gases from a coke furnace are often heavily charged with carbonic oxide (CO), resulting from too small a supply of air. To ensure bright and active combustion of coke, a fire must be of some depth or thickness. The air fed through the grate at once unites with the glowing fuel. It should always be remembered that when supplied with sufficient air carbon at once burns to its dioxide, CO_2. Hence, in passing through the fire all the oxygen is taken up, and when the carbon dioxide has still to traverse a further thickness of glowing fuel, the hot carbon becomes dissolved; the dioxide gas is changed into the monoxide; and the furnace gases pass away to the chimney, after producing less than one-third of the calorific capacity of the fuel, or 2,453 calories, in place of 8,137; or 4,415 B.Th.U. in place of 14,647.

If, however, air be supplied above the fire, the carbonic oxide will ignite and burn with a clear bluish purple flame, giving out a further 5,684 calories, or 10,232 B.Th.U.

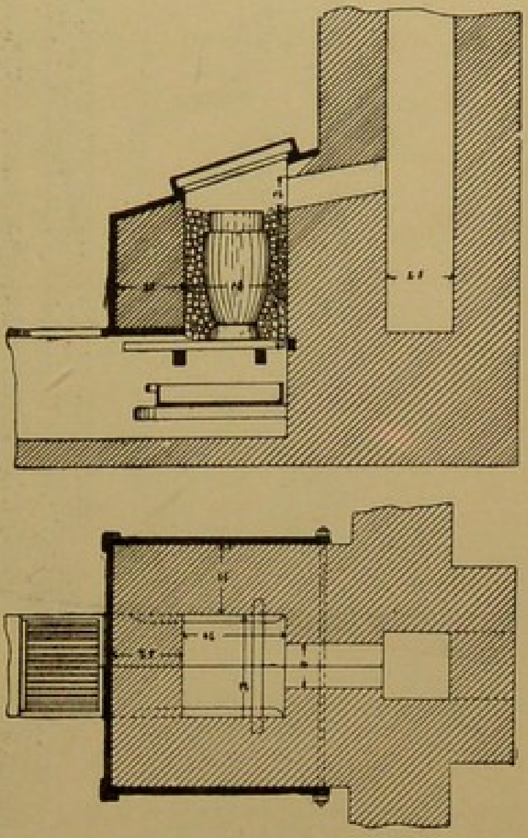

FIG. 3. COKE FIRED CRUCIBLE FURNACE.

An example of a coke fire is that of Fig. 3, which shows a crucible furnace heated by coke and fed by air below the grate. All the oxygen will be taken up in the deep fire, and carbonic oxide alone will escape to the flue. If air be admitted above the crucible it will produce the characteristic flame of carbonic oxide, but the heat of this second burning will escape wasted to the flue. Properly to use this heat the coke should be wholly below the crucible, and there should be openings to admit air to produce flame to play round the crucible.

The loss due to the high temperature of the gases

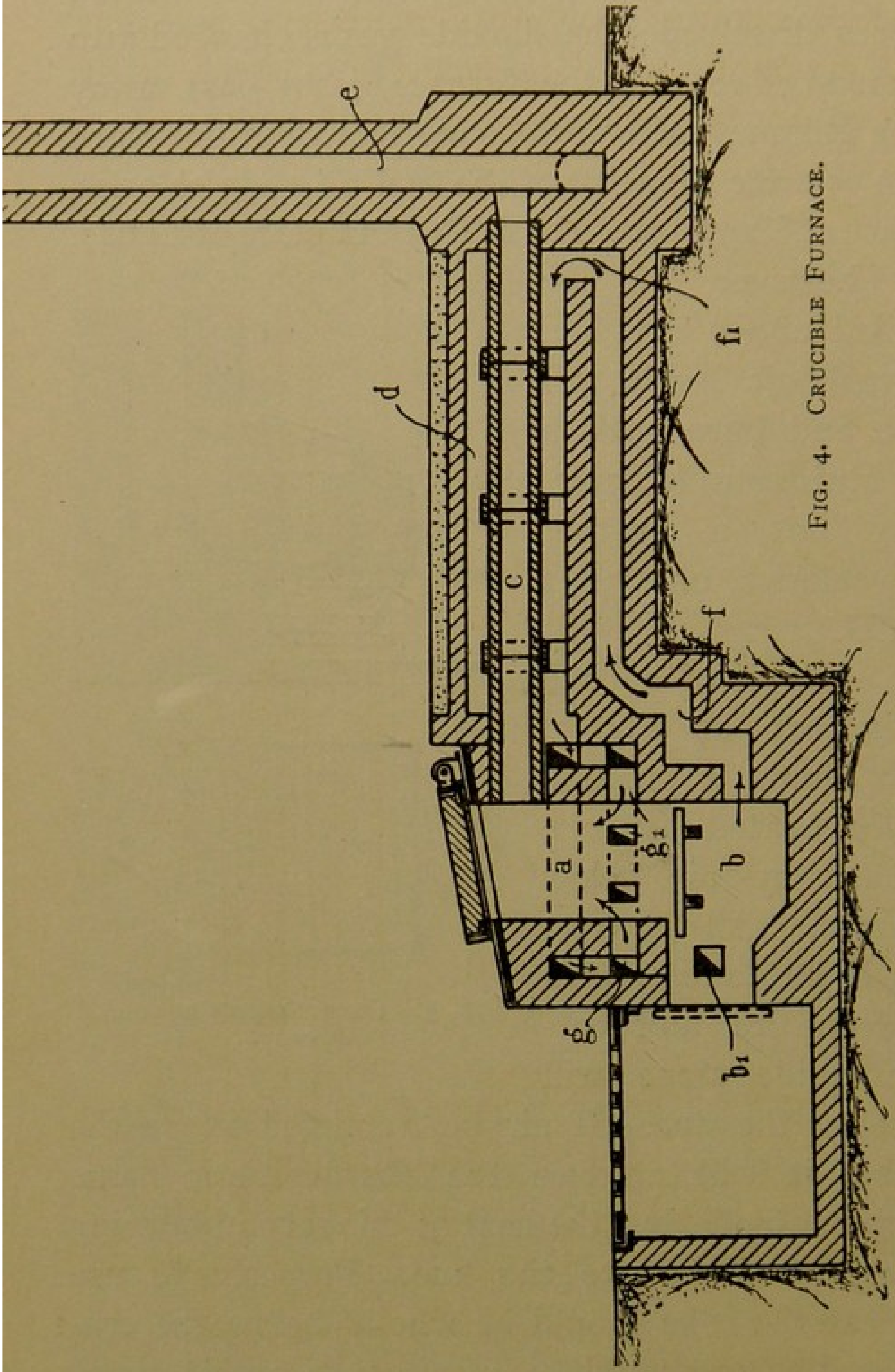

FIG. 4. CRUCIBLE FURNACE.

from a furnace of the type of Fig. 3, as well as the loss due to the production of carbonic oxide, is avoided in the furnace (Fig. 4). Here air is admitted elsewhere than at the grate by lateral openings, which supply oxygen (air) nearer to the top of the fire in order to secure more perfect combustion.

The waste gases flow to the chimney by the flue *C*, around which the air is drawn as shown by the arrows, and delivered through the openings g_1, *g* and *a*, to the furnace. With this design there is less stoppage from clinker. The waste gases may also be employed to heat a second supply of metal prior to placing it in the crucible, as in the construction shown in Fig. 5. In this case the metal to be heated, is placed between the crucible chamber and

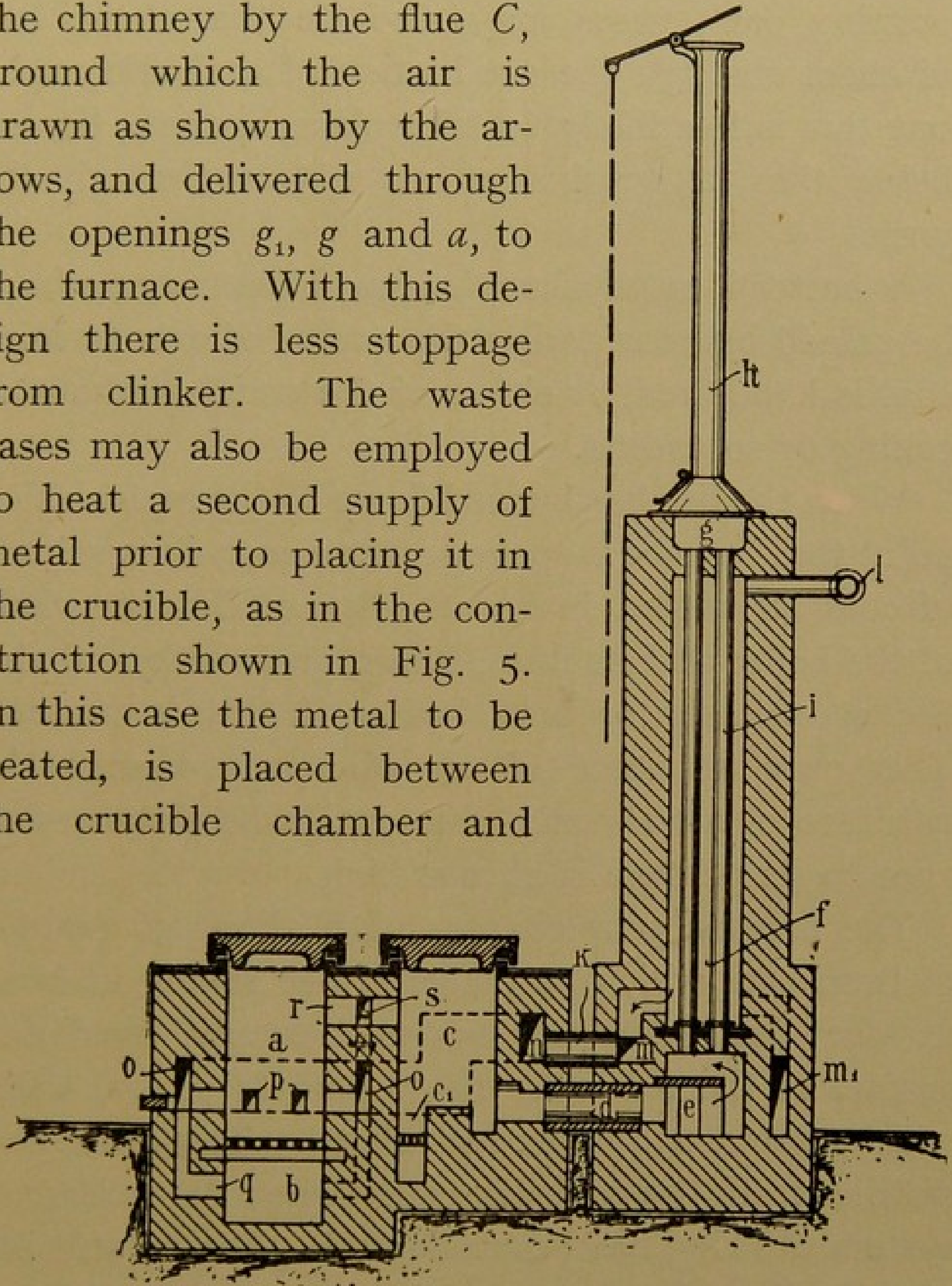

Fig. 5. Crucible Furnace.

the regenerative air heater as shown in Fig. 4, namely, in the second chamber *C* (Fig. 5). In this furnace *f* is the air heater supplying hot air to the primary furnace at *q*, *p*. The second furnace has a half grate *c*, and if necessary, metal can be melted as well as in the primary furnace. In burning coal, there may also be the above loss of effect through the production of carbonic oxide, but this is less likely to take place, because, the fire being thin, a surplus of air enters through the grate.

A better idea of the whole problem may perhaps be gained by considering the course of events when coal is hand-fired, by either of the usual methods of coking or spreading.

When the fire has burned down to the replenishing point the fire door is opened and an enormous volume of cold air rushes in over the fire, cooling the whole of the boiler and its flues, tubes, brickwork, and also the economizer or feed heater, if this is present. This easy entrance of air obviously checks the entrance of air through the grate, where the resistance to its passage is always high.

The fireman now charges with about 56 pounds of fresh coal, which he places either wholly in front at the dead-plate, or spreads evenly over the surface of the red fire. In 56 pounds of coal there will be about 250 cubic feet of gas. This is rapidly distilled from the coal, especially when the spreading system of firing has been adopted. The volatilising of solid fuel absorbs an enormous amount of heat, cooling down the red fire.[1] Meantime the boiler itself continues to absorb heat, so that the green gases pass into the flues unburned, or they are only partially burned. Usually, the fire door being open, the freshly produced gas ignites at once, for the first shovel of coal does not blank the whole of the red fire surface, and when the full charge of 56 pounds is complete there are huge volumes of flame pouring over the bridge. The door is then closed. The air supply being thus shut off and the fire choked with green coal, the flames are not supplied with oxygen through the grate, and become extinguished. The sudden cooling exercised on the heated gas by the boiler plates is said to spilt them up into lighter hydrocarbons and carbon. This free carbon is soot, which, floating in the stream of gas, produces black smoke. In black smoke there is not merely black carbon, but there is half-burned carbon in the shape of carbonic oxide. When the coking system is employed, the fire is burned through in patches. The distillation of gas is more prolonged, an excess of hot air is coming through the thin fire, and the gas mixes with this in its passage over the hot fire, and perfect combustion is more easily obtained.

The coked mass of fuel, when freed from its volatile gas, is pushed back over the fire by a rapid push of a wide rake, and a fresh charge is soon after put to coke upon the dead-plate. Wye Williams pointed out these things many years ago, and insisted on

---

[1] Vide *The Electrical Review*, Aug. 30, 1901.

the supply of air above the grate by means of openings in the fire door which admit air through perforated plates in fine streams, so as the better to mingle with the gases.

A good fireman can use these door grids successfully. They should, however, be arranged automatically to open as the fire door is closed after firing. They should then open slowly a little wider, and slowly close in about two minutes or so, as may be found necessary, thus regulating the supply of air to the output of gas. After all the volatile hydrocarbons have been driven off, the solid carbon on the grate will usually secure sufficient oxygen. About three or four square inches of air opening at the door is found necessary, for each square foot of grate area.

The air may be admitted at the bridge, but in that case it loses the benefit of the heating effect of the fire, and of the better mixing effect. Effective mixture is of prime importance, as also is a sufficient temperature. This latter is the point at which the Lancashire boiler, with its water-arch furnace, is apt to fail.

In that class of water-tube boiler wherein the gases rise vertically from the fire, and pass to the tubes where they are promptly cooled below ignition point, the mixing action is seriously deficient, and this was attempted to be remedied by Belleville, who injected air at a high pressure horizontally over the fire surface, to whirl the gases and burn them before they rose between the tubes. The space for this action is, however, too limited for success to follow.

No doubt mixture is effected by the water tubes, and the gases will often ignite and burn uselessly beyond the boiler. In the sequel it will be seen how the various points above named have been more or less provided for. We would specially urge the important essentials of mixture and temperature. Practice has shown that unless there is a draught of at least half an inch of water gauge, the admission of air above the fire does not take place satisfactorily, and in such cases it is usual to aid its introduction by a steam jet, placed so as to point from above the door towards the middle of the length of the fire. Experience also shows, that it is easier to prevent smoke by first admitting too much air at the door, and closing rapidly, than by admitting too small a quantity. If too little air is initially admitted, the gases do not burn freely, and soot is produced with less temperature, and it is difficult to re-establish perfect combustion. By admitting an ample volume of air at first, and putting the gases into active combustion, there is at once produced a high temperature, and the door grids may be sooner closed, for combustion will continue with a less excess of air above the chemical minimum.

It will be apparent from the foregoing that the difficulty in burning bituminous fuel lies in the fact that it is a complex substance, and burns partly as a solid and partly as a gas. The gas must be burned in a time much shorter than is necessary to burn the solids. The régime of the furnace is constantly changing. The fire is cooled during volatilization of the gas. Hence the dictum "little and often," as applied to the firing process, so as to reduce fluctuations to a minimum. But this implies many more openings of the furnace door, and has only been carried into practice by the processes of mechanical stoking. The machines for this provide a continuous feed of coal, either by the coking process, or by the process of sprinkling. The evolution of gas is thereby evenly distributed. The régime of the fire is more constant, and the supply of air, once found best, can be adhered to as closely as atmospheric changes will permit.

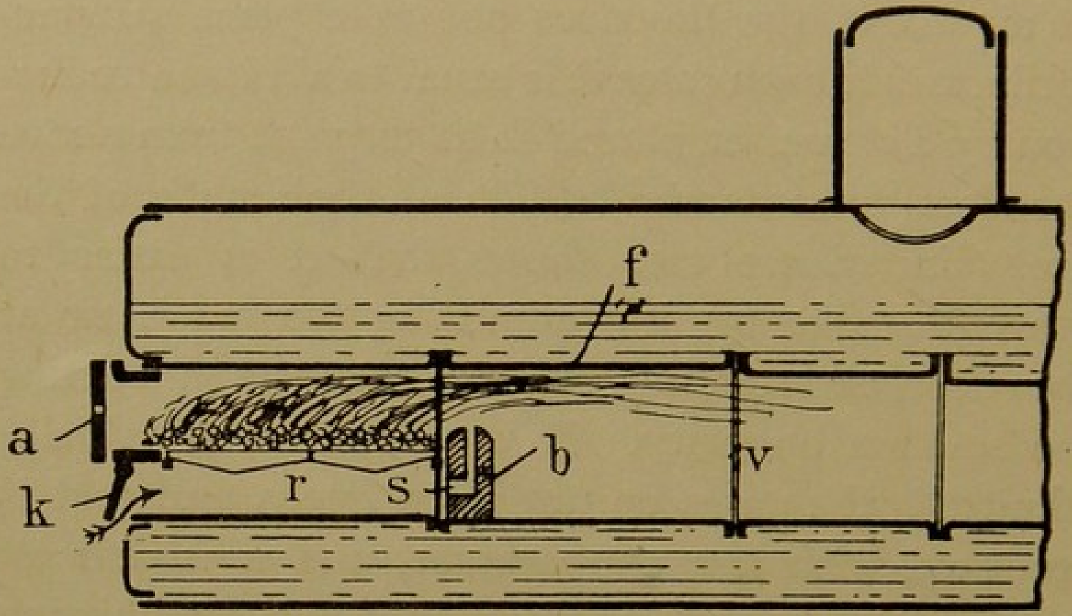

FIG. 6. ORDINARY FURNACE OF CORNISH BOILER.

The régime is less regular than it would be did coal not contain dirt to form clinker to choke the grate. Hence the use of moving bars, which tend more or less to be self-cleansing.

In Fig. 6 is shown a usual form of furnace of the Lancashire, or Cornish, or similar type of boiler. Here *a* is the door, *b* is the bridge, shown with an air passage in place of the door being perforated. *S* is a damper to regulate air admission through *b*. An ashpit damper *k* controls the air admitted below the grate, and, incidentally, through *b*. It is often necessary to limit the air flowing through the grate, in order to assist its entrance above the fire. But in this design the damper *k* cannot be used to do this, without at the same time controlling the air supply through *b*. For this reason, apart from other reasons, the secondary air supply is better effected through the door *a*, than through *b*. The damper *k* then affords a powerful means of controlling the supply of air to the furnace, both below as well as above the grate.

The Westphalian coal of Germany contains 4 per cent. of tars, 4 per cent. of gas water, and 16 per cent. (equal to 30 cubic metres per 100 kilos of coal) of gases; in all, 25 per cent. of volatile matter. Many English coals contain 35 to 37 per cent. of volatile matter. A study of the above type shows that the following conditions must be fulfilled, as already pointed out in general terms.

1. A temperature above 700°C.=1292°F. in the furnace, and no contact of the hot gases with the colder walls of the furnace, until combustion is complete.

2. A sufficiency of oxygen in the combustion space, preferably in a hot state.

3. Skilful firing of the raw fuel evenly over the fire surface.

The first condition may be secured by the arrangement shown in Figs. 7 and 8, which consists in lining the furnace with firebrick internally. This prevents serious abstraction of heat from the fire, and secures so high a temperature that the gases will burn if only supplied with oxygen as per condition 2. Most patented devices provide for such air admission at the bridge, and others provide for its admission at the door, which we prefer, but very few seem to consider the essential feature of temperature at the place of mixture.

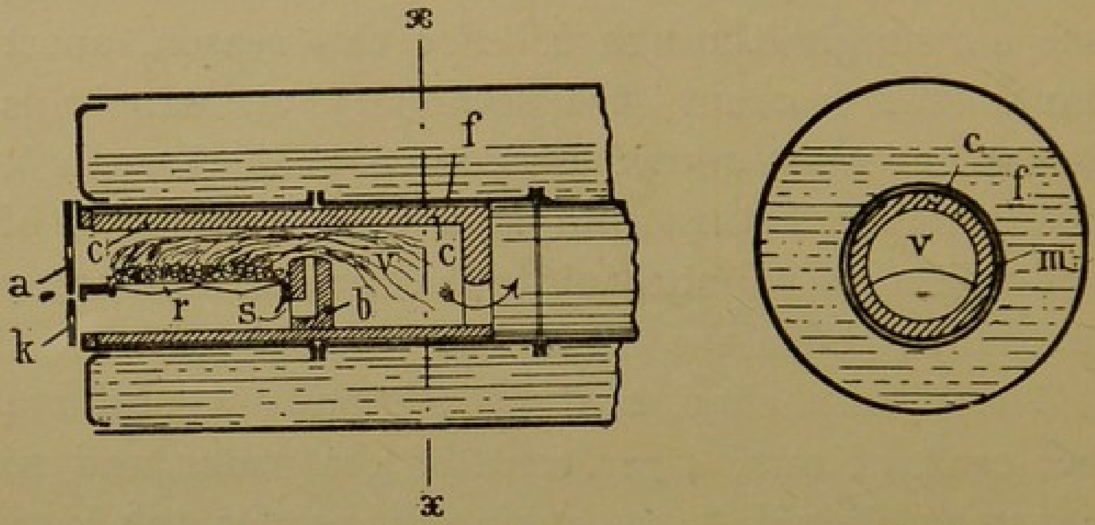

FIG. 7. FIG. 8.

REFRACTORY FURNACE FOR CORNISH BOILER.

In Fig. 7 this is provided for, by extending the fire-brick lining, as shown. With bridge admission this extension will probably be greater than with door admission. The amount of secondary air thus admitted should be kept down as nearly as possible to the theoretical or chemical minimum, or the

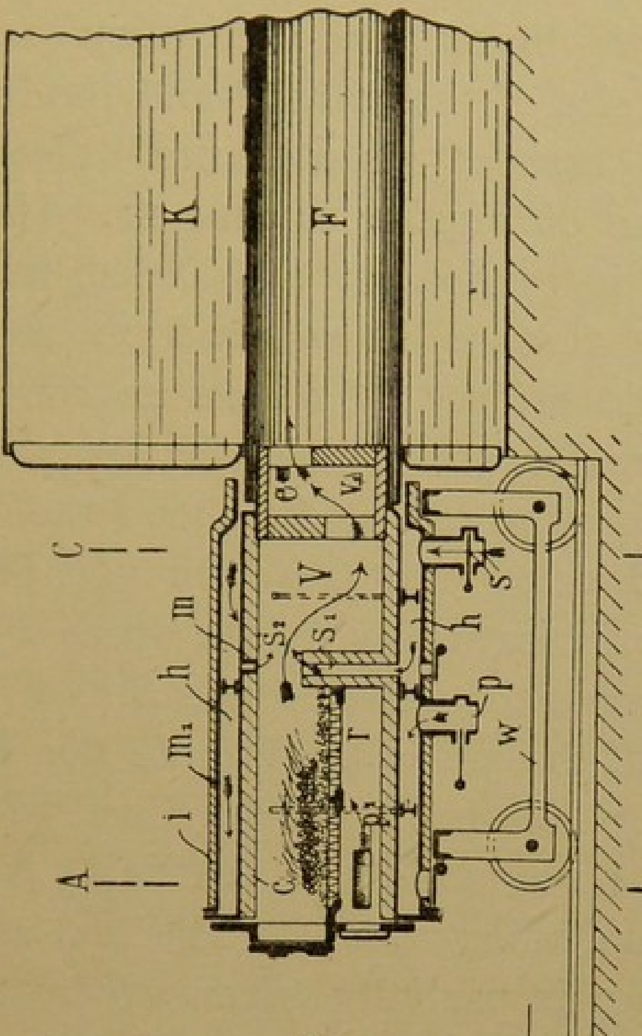

Fig. 11.

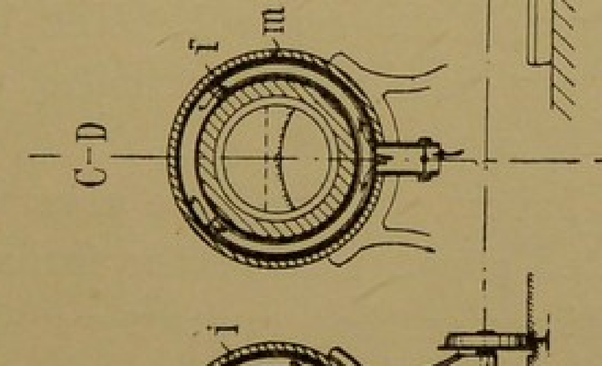

Fig. 10.
External Furnace for Lancashire Type Boilers.

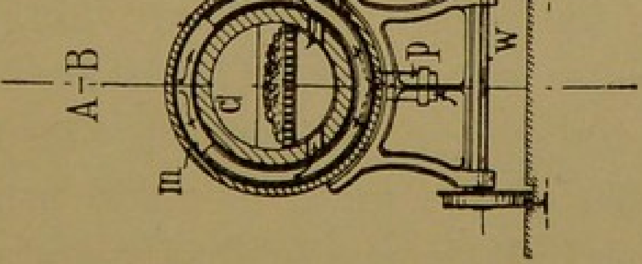

Fig. 9.

cooling effect will be excessive. It is because so many devices admit too much air, that they do not prove economical.

The fire-brick lining, however, very seriously diminishes the size of the furnace, and the lining is not free from cost of maintenance. Hence the external furnace of Figs. 9, 10 and 11. Here the whole furnace is carried on a wheeled frame or platform. The furnace is enclosed in an outer case *i*. A split bridge S_1 admits secondary air from the external space *h*, through which further secondary air is admitted at S_2, above the bridge. Air is admitted below the grate through passages *p*, also in communication with the space *h*, which is supplied through the valves *p* and *S*.

Combustion of the gas takes place in the space *V* and beyond, the whole furnace being lined with fire-brick as at *C*, no extension of the lining is necessary in the actual boiler tube F. The heat radiated from the furnace is partially taken up by the air which flows through the space *h*. The length is two metres and the diameter half a metre, the grate area $1\frac{1}{2} \times \frac{1}{2}$ m. = 8 square feet.

For English boilers, the fire-grate area would be larger than stated above, because the furnace tubes have a larger diameter than appears usual in Germany. Thus for boilers of 7ft., 7ft. 6in. and 8ft. internal diameter, the furnace tubes are made 33, 36, and 38 to 39 inches diameter respectively, and the length of the grate is made usually 6ft. for hand firing. It is possible to maintain these widths with external furnaces, and it should not be impossible to employ a single breadth grate in the external furnace of a Lancashire boiler, so securing a grate of six to seven feet in breadth, if the thrust of the arch can be properly taken up.

Earlier attempts to secure the results possible with external furnaces have failed, from too great massiveness, and want of means for preventing great loss by radiation. With the furnace illustrated, these losses are much reduced, by the air passing through the space between the casing and the furnace. Where there is as usual a spare boiler, the furnace may be wheeled from any boiler, which is to be laid off for cleaning or repair, to the spare boiler which is to be freshly started. This would help to reduce loss of heat stored in the furnace, which is estimated at 8·6 kilos of coal. This loss may be calculated, if the mean temperature of the mass of the furnace be known, the specific heat of firebrick being about 0·2. It has been argued that external furnaces are not economical, that steam cannot be raised with economy unless the boiler is exposed to the direct radiation of the furnace, and that with external fires this radiant heat disappears in some mysterious manner, being incapable of discovery either in the form of water evaporated, or of heat in the waste gases, and that in fact no one knows what does become of it. This explanation is unsatisfactory and improbable. It is doubtful if any satisfactory proof can be afforded of its truth, and grave doubts are thrown on the claim by Mr. F. Grover, who informs us that the smokeless combustion of Indian coal in such furnaces, appears to have been also coincident with a marked economy. A similar principle is carried out with water-tube boilers, by the construction of the furnace shown in Figs. 12 and 13. K and K_1 are a pair of firebrick arches thrown across the fire, so as to form an extended furnace and combustion chamber, in which combustion may be completed by aid of the secondary air, drawn through the hollow walls

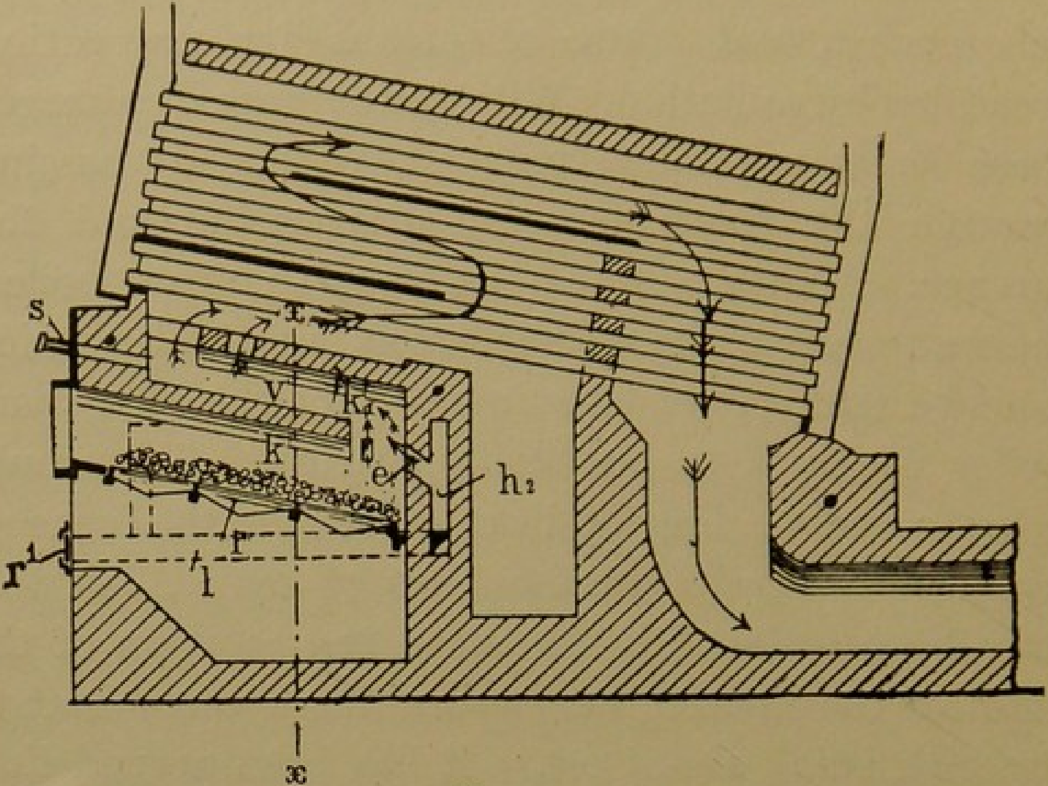

FIG. 12.

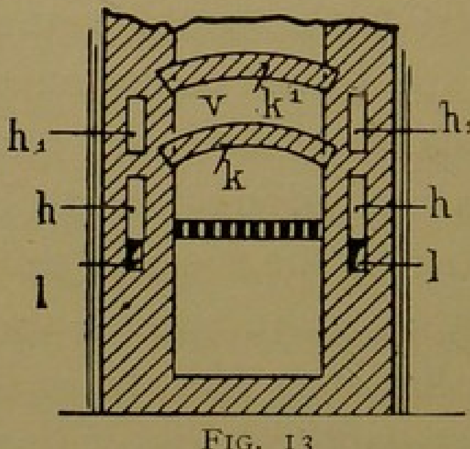

FIG. 13

BRICK FURNACE OF WATER TUBE BOILER.

h_1 h_1 to the bridge wall at e. The volume of this air can be controlled by the damper r^1.

Sight holes at S, and if possible through the side walls near the bridge, are provided. The upper arch may be perforated as shown. There is always more or less trouble with these arches in ordinary practice, because they are built with far too little care and forethought. Mr. Page, of Stourbridge, says that for sound work, a fire block must not be machine pressed from a lump of clay. This is apt to cause planes of internal shear at which failure may occur. All specially stressed brick must be hand pugged into its moulds and should be burned at a temperature exceeding that at which it will be used. Bricks ought to be absolutely dried before going into work, and a new arch must be slowly warmed up. Its face may be smeared with a less refractory cement which will run, and set the arch face into a solid mass; this will minimize the common danger of the bricks splintering off at the first severe heat. The new electric furnace product, *Siloxicon*, might be employed for this purpose.

A well-built arch of good bricks, should last a year.

In such a furnace as this, the gases are compelled to travel over the full length of both arches, before coming into contact with the water tubes. As in other cases, the secondary air can be admitted—probably with advantage—at the furnace door.

The whole boiler must stand higher than when it is set in the usual manner; but the usual manner of setting a water-tube boiler is so barbarous and unscientific, that it does not merit a moment's consideration.

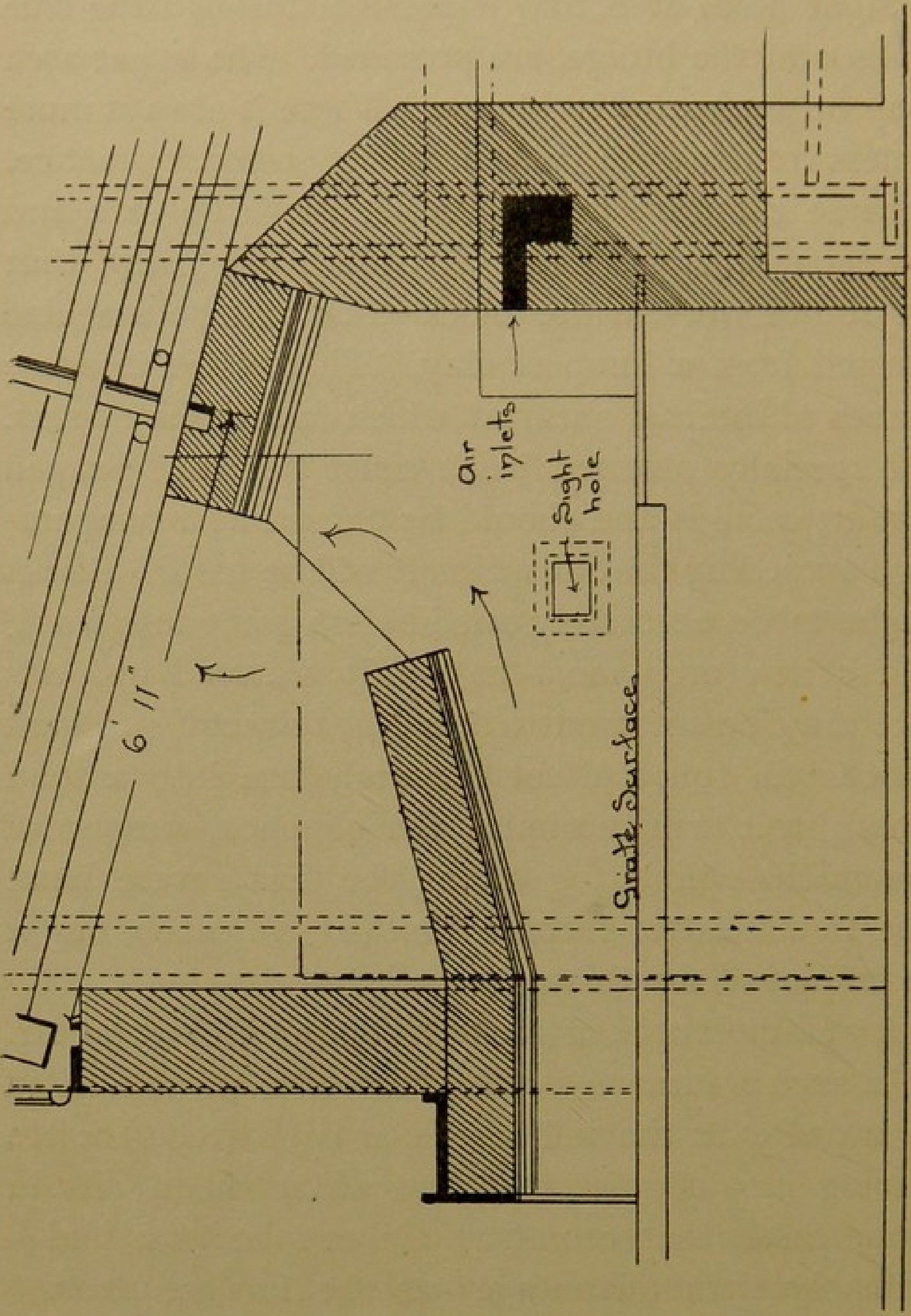

Fig. 14. Refractory Furnace for Water Tube Boiler.

It is, however, to be said that even better results can be obtained by an extension of the principle of Fig. 12, that is, by raising the boiler even higher, and considerably enlarging the combustion chamber, as in Fig. 14.

It is unfortunate that so little attention has been paid to the art of stoking. This has been too much considered as only an unskilled labourer's work, whereas it involves the economical conversion of valuable coal into heat, and a fireman's wages are but a small proportion of the total cost. In a week of 56 hours a high class fireman has been known to fire 80 tons of coal, but 50 is a good week's work. He may thus be handling twenty to thirty times the value of his wages, and a difference in skill that will save only three per cent. of the fuel, may well be worth an addition to his pay of one-half. A good man can, under fair conditions, fire Lancashire type boilers without smoke and with economy. The furnace of such a boiler is in fact near the critical point, and it will smoke on slight cause. Smoke prevention apparatus should be of such a nature, as to widen out the critical area, by improving or insuring the necessary conditions, without introducing uneconomical fads such as excessive air.

All apparatus should aim to reduce the air supply to a chemical minimum. This will always be possible in a refractory furnace of sufficient length, because the mixture of air must be complete in time, and combustion will go on so long as there are no serious cooling effects. Practical success is secured where, without excessive furnace and combustion space, and with an excess of air of 30 per cent. above the theoretical, there is no smoke but a light occasional haze. In hand firing, as already seen, coal is applied either by spreading or by coking. The spreading system is variously modified. Either coal is fired over the whole fire area at once, or it is fired over the front and back ends alternately, the object in each case being to preserve a red fire over half the area, in order to supply part of the secondary air to the gases from the other half, and to keep up the temperature.

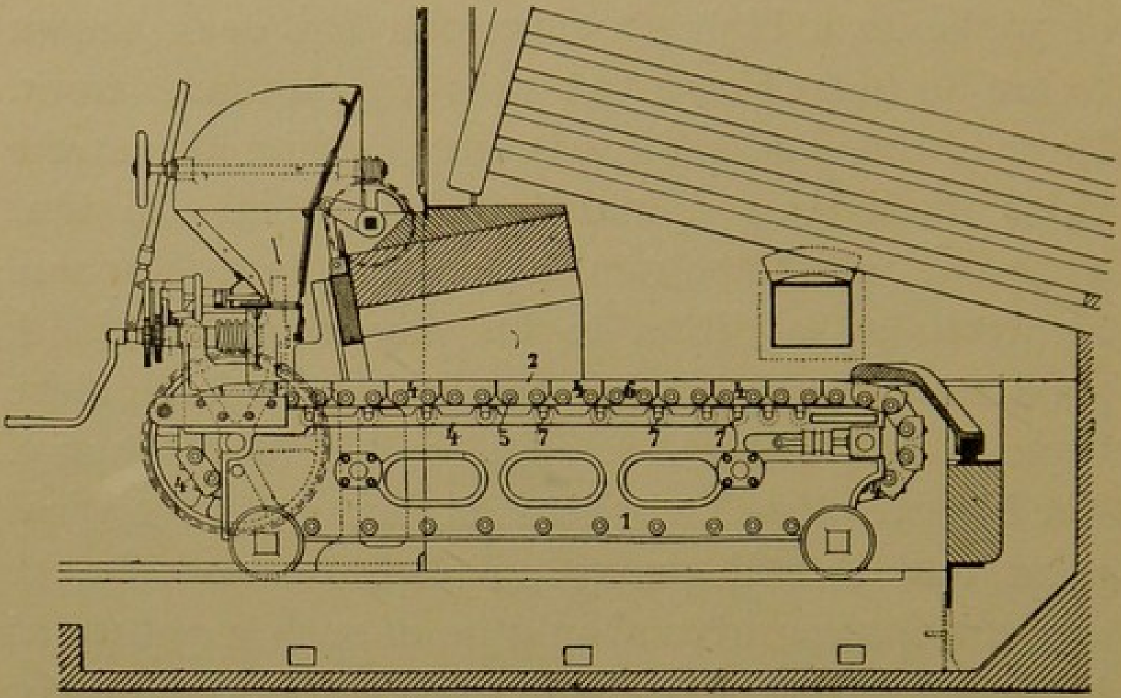

Fig. 15. The Chain-Grate Mechanical Stoker.

In stoking by machinery, these various methods are all more or less approximated. A perfect mechanical stoker is not known, but a fair amount of success is secured by them, and they cannot be regarded as altogether unsatisfactory.

One of the oldest forms of mechanical stoker is that illustrated in Figs. 15 and 16. It has lately come again into prominence as a stoker for water-tube boilers, but its inventor was one Juckes, and it was at one time extensively employed in Yorkshire for under-fired Lancashire boilers, practically as shown in Fig. 15, but sometimes with the chain grate brought much further forward, so as to provide a considerable additional length, on which coal was hand distributed. This coal passed under the edge of an adjustable vertical plate, which levelled it to an even thickness. It then passed slowly under the arch of firebrick which protected the front lower end of the boiler, gradually becoming coked as the moving chain grate carried it to the bridge. Secondary air was admitted by leakage through the green coal under the "doctor" plate, and through the bridge-end of the fire where burned thin.

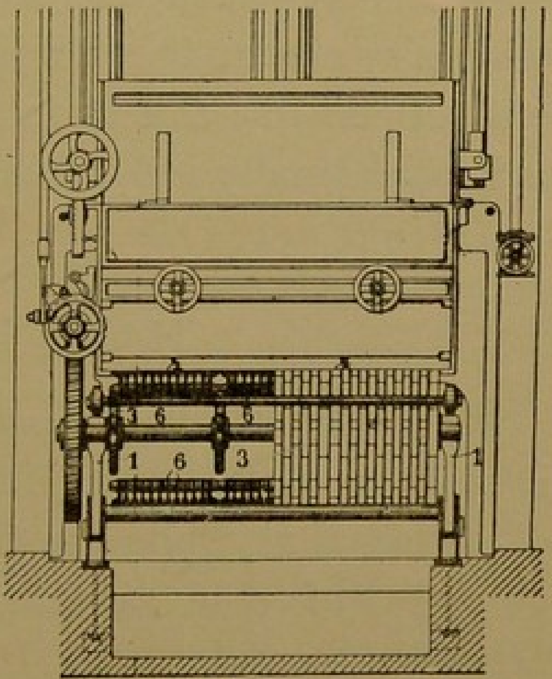

Fig. 16. The Chain-Grate Mechanical Stoker.

The difficulty then, as now was, that the burned-out fire admitted too much air. The furnace was intensely hot, and under-firing large shell boilers not being approved by the Boiler Insurers, the Juckes furnace fell into disuse with the system, until it was resuscitated for water-tube boilers.

The chain-grate furnace is always clean, and it was fairly smokeless under the shell boiler, but of course it must fail under the straight ascending flow of the usual setting of the water-tube boiler. It will work smokelessly with a setting such as that of Fig. 12, and is practically perfect when arranged as in Fig. 14, which is the arrangement employed by Mr. Miller, of the Kensington and Notting Hill Electric Light Station.

The thickness of the fire at the bridge end is kept up by means of the bridge plate, which allows the advancing fire to heap up, and the surplus falls over into the pit beyond, where it can burn out. The bridge plate must be hollow, and cooled by a constant flow of water, or it will rapidly burn out. These grates sometimes give trouble by bending, and by failure of the link pins. Mr. Miller discards pins, and casts bosses and recesses on the links themselves, which are so shaped as to avoid the wide air gaps, at the bending of the chain round the end rollers. In this form of chain, each line of links is longitudinally independent.

HAND FIRING.

While hand firing possesses the advantage that it may be done by an intelligent man, it has the objection that, while the firing is in operation, great volumes of cold air are rushing in at the door. Hence such patents as Fig. 62, where the attempt is made to get rid of part of this objection. Mechanical stoking does avoid this difficulty, but these machines have their troubles also. Excepting the chain grate, the ordinary moving bar of the mechanical stoker, requires to be cleaned at intervals. To do this, the hopper feed is stopped, and the grate burned bare, the dampers being gradually closed as the fuel burns off, and completely closed during cleaning. When clean, the feed is restarted, the coal first fed will often be ignited by previous back burning and will at once flame. If the draught is good the coal will burn very fiercely, and it requires a long time to get the grate fully covered again, during which time cold air is rushing freely through the bare grate, and diminishing the duty and efficiency of the boiler and of the economizer also. If to check this, the boiler dampers are closed, there will be too small a volume of air drawn in above the fire to burn the gases, and black smoke will be made. In such a case, a damper may be placed under the grate, so as to shut off air from the rear of the grate, without diminishing the air supply above it. In this way the gases receive the air necessary to burn them, and the fuel on the grate burns slowly. When the fuel has travelled as far as the bridge, the ashpit dampers are again opened, and regular working is resumed. This ashpit damper is also a useful appliance for a hand-fired boiler, for it enables the draught to be regulated so as to give the desired intensity of combustion, without diminishing the draught above the fire, the full chimney draught being available to draw in air to burn the evolved gases.

BROADBENT'S APPARATUS

An appliance to regulate air admission is that of Broadbent, which consists of a set of louvres in the furnace door. These are all jointed to a middle vertical bar, which serves as the weight for a piece of clockwork. This clockwork has a springless, heavy escapement wheel, like a fourteenth-century clock, which oscillates under the pull of the weight, and allows this to run down. The clock is connected by a chain to the louvre weight, so that when the furnace door opens, the lever on the clock falls back over a ratchet wheel, and when the door is closed, the ratchet holds back the lever, and the louvres are fully opened to admit the maximum air supply over the fire. The escapement of the clockwork then begins to move, and allows the louvres to shut in about two-and-half to three minutes, after which time there is no further hydrocarbon gas, to distil off the last charge of fuel. The process is then repeated at each charge of fuel. Similar results were aimed at by means of door louvres, hung to a ratcheted lever on a shaft overhead, which slowly revolved and let down the louvres at a fixed rate.

Oil cataracts also are employed for the same purpose, and in skilled hands these various appliances serve the purpose of admitting air when needed, without allowing it to continue too long. With means for ensuring sufficient temperature, they would undoubtedly be very good smoke preventers.

UNDER FIRING

Great store has been set on the idea of feeding coal from below the fire, so that the green coal should give off its gases below the red coked fuel above, which will thus heat the gas and assist it to burn.

This end has been variously attained. One such device is seen in Fig. 68, German Patent No. 123,300, described on page 172. Many years ago, Mr. Holroyd Smith introduced coal to the furnace by means of long helices, which carried the coal along longitudinal troughs in the grate surface. The gradually reducing size of the helices, and of the troughs, compelled the coal to escape upwards. The principle of under firing has not come much to the front as regards English inventions.

The Hopcraft furnace, which came out with such a flourish in 1889, had a circular revolving grate, inclined at an angle of 25°. Coal was fed through a central pipe, round which the grate revolved, by means of a jointed series of flights or short helices. The revolution of the grate set up a weak line in the fire, at the circumference of the circular part, and the draught, which was by fan, spent its energy round this weakened channel, which it blew into a state of brilliant incandescence, the rest of the fire remaining dull and dead. The furnace proved a complete failure; and the under-feed system has not met with much success until recently, when certain American under-feed furnaces have been introduced. These possess the novel feature of a grate inclined downwards from the fuel supply trough, with a modification of the step grate placed across the furnace. An example of this grate will be found in the section dealing with American Patents.

In the Vicars stoker, short straight bars are employed, which have a forward movement all at one time, but a return movement which takes place at two distinct times, all the alternate bars first moving back, followed by the remainder. The net effect is to carry the fire forward. The bars receive their fuel from a hopper, out of which it falls in front of a pair of wide reciprocating plungers. These thrust it forward upon the bars, where it becomes coked as it moves forward under the fire-brick arch, and gradually burns off towards the bridge. The still unconsumed fuel falls over the bridge into the hollow beyond, and is burned out, the ash and clinker being cleared from under the grate, and falling preferably down the hopper ashpit to a conveyor below.

The fire-brick arch occupies a considerable length, and combustion is fairly smokeless. A high percentage of CO_2 can be secured by this stoker.

Objection is raised to stokers of the sprinkling order, that the dust of the coal is carried by the draught into the flues, and even out of the chimney top. Either by damping the coal, or by providing suitable chambers for the dust, this may be prevented, but damping cannot be recommended, for the reasons given on pp. 140, 141, Chapter IV.

The sprinkling mechanism is various. Some stokers throw their coal, by dumping it in small quantities in front of spring actuated shovels, which throw the coal over a limited area of the furnace at each throw. The severity of the throw is varied by the action allowed to the spring, and thus the whole fire surface receives its share of fuel, which is spread by the bottom of the throw chamber or by experimentally determined semi-obstacles. Other sprinklers consist of rapidly revolving wheels or fans, upon which the coal is dropped from the hoppers. These wheels revolve on a vertical axis, or they may revolve on a horizontal axis.

In the stoker of the E. S. E. Stoker Co., of Blackburn, the sprinkling is alternately along the sides of the fire, so as to resemble side firing by hand.

In all, it will be observed that fuel is supplied continuously, and maintains a constant condition of the furnace. Such smoke as is made is steady in amount, and constant, and though it is maintained at a density less than what may be called the " prosecution blackness," nevertheless its daily volume is sometimes considerable, and mechanical stoking cannot be considered by itself as a smoke preventer. It must be employed with the same precautions as are necessary with hand firing.

Anthracite coal cannot easily be stoked by any system of coking, and it must be kept quiet during burning. It is therefore not suitable for firing by mechanical stokers of the coking type. Nor does it require secondary air to burn off volatile gases.

Anthracite must, however, have a secondary air supply, to burn the carbonic oxide, (CO), if the fire is too thick to allow an excess of air to pass through it. With bituminous coal, only from a fourth to a half, of the total heat, is actually set free at the grate. Considerable heat is absorbed in volatilizing the solid coal, and the gases which absorb this heat pass off and burn in the upper part of the furnace, or beyond it, so that the fire grate is not exposed to very severe heat. Anthracite coal burns almost wholly at the grate surface, and the temperature produced is high. Any slightly projecting bar will melt off, and there is usually considerable trouble with the grate. Special grates for anthracite consist of flat plates, pierced with holes. Round each hole, the plate rises up in the form of a low hill, and the area between the hill tops, which are perhaps a quarter of an inch high, becomes covered with ashes which protect the plate surface.

Summarizing the whole question of mechanical stoking, it may be pointed out how very much better fitted for perfect combustion is the underfired boiler, than the internally-fired boiler, owing to the large space available for the grates. One of the greatest enemies to economy is the creation of bare patches in the fire. This we have seen is the cause of trouble with chain grates. Certain machine stokers minimize the trouble, by using short bars, and by dumping the still unconsumed fuel, into a back pit, where it can burn out to a finish. But in the inclined grate, the aid of gravity is called in, so to agitate the fire, that it packs downwards automatically, and closes up its hollow parts by drawing upon the thicker bed of fuel at the upper end of the grate. These grates are so arranged that the fire is approximately self-regulating in thickness, for as it packs downwards it becomes self-supporting, and ceases to move down hill so very rapidly. It is difficult to imagine anything much better than the inclined step grate, but it requires to be allowed for in original construction. It should always be combined with the over arch of fire-brick, and with the general arrangement of furnace and direction of flow of gases, which have been already pointed out as essential for obtaining a good mixture and a sufficiently high temperature.

CHAPTER III

IMPROVED METHODS OF BURNING FUEL.

STEP GRATES AND GAS FIRING.

STEPPED grates have been little used in Great Britain, simply because under-fired boilers have gone out of favour. A step or an inclined grate affords the simplest means of moving the fuel along the grate as combustion proceeds, thereby closing up voids and preventing excessive admission of air. When the angle is properly chosen (it ought to be adjustable) an even and uniform bed of fire can be obtained by this method of construction.

Two forms of inclined grate are in use in Germany and on the Continent. In one, the grate is of the usual form with straight bars, but it is inclined at a steep angle as in Fig. 17. This still retains the disadvantage, that fine coal and dust easily fall through the bars. Coal of strongly coking property, or which produces much clinker, is also not found satisfactory on such a grate.

In the true step grate, as in Fig. 18, plates are arranged as in a staircase, but the risers are omitted, and the openings thus made afford access for air.

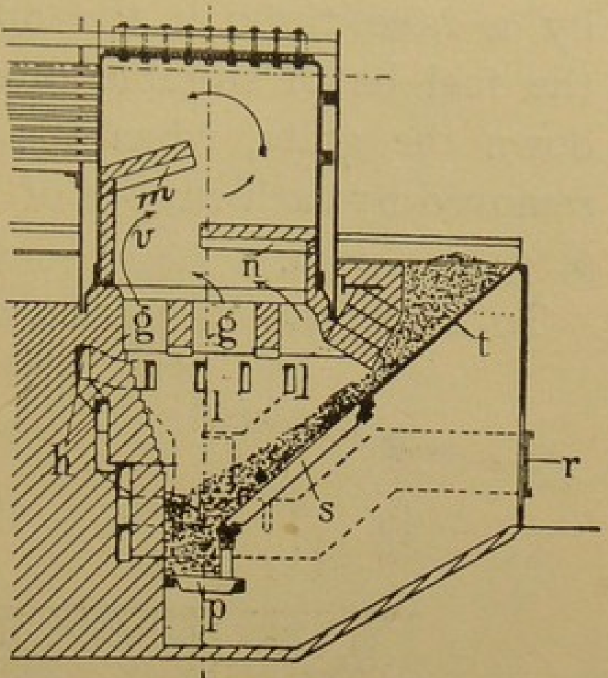

Fig. 17. Inclined Grate.

This form answers admirably for fine coals, lignite, peat, and tan bark, or sawdust, which cannot be burned advantageously on ordinary grates.

In Fig. 17 the simple inclined grate is shown fed from a hopper t, ash and clinker collect on the little bars p, and secondary air is admitted at l, through lateral passages h controlled by a damper r. The gases thence proceed to the boiler, which in this case is seen to be of locomotive type, with two brick arches, m and n, to divert and mix the gases, and diffuse them over the volume of the dome of the combustion box before they escape to the tubes.

The step grate of Fig. 18 is shown, applied to a somewhat similar furnace, in advance of a flue tube boiler. Coal supply from a hopper is regulated by a doctor plate b, secondary air is admitted at l l, and regulated by a damper r, which controls the heating rays h, h_1.

Ash and clinker are deposited on the lower shutter p, and may be let down upon p_1 by withdrawing p. On replacing p, the lower shutter p_1 being drawn out, deposits the intercepted ash and clinker in the ashpit. The fire can be helped down by a rake through the opening *k*. If, however, the fuel be of suitable quality, the fire will slide down the grate, when the support at the foot is removed by each cut out of ashes when the shutters *p*, p_1 are used.

To note the perfection of combustion, a sight-hole *e* is provided in the side wall. The products of combustion are finally passed into the boiler flue. Grates of the form of Figs. 17 and 18 are usually inclined at an angle of 45°, those of Fig. 18 being at about 35°. These inclined grates, with brick combustion chambers, are, in a sense, a sort

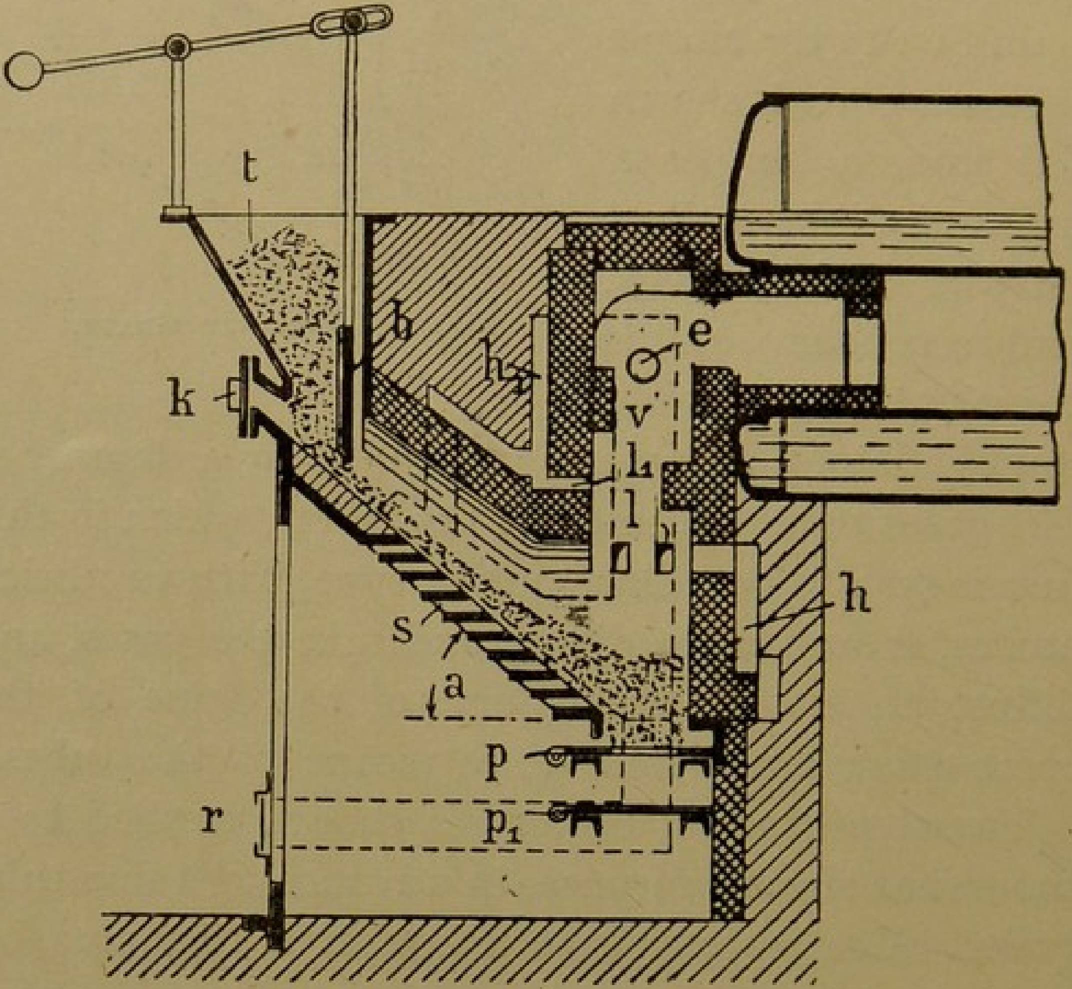

Fig. 18. Stepped Grate.

of half-way house on the road to gas firing. When the grate is very steeply inclined, there are few voids in the fire. Much carbonic oxide is produced, and unburned hydrocarbons are given off from the thick mass of fuel. As both the fire thickness and the secondary air supply are controllable, the combustion ought to be perfect and smokeless. The heating of the incoming air by the walls also makes for economy. This half-gas firing is not sharply differentiated from other methods of firing, but there is a gradual transition from the ordinary plain furnace to the actual gas producer, and no attempt need be made to define the limits. Thus it would be difficult to say whether the reverberatory furnace

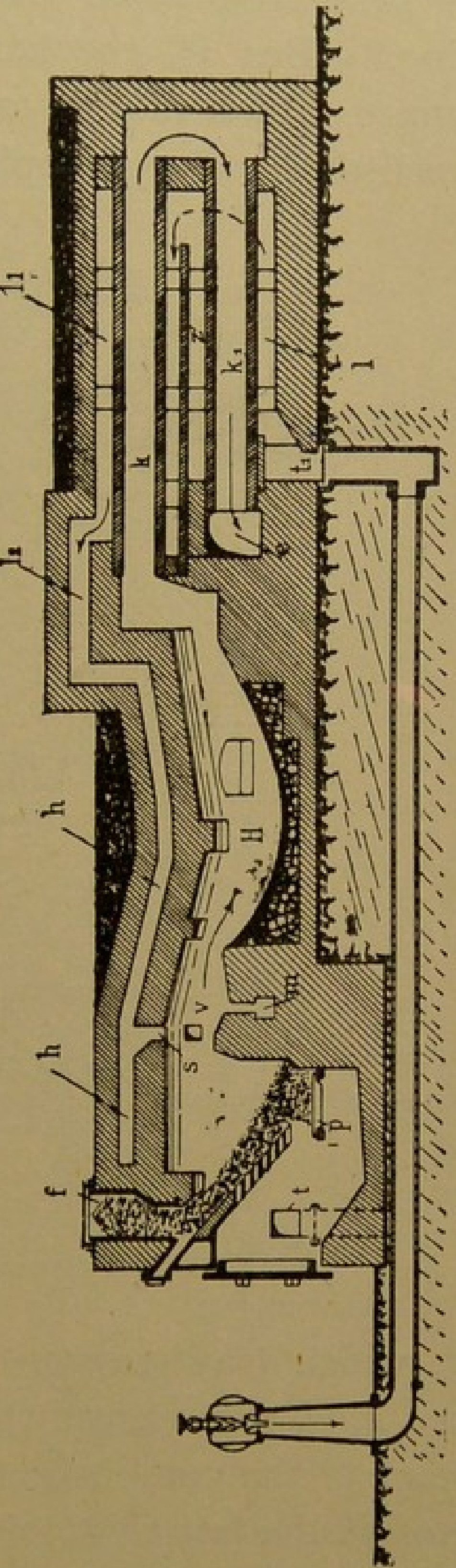

Fig. 9. Reverberatory Furnace.

of Fig. 19 belongs to the gas-fired type or to the solid-fired type. Hence the term "half-gas firing." But all the heat of the fuel goes to the furnace, which in this case is shown with a steam impelled secondary supply of regeneratively heated

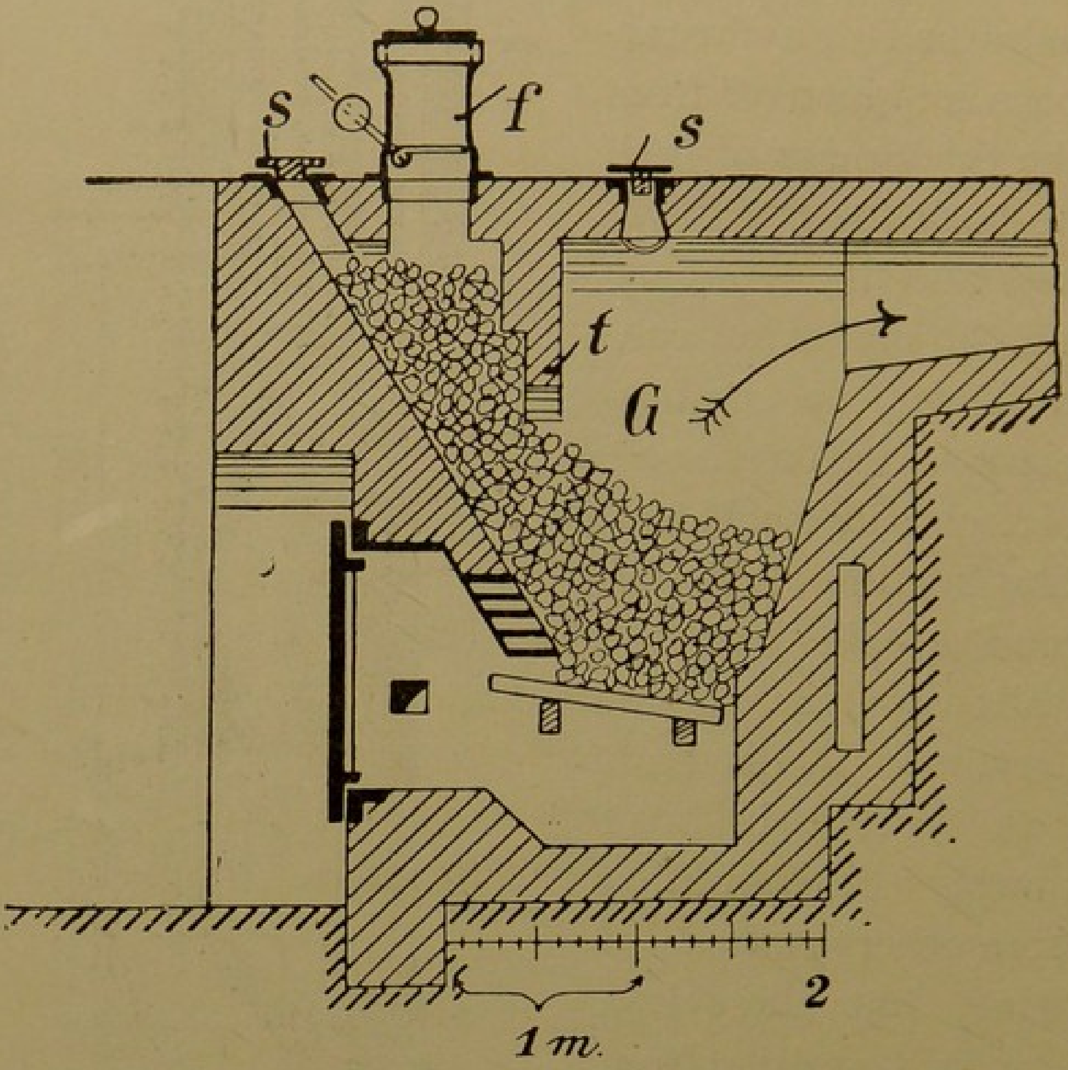

FIG. 20. GAS GENERATOR, ORDINARY TYPE.

air, which traverses the passages z^1 heated by the flues k, k_1 and enters the furnace at S and m to complete the combustion prior to the arrival of the gases at the hearth H of the smelter. The air, even though hot, is less heavy than the gases, and is thought to mix better when forced in above these at the top of the combustion chamber V. Careful regulation is necessary, which is effected by the damper t_1.

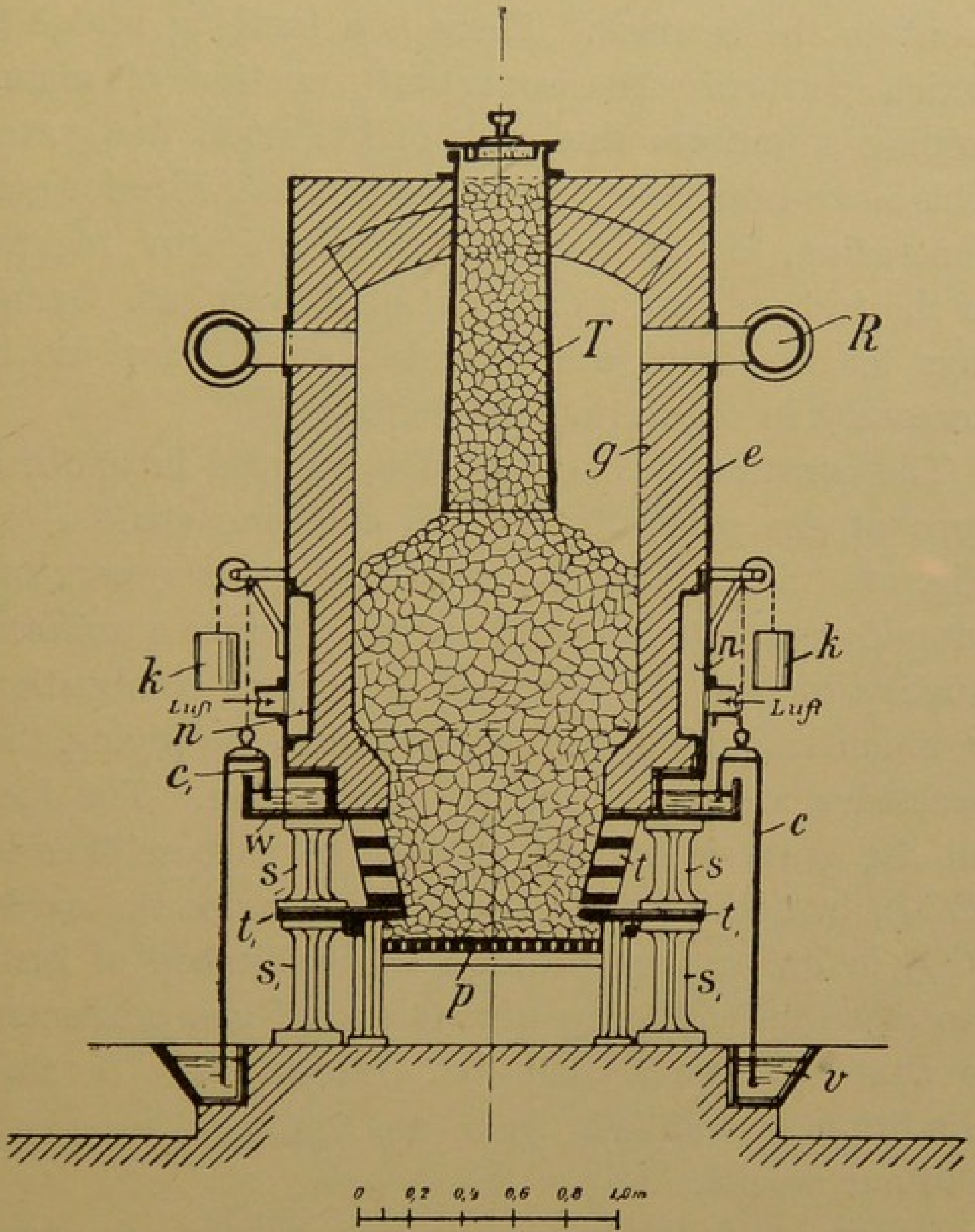

Fig. 21. Centre Feed Gas Generator.

The use of forced draught, or compressed air, offers advantages which have not yet been fully grasped by engineers.

A gas generator of ordinary type is shown in Fig. 20. It does not differ widely from Fig. 19. The fire is thicker, 60 cm. to 1 m.=24 to 40 inches. This thickness is obtained by using a steeply inclined front to the furnace. There is a hanging bridge *t*, which performs the important function of maintaining a uniform thickness of fire upon the grate. This is an important and essential requisite for gas generation, as it preserves the uniform régime of the furnace and a constant quality of gas. Openings for fire irons are provided at *S S*, for use if necessary in regulating the fuel.

The constant fire thickness is secured in another type of gas generator by the charging shaft *T* of Fig. 21. Since with the same fuel, a gas generator, properly regulated, should always produce a uniform quality of gas, the problem of perfect combustion is much simplified and resolves into supplying the necessary air for secondary combustion. The fuel on the grate is burned at once to carbon dioxide (CO_2), but this is all converted to carbonic oxide (CO) in its passage through the thick bed of fuel. An essential condition of the use of gas producers is that the work shall be continuous. If this condition is fulfilled, their use leads to economy without smoke.

In Fig. 22 is shown an application of a gas generator to the firing of a boiler. The generator and the boiler here shown are one of a series, arranged in parallel on a common gas flue *H*. The boilers are of Lancashire or Cornish type. In front of each tube is a gas combustion chamber V, V_1, V_2.

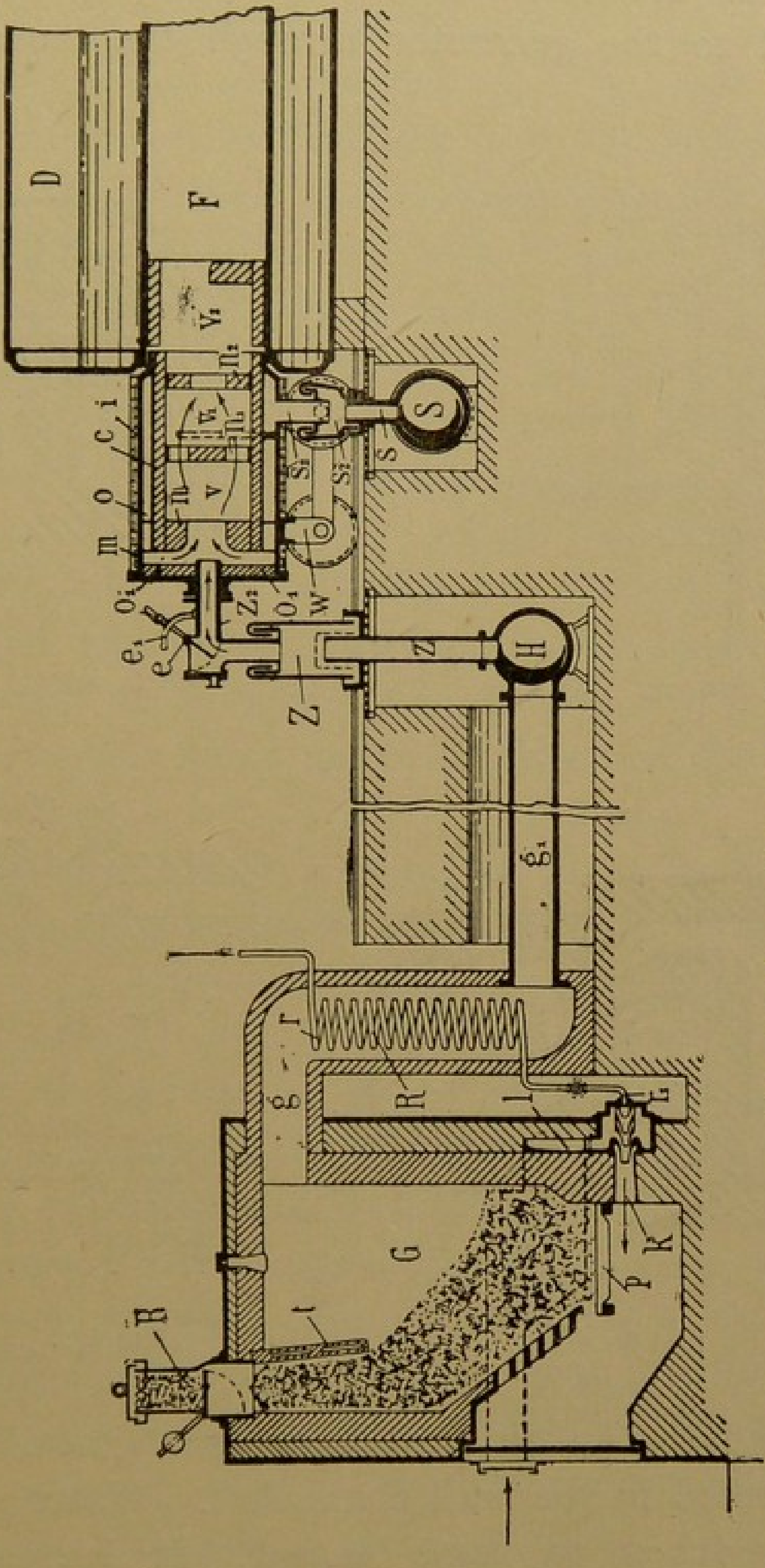

FIG. 22. BOILER FIRED BY GAS GENERATOR.

Air is supplied through a main *S* through branch pipes S_1, S_2 to the individual combustion chambers. At R is a coil, to superheat the steam supplied to the generator through the blower L,

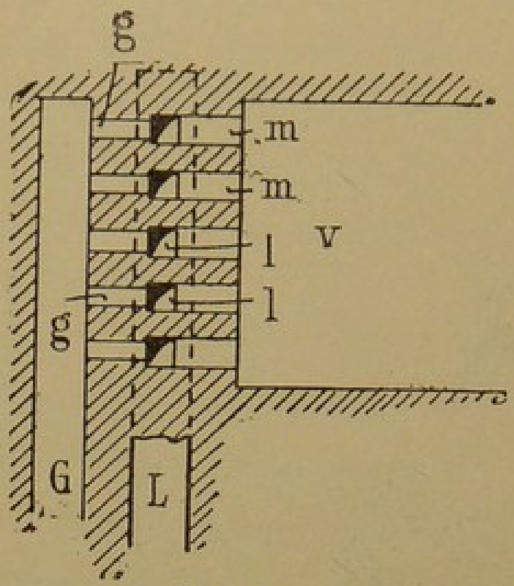

FIG. 23.

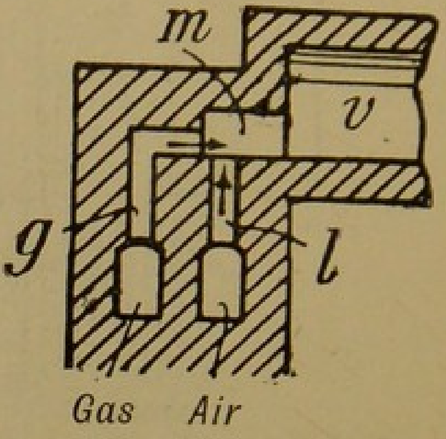

FIG. 24.

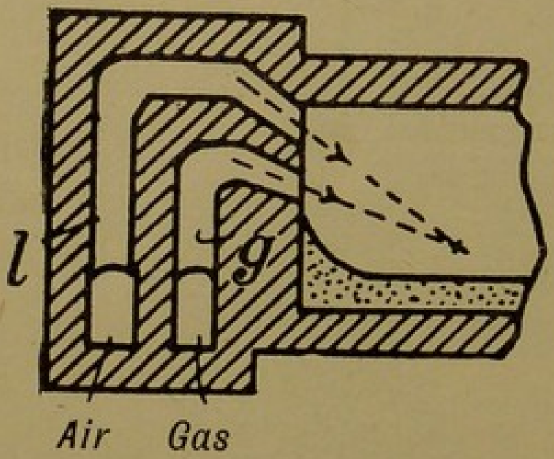

FIG. 26.

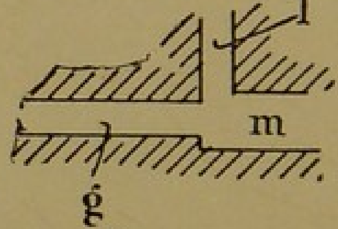

FIG. 25.

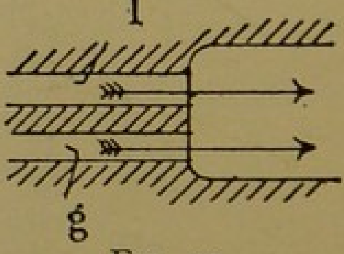

FIG. 27.

which induces an air flow under the grate. This air is heated in the wall channels *l*. Water gas is thus produced to some extent. It leaves the generator at a temperature of 600°C. (=1112°F.), and some of this heat is saved in the steam coil *R*. The gas passes through a pipe g_1 to the water-sealed bell *Z*, and thence to the chamber *V*, through a regulator *e*. Air is admitted at o, o_1, and thorough mixture is secured by means of the baffles n, n_1, n_2. This air is heated in the space between the combustion chambers and the outer casing. The combustion chamber is mounted on a carriage, and the bell *Z* being raised, severs the one joint between the gas producer and the furnace. Another bell at S_2 serves to disjoint the secondary air main.

An important feature of all gas-firing systems is the ease with which the secondary air can be heated, and if done with otherwise wasted heat, the economy is obvious. The question of mixture of the gas and air is however not given the attention it deserves.

If a wide hearth is to be gas fired, the air and gas must be divided into several streams, as in Fig. 23, where *g*, *g*, are the gas openings, and *l*, *l* are secondary air ducts, delivering preferably above the gas supply, as shown in Figs. 25, 26, 27, rather than as shown in Fig. 24; since the mixing is more rapid and perfect when the air comes from above the gas.

For a short hearth the arrangement of Fig. 25 is recommended. For longer hearths Fig. 26 may be used. A very long flame may be obtained by parallel flow of air and gas which retards the mixing, as compared with the impinging effect of Fig. 26.

When, however, a reducing effect is required, the air should be brought in below the gas. This retards the complete combustion, and secures the reducing effect sought for.

DUST FIRING.

Perhaps the most perfect system of burning coal is to reduce it to a fine dust, and blow it into a brick-lined furnace, by aid of the air required to burn it. Thus applied, coal dust burns like gas, with a hot and fairly short flame, the rapidity of combustion varying with the fineness of the dust. So applied, coal should of course be freshly ground. The objection to dust firing is, that the fine ash or incombustible portion of the coal, is carried forward with the waste gases and out at the chimney top, thus becoming a public nuisance. A remedy for this could probably be found in a circular depositing or whirling chamber, "or stive" room, in which the gases would part with their load of dust. The cost of grinding is an item of some expense, that should however be partly covered by the cheapness of the coal, which may be the finest slack. It ought also to be possible, to suit the air supply very closely to the chemical minimum.

In order to grind coal efficiently, it must first be dried. It is stated by Mr. C. O. Bartlett that twice the quantity can be ground when the moisture is reduced to 1 per cent. than can be ground when it is left at 2 per cent. Not more than six or eight pounds of moisture can usually be dried out per pound of fuel burned, and it is not advisable to deliver the dried coal above 150°F. Of course the fuel spent in drying should save some of that necessary in the steam boiler, when coal is burned undried. The same engineer thinks that coal will all be burned as dust, but fully recognizes the dust problem, and the necessity for catching it. The system of coal-dust firing seems to the Authors to be sound in principle, if only it can be successfully applied. The prevention of the fine ash nuisance produced in the flues and spread over the surrounding property is, however, essential to such successful application.

LIQUID FUEL.[1]

Liquid fuel may be almost classed with dust coal. It is fired by heating it to render it as limpid as possible, after which it is blown from an injector or atomizer by means of air preferably hot, at not less than 20 pounds pressure, or by steam, preferably superheated. Liquid fuel is burned either alone or in combination with solid fuel. As with solid fuel, it must be well mixed with air, and the temperature must be well preserved until combustion is completed; to which end furnaces are more or less lined with fire-brick. It is easier to burn liquid fuel with a small excess of air, than it is to burn solid fuel. It is free from the objection of dust, which applies to dust fuel, and would become a very general fuel if its production could be extended.

---

[1] See *Liquid Fuel and its Combustion*. W. H. Booth. Constable and Co.

It may be noted here, that high temperature is promoted by perfect air mixture, because of the more rapid combustion—and perfect combustion tends to shortness of flame. Hence good conditions act and react on each other, to produce the best results—for when the flame is short there is less risk of premature cooling by the boiler plates, and there is less need for long continued fire-brick lining, and therefore a longer path for the gases in contact with the boiler plates. In Fig. 28 is shown the liquid fuel atomizer by M. Guyot, as used in certain tests at Indret, of the French torpedo-boat boiler, Fig. 29.

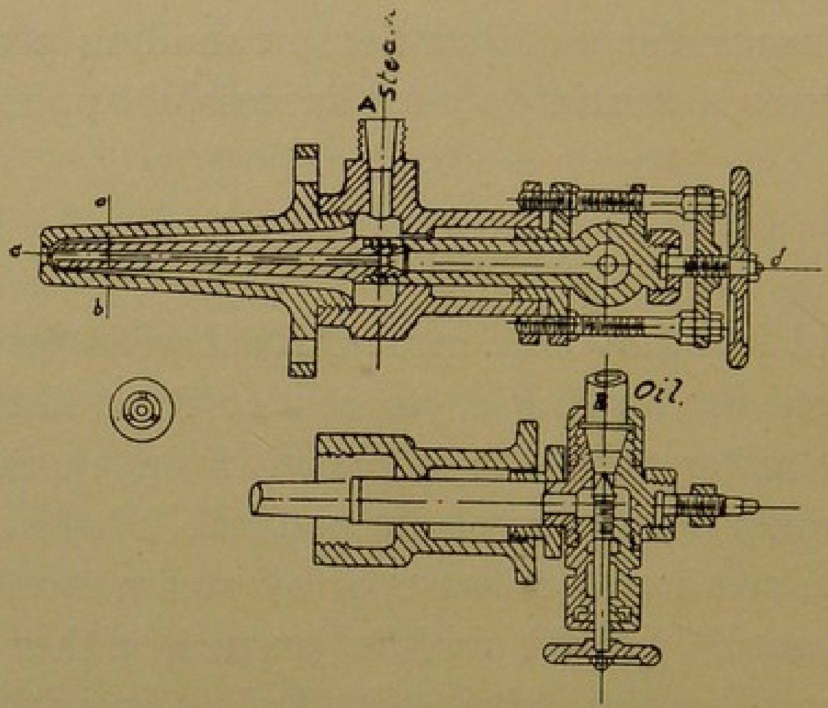

FIG. 28. GUYOT LIQUID FUEL ATOMIZER.

From these figures will be seen how the furnace is lined with fire-brick, to conserve the temperature of the burning oil, and also a usual arrangement of air atomizer, showing the oil and steam passages.

These atomizers are all much alike in form, and differ only according to the ideas of their designers, as to the best degree of atomization that can be secured.

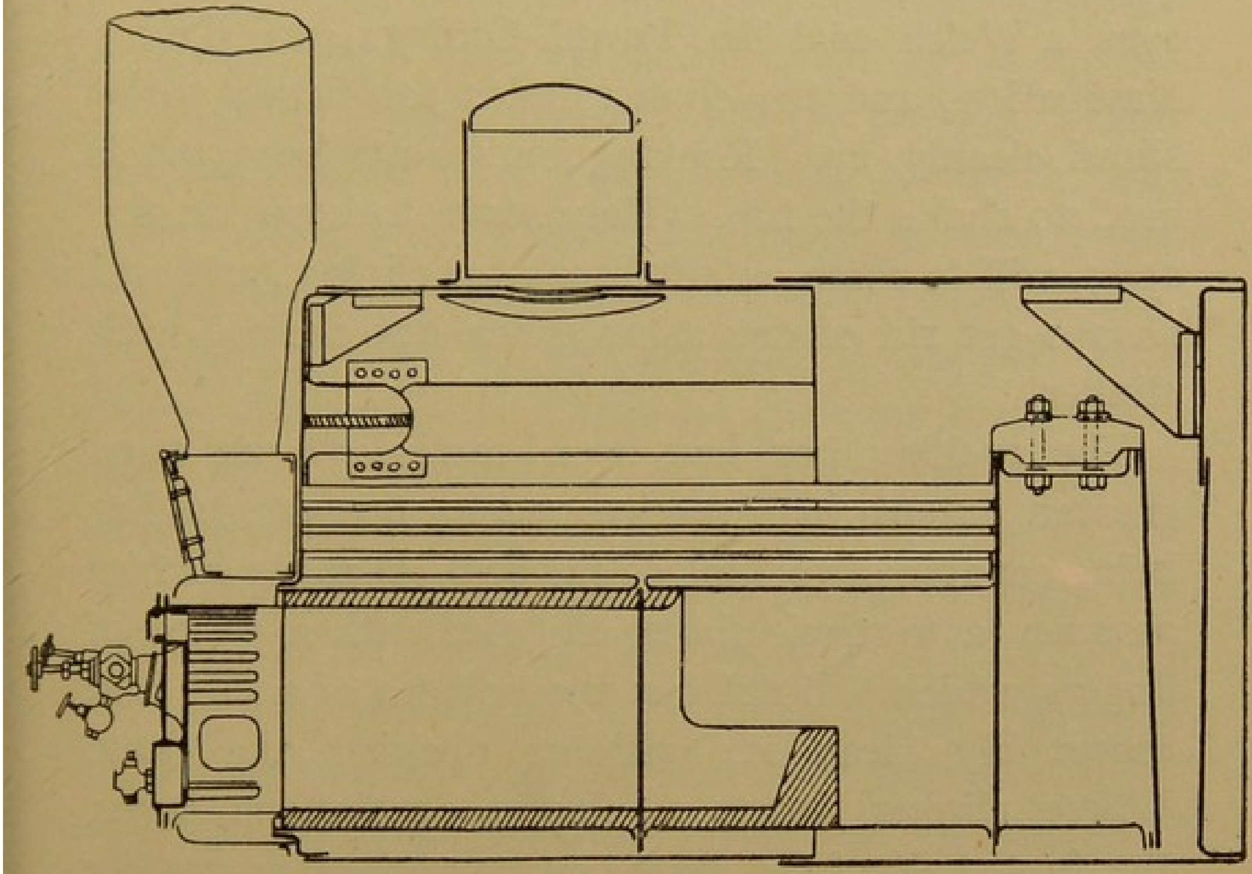

FIG. 29. LIQUID FUEL FIRED FRENCH TORPEDO BOAT BOILER.

SPECIAL FIREBARS.

An enormous variety of special firebars and grates are made as smoke prevention devices. Some of these bars are hollow and convey air to a split bridge heating the air in its passage. Other grates are so arranged as to divide the air which passes through them into a greater number of finer streams than do plain bars. A certain French firebar resembles a plain ¾-inch bar cut across to form squares, the whole grate area being composed of square surfaces $\frac{3}{4}'' \times \frac{3}{4}''$ or $\frac{7}{8}'' \times \frac{7}{8}''$, with air spaces of $\frac{1}{8}''$ to $\frac{3}{16}''$. Such a bar suits briquette fuel which has been made of washed coal and does not clinker, but it speedily chokes with clinker when used with even a Welsh coal like Powell-Duffryn, or Nixon's Navigation, and the clinker holds too firmly to be sliced cleanly up. Rocking bars have been much used to shake the fire. They serve to keep the fire open, will to some extent break up clinker, and will always get rid of dry ashes when not choked with clinker.

The rocking bar has been carried to an even greater extent in America, each transverse bar being capable of rocking so far back, that its surface assumes a vertical plane, and presents a series of fingers, which will cut out the bottom of a fire, and thoroughly clean it, without opening the door. Where clinker forms a plastic continuous layer, the front half of the grate can be rocked separately from the rear half. Clinker cools rapidly and becomes brittle, when the fire is taken from above it. To clean in such cases, the fire is all drawn to one end of the grate. The clinker rapidly chills, on the other half being opened by the bar movements. As soon as cold and brittle, the bars are rocked back to the cutting position, and the clinker cut into the ash pit. The fire is then pushed back upon the cleaned half of the grate, a little fresh fuel being added, if desirable, to furnish gas for the excess of air admitted through the bare grates, and the front half is similarly cut clean, and re-covered with fuel. A more special American grate is the down draught variety, fuel being fired upon an upper grate of water tubes, and all gases escaping only downwards through the fire. A secondary grate below catches the fuel, which falls freely through the somewhat wide upper spaces. With a thick body of upper fire the gases will come through fairly hot, and prepared to unite with the secondary air admitted between the two grates. In all these various appliances, success will be more or less obtained as the mixture of gas and air is able to unite and continue its combustion at a sufficient temperature. The steam jet admitted above the fire door, and pointed towards the central part of the fire, is often employed to assist the inflow of air through the door grids, when the draught is otherwise insufficient. The steam jet appears sometimes to produce an effect out of proportion with its intensity, causing the flames to spring into great activity. Possibly this effect may be related to the supposed necessity for the presence of aqueous vapour when hydrocarbons are being burned, a point worth mention, if perhaps not fully established. Since the presence of aqueous vapour in the waste gases raises the specific heat considerably (see Appendix), it is more than doubtful, however, whether the increase of heat losses up the chimney, under such circumstances, does not more than balance the supposed gain.

DAMPERS AND DRAUGHT.

A proper understanding of the action of a damper will do much to assist smoke prevention. Draught is regulated by means of dampers, which are simply sliding valves, or hinged doors, placed in the path of the gases. If a boiler is under-loaded, and has a large grate area, it is the common practice partially to close the dampers at the chimney base. This reduces the intensity of the draught, and diminishes the rate of combustion on the grate. Obviously the draught of air through the furnace door is also reduced, and sufficient air will not enter to burn the hydrocarbon gases above the fire. If this sluggish state is normal, the proper course to follow is to shorten the grate to such an extent, that the rate of coal combustion per square foot of grate surface per hour shall be increased. With fair chimney draught, about 21 pounds may be secured, and the grate surface should be shortened until this rate is secured, more or less according to circumstances, providing always that a surplus possible damper opening still remains for emergencies. The shorter fire may often be kept thicker and a more efficient use of air can be secured. Mr. Longridge has obtained such results, and cut down the air supply below 15 pounds per pound of fuel.

If this draught question be considered in view of the necessity of admitting air through the doors, it will be perceived that much may depend upon the position of the dampers. If instead of dampers in the flue there is a damper placed to regulate the admission of air below the grate, there will be given the power of a double regulation. By adjusting the flue dampers the draught can be regulated to suit the flow of air through the door grids to the gases produced, whilst the ashpit damper will regulate the combustion of the solid carbon on the grate. The whole régime of the furnace can be kept under control by these two dampers, and it is as well to state here, that where there are two or more boilers, the flue regulating dampers should be those of each boiler, the damper at the foot of the chimney being usually fully open.

Many careful firemen will slightly close the ashpit dampers after firing, in order, if necessary, to add to the flow of air through the door grids.

On the general question of draught and fire thickness, it may be laid down as a general law that large fuel, thick fires, and heavy draught, can be worked together. With too thin a fire, a heavy draught exerts a blow pipe effect in parts, and blows holes in the fire known as "volcanoes." It is not easy to force air through a thick fire of very small coal, as this lies too close to permit of free air passage. Hence the necessity in such cases of a thin fire and a gentle draught, and possibly a maximum combustion of as little as 12 pounds per hour per square foot of grate (nearly 60 kilos per square metre). Obviously the gentle draught necessary to avoid blow holes through the fire, reduces the flow of air through the doors, unless regulation is by the ashpit damper.

Forced Draught.—In the event of insufficient draught, it becomes necessary to assist it. This may be accomplished in several ways.

The ashpit may be closed, and air forced into it by a fan, or by a steam worked injector. By these methods the indraught of air at the doors is of course shut off, or much reduced, and it is necessary that a passage for air should be made to conduct air from the ashpit to the inside of the door, whence it can escape through the inner perforated plate to the fire. The passage for this air must be controlled by a valve—automatically if desired—to admit air above the fire after stoking. (Further remarks on this subject will be found in Chapter IV.)

Closed Stokeholds.—At sea the stokehold is closed, and supplied by fans with air at a considerable pressure, which is therefore as free to pass through the door grids as by way of the grate.

Induced Draught.—Usually for stationary work, a fan is placed at the base of the chimney to draw the waste gases from the boilers. This induced draught in every sense is managed like the natural chimney draught, the speed of the fan being capable of regulation down to the minimum intensity which will draw sufficient air above the fires. Assisted draught should always be capable of being so managed as to produce better combustion, enabling fires to be carried of greater thickness, producing more intense combustion, and higher furnace temperature, and generally improving the boiler efficiency if the fires are attended with corresponding care.

The importance of a minimum air supply, and a minimum chimney temperature, may be gauged from the facts that an ordinary furnace temperature is 2,500°F. (=1,371°C.), and a chimney may have a temperature of 600°F. (=315°C.), thus showing that nearly a fourth of the heat has gone up the chimney. If by reducing the excess of air the furnace temperature is raised, and the chimney temperature is possibly reduced, there is not merely a less ratio of wasted heat thermometrically, but there is also a less weight of wasted gas at that temperature. To drive an induced draught fan may require 1 per cent. of the power generated in an ordinary good plant, or say, 10 h.p. for a 1,000 h.p. plant. But the chimney waste represents heat, which if equally utilized would give 333 h.p. under the above ratio of waste. If only 10 per cent. of this could be utilized by more extended feed heater surfaces, and less excess of air, it would represent 33·3 h.p. saved by the use of a 10 h.p. fan.

A steam induced draught can perhaps be worked with about 5 per cent. of the steam produced, and is not so economical as a fan.

The benefit of any forced draught comes in more especially where conditions are variable, as in an electric light station, where the worst draught is apt to accompany the maximum and most sudden demand for steam, as when a black fog descends suddenly on the district, and acts naturally as a damper on the chimney draught.

The disadvantages of *induced* draught as compared with *forced* draught are—that air leakage may easily occur between the boiler doors and the fan, and the volume of waste gases passing up the chimney may thus be unnecessarily augmented. If all the brickwork and dampers are tight, one system of artificial draught is as good as the other.

Some remarks on testing for draught, will be found in Chapter IV.

CHAPTER IV

The Examination of the Waste Gases, and Control of the Combustion Process.

IT has been pointed out in Chapter II that three conditions are essential for the attainment of perfect and smokeless combustion, without loss of economy. These conditions are—

1. A sufficiency of air in the combustion chamber, but not an excess of the same.

2. A sufficiently high temperature in the combustion chamber.

3. A perfect admixture of the air and volatile hydrocarbons in the combustion chamber.

The absence of smoke is no absolute guarantee that perfect combustion and the highest economy are being obtained, for, as already observed, this absence of smoke may be the result of using a large excess of air in the combustion process. It is therefore necessary to have the waste gases passing to the chimney regularly examined, in order that the engineer in charge may know exactly to what extent the conditions of perfect combustion are being maintained in the furnace or boiler plant. This examination must cover the following points—

A. Colour and appearance.

B. Draught and temperature.

C. Chemical composition.

It is obvious that in carrying out this examination, the methods and apparatus employed may vary from the most simple, to the most elaborate and expensive. In the following pages only the apparatus and methods adapted for works use will be described in detail. For the purpose of checking the combustion process as carried on upon a large scale, it is unnecessary that the methods of draught and temperature determination, or of gas testing employed, should be more than approximately correct, and if the margin of error is constant and is within 5 per cent., the results are of undoubted value for practical purposes. For descriptions of methods and apparatus which yield more correct results, the reader is referred to the standard work on *Technical Gas Analysis*, by Winkler and Lunge (1902 edition).

A. COLOUR AND APPEARANCE OF THE WASTE GASES.

When perfect combustion takes place, the gases while still in a flaming state are transparent. If the refractory combustion chamber of the boiler setting of Figs. 7, 12 or 14, be examined through a sight hole, they may be observed after a charge of fuel to be full of opaque gas or smoke, should there be an insufficient air supply above the fire. By opening the air grids and admitting air, the space will be observed quickly to clear, and soon the opposite brickwork will become clearly visible and of a bright red or white-red colour. It is not possible to inspect a furnace properly without a coloured glass. The best glass to use is a violet blue. Flames looked at through such a glass will, if in a state of imperfect combustion, be resolved into streams of dark coloured gas. But when combustion is perfect, the interior of the furnace and the fuel assume a lavender grey colour, all rays of lower intensity being cut off by the glass. Red and yellow flames are cut out, and the ordinary flame from a grate directly under a water-tube boiler, from which the gases rise vertically between the cold tubes, will quickly be shown to possess very little radiant light capable of passing through blue gas. It appears probable that smokeless combustion cannot be secured unless the combustion is taking place at a temperature producing light rays, which penetrate the blue glass. This penetrative power is an indication of the actinic power, and a proof of intense action.

The process of combustion can very well be watched in this way; and the glass enables one to see the dun coloured unburned gases as they travel in dark streaks towards the zone of perfect combustion, where they gradually disappear, becoming perfectly burned.

THE ESTIMATION OF SMOKE.

Engineers will often find it necessary to estimate accurately the colour of smoke, so that its density may be stated. A standard chart ought to be decided on. There is nothing better than Ringelmann's smoke charts of six grades, viz. No. 0 to No. 5, named respectively nil, light grey, dark grey, very dark grey, black and dense black.

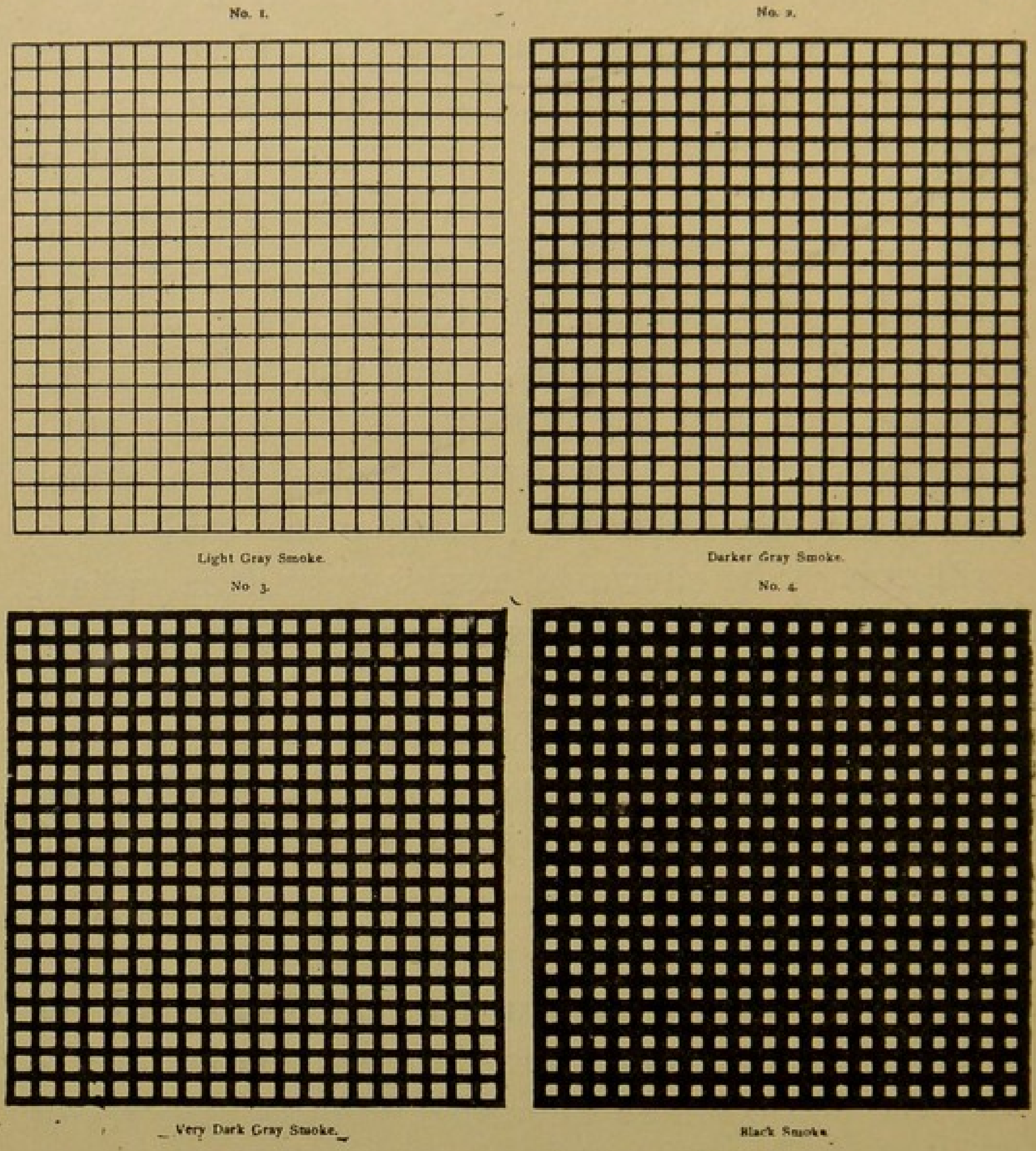

FIG. 30. RINGELMANN'S SMOKE CHARTS.
No. 0—All White. No. 5—All Black.

No. 0 card is pure white, and No. 5 is all black.

The other numbers consist of ruled black lines at right angles as follows—

No.	1.	Black	lines	1	mm.	thick,	spaces	9	mm.	wide.
,,	2.	,,	,,	2·3	,,	,,	,,	7·7	,,	,,
,,	3.	,,	,,	3·7	,,	,,	,,	6·3	,,	,,
,,	4.	,,	,,	5·5	,,	,,	,,	4·5	,,	,,

or in the same proportions.

The cards thus consist of a number of white squares divided by black lines. Placed 50 feet from the eye they take on the appearance of uniform colour, according to their naming. Such a card hung in the light in a line with the chimney top, enables the smoke density to be estimated very closely.

The cards ought to be at least eight inches square.

Fig. 30 shows four of these charts reduced in size.

B. Draught and Temperature.

These measurements should be carried out at an observation-hole, placed in the top or side wall of the branch-exit flue of each boiler or furnace, at that point where it joins the main-flue to the chimney. There is usually a damper at this point, and the observation-hole should be about 24 inches, on the furnace or boiler side of it.

It saves much trouble if such holes are left in the brickwork when the flues are being constructed, and a 30-inch length of 1¾-inch wrought iron pipe with a flanged top should be set with fire-clay in the hole thus left, in order that a straight and clear passage into the flue may be kept constantly ready for use. When not required for testing purposes, this pipe can be closed with a $1\frac{1}{2}$-inch bolt.

For comparative rough draught measurements, the apparatus shown in Fig. 31 is sufficiently exact. The U-tube is $6\frac{1}{2}$ inches in height, and of glass $\frac{5}{16}$ inch inside diameter. It is half filled with water, or in special cases with some lighter and more mobile fluid. The limb marked *B* is connected to a hard glass tube, passing at least two feet into the flue, and firmly fixed in the observation-hole by cotton waste. The scale *C* behind the U-tube slides in a groove, and this movement enables the water level to be easily adjusted to zero, before making the test, and thus saves trouble when filling the tube. Should the pull of the chimney be equal to less than

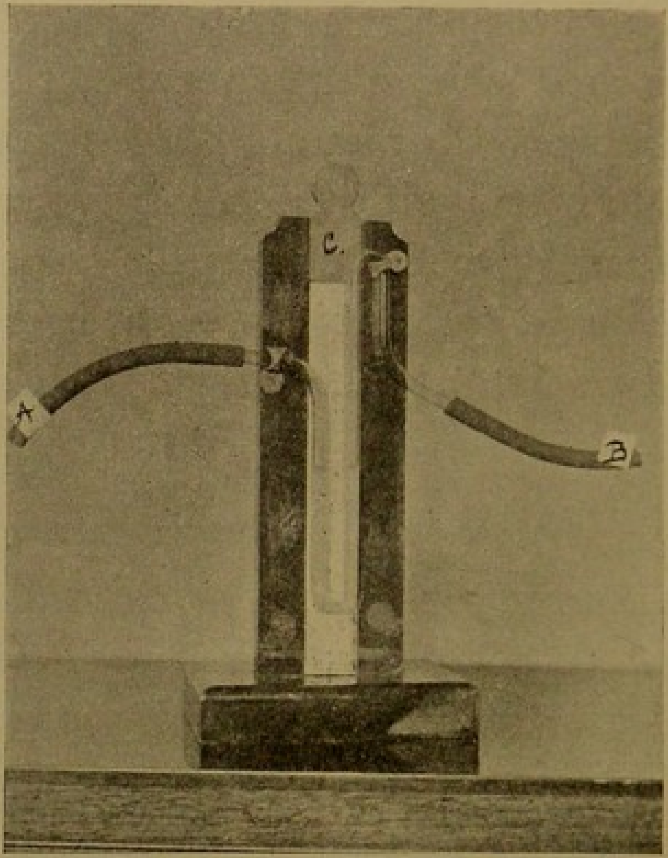

FIG. 31. DRAUGHT MEASUREMENTS GAUGE.

one inch of water, a greater range of reading can be obtained by connecting the limb *A* to the flue by a second hard glass tube, with its further end bent at right angles, and turned in the direction from which the gases are travelling. This tube must project well into the flue for accurate results. The readings of the apparatus can also be amplified by using ether or alcohol, in place of water, for filling the U-tube, but in this case a calculation will be requisite in order to obtain the draught measurement expressed in inches of water, the factor depending upon the specific gravity of the liquid used.

This instrument, in more elaborate form, can be employed for measuring the speed of the draught in boiler and furnace flues, and is then known as the "*Anemometer*."

For a full description of its use for such purposes, and the methods of calculation, readers are referred to the larger books on this subject, by Lunge and Poole.

As regards the draught which ought to be maintained in each boiler-flue in order to obtain perfect combustion of the fuel, a pull equal to at least ¾-inch of water ought to be observed at the point named, when the furnace doors and air slides are closed and the dampers are drawn to their full extent. This would signify a 1-inch pull at the base of the chimney. If this difference in water level is not found when making the test with the draught-gauge, a special examination should be made of the condition of all the brickwork of the flues and boiler casings, and where necessary pointing should be undertaken. If no improvement results, steps must be taken to reduce the work placed on the one main flue or upon the one chimney —for perfect combustion is impossible in the absence of sufficient draught, and many failures to attain it are no doubt due to this simple cause.[1] The engineer in charge of the boiler or furnace plant ought therefore to make daily tests with the gauge just described on every furnace and boiler under his charge, and any deficiency in draught should at once be noted and remedied. Too low a temperature of the exit gases is in some cases the cause of defective draught. The draught above the boiler fires should be about $\frac{3}{8}$-inch, when working under normal conditions.

The temperature measurements can be made with ordinary mercury thermometers up to 300°C.; or with mercury thermometers of a special type up to 530°C. For temperatures above 530°C., either a water pyrometer, or an electrical pyrometer of the Chatelier type, must be employed.

A case and carrier suitable for a mercury thermometer, designed for taking the temperatures of furnace and boiler flues, is shown in Fig. 32. *A* is a "high temperature" mercury thermometer constructed of special hard Jena glass, containing nitrogen under pressure in the upper portion of the stem, and graduated up to 550°C. *B* is a strong

---

[1] Defective baffle walls, at the base of the chimney, are sometimes the cause of defective draught.

case of 1-inch brass tubing into which this thermometer fits; the lower portion *C* being filled with brass filings, which serve as a protection and heat carrier to the bulb of the thermometer. This lower portion of the case *C* screws into the main tube, and the thermometer is fixed into the casing by aid of asbestos plugs and two brass washers. When required for use, the brass casing *B* is fixed in the iron carrier *D*, which is constructed of ½-inch wrought iron rod, and is flattened out at the lower end to permit of the brass thermometer being fixed firmly upon it. A hollow step holds the base of the brass case, and a sliding cover *E* is used to

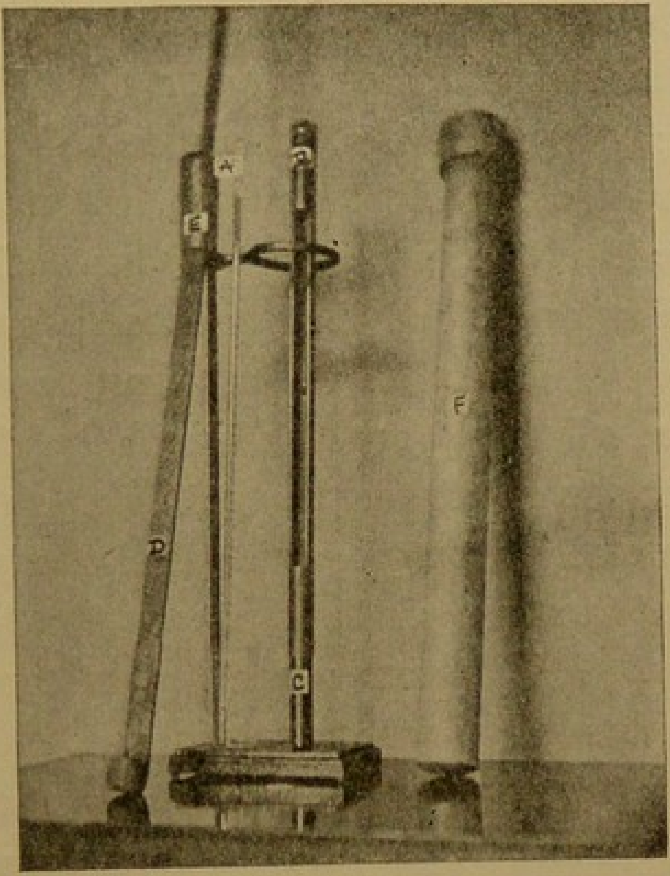

FIG. 32. CARRIER FOR MERCURY THERMOMETER USED IN TESTING FUEL TEMPERATURES.

hold the top of the case firmly against the iron rod. The carrier *D* can be made of any length, and is provided with a handle at its upper end, so that it may be hung in the observation-holes in any of the flues for obtaining temperatures. Owing to the mass of filings which surround the bulb of the thermometer, and to the thickness of the brass casing, the thermometer must be left at least ten minutes in the flue before withdrawing for reading the temperature; and some little practice will be requisite to obtain quick readings of the mercury level on withdrawal. It is necessary to have the light at a particular angle for this purpose; and to have cotton waste handy, for removing soot from the glass. An oil lamp or candle will be found most convenient for obtaining the readings quickly. The mass of metal surrounding the thermometer is here of some advantage, since it causes the loss of heat to be slow. *F* is a stout wooden case for protection of the thermometer when not in use.

The "high temperature" mercury thermometers are expensive and fragile, and for works use, the water pyrometer is a more practical and useful instrument. Fig. 33 is from a photograph of an inexpensive water pyrometer which can stand much rough usage, and yields results sufficiently accurate for ordinary works requirements. *A* is a small piece of wrought iron, 1⅛ inches in length and ⅝ inch in diameter; *B* is a tin measuring vessel holding 118 cc. of water when filled to the brim; *C* is a cup of hard lead, about 2¾ inches in diameter and 3 inches high, holding about 236 cc.; and *D* is a carrier for the small iron block *A*. This carrier is similar in design to that shown in Fig. 32, and is provided with a sliding hood which holds the iron block in position, and also protects it from soot; this last being a very important detail.

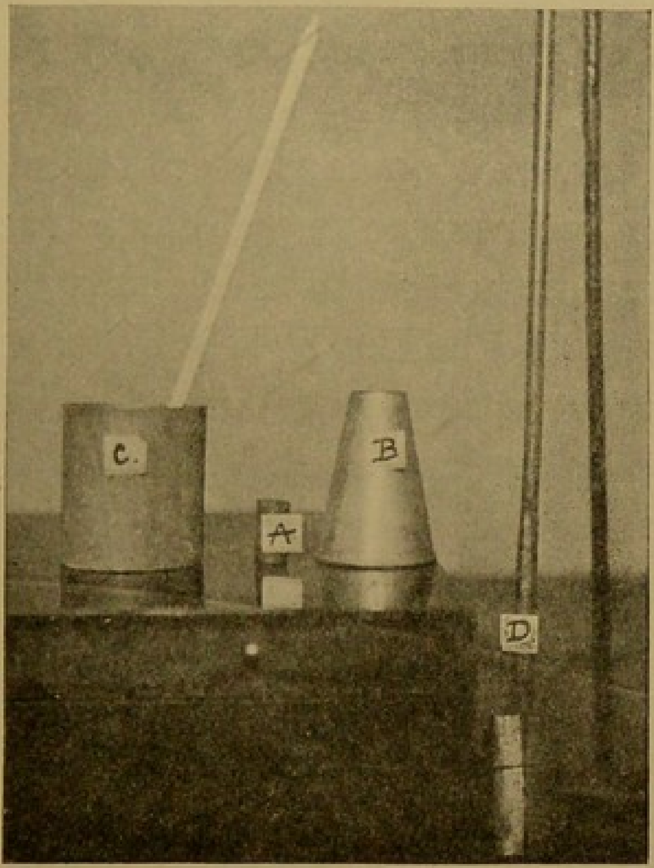

Fig. 33. Water Pyrometer for Testing the Temperature of Flue-Gases.

The water pyrometer is used, by inserting the block of iron in the carrier *D*, and by placing the latter in the observation-hole of the flue, the temperature of which is required. The block and carrier must remain at least ten minutes in this position. While the carrier and block are attaining the temp-perature of the flue, 118 cc. of clean water are measured off into the lead cup *C*, and the temperature of this water is carefully taken with a thermometer reading up to 50°C. and graduated in fifths of a degree. The cup *C* and its contents must be placed on a support which is at the temperature of the air, as it would obviously lead to error if the cup were placed on warm brick work, or upon a hot boiler-plate, during the observation. This warning may seem superfluous, but users of this instrument in some cases, will no doubt require to be told to take this obvious precaution.

After the water in the cup *C* has arrived at a permanent temperature, and the necessary ten minutes have elapsed, the holder *D* is withdrawn from the flue, and the portion containing the iron block is held horizontally just above the cup, from which the thermometer has been removed. A short piece of stout iron wire is used to push back the cover along the carrier, and the block of heated iron is allowed to fall into the water. The cup is then gently rocked to agitate the water and the block, and also to prevent softening or fusion of that part of the lead bottom upon which the iron block rests. After the lapse of one minute, the thermometer is again inserted and the readings taken. The rocking motion is again employed for another half minute, and a second thermometer reading is taken. If no rise of temperature be noted, the observation is complete; if a slight rise of temperature occurs, the agitation of the block and water is renewed for another quarter minute.

The calculation which is necessary to obtain the flue temperature depends upon the relative weights of the block, of the lead cup, and of the water; and for works use, it is advantageous to arrange that a simple factor, say, 25 or 50, shall yield the required result.

The formula for calculating the temperature is as follows—

$$T = t^1 + \frac{p^1 \, (t^1 - t^\circ)}{pc}$$

where T = the temperature of the flue or block.
t° = temperature of the water in the lead cup before the observation.
t^1 = temperature of the water in the lead cup after the observation.
p = the weight of the iron block.
c = specific heat of the iron.
p^1 = the weight of the water within the lead cup, plus the water equivalent of the cup. The last is obtained by multiplying the weight of the cup, by the specific heat of the hard lead, namely —·035.

The portion of the above expression $\frac{p^1}{pc}$ may, as already stated, be converted into a constant factor (x), and the formula then becomes—

$$T = t^1 + x \, (t^1 - t^\circ)$$

—that is, the temperature of the flue is equal to (x) times the gain in temperature of the water in the cup, added on to the final temperature of the water. For determining high temperatures, the factor should not be less than 50, otherwise the water in the cup will be raised beyond the reading limit of the thermometer; for low temperatures a factor of 25 will yield satisfactory results.

In the water pyrometer shown in Fig. 33, the iron block weighs 46·1 grms., and the water equivalent of the cup is 18·00 grms. When using 118 cc. of water in the cup, the factor (x) is 25·9, and when employing 200 cc. of water, the factor is increased to 41·5.

The errors of this instrument are due to radiation losses, which are partly guarded against in the more elaborate forms of it devised by Fischer and by Siemens and Halske, and to changes in the specific heats of iron and of lead, as the temperature increases. Corrections can be made for this latter error, when greater accuracy is desirable, but for merely comparative works tests, these corrections are unnecessary.

Pyrometers of the electrical type are based, either upon the changes in electrical conductivity due to the rise in temperature, when the active portion of these instruments is inserted in the hot flue, or upon the current set up in thermo-couples, under similar conditions. The more expensive forms of these instruments yield accurate results, and when provided with recording cylinders, they form the most convenient means for checking flue temperatures. They require calibrating at stated intervals, however, as they alter during use. For descriptions of these instruments and of their applications, readers may consult the larger works on this subject by Lunge and Poole. A recording pyrometer based on the pneumatic principle is also largely used in America, and is known as Uehling's pneumatic pyrometer. A brief description of it is given in Poole's book on *Fuel*, 1901 edition, p. 153. This instrument is stated to yield reliable results for all temperatures.

As regards the temperature which ought to be maintained in boiler furnaces in order to obtain perfect combustion, the following figures are given for a Lancashire boiler by Hiller[1]—

Temperature in boiler furnace .	1,535°C.	2,800°F.
Temperature six-feet behind bridge	980°C.	1,800°F.
Temperature in drop flue at end of fire-tube	535°C.	1,000°F.
Temperature at exit into main flue	340°C.	650°F.
Temperature at base of chimney (minimum)	150°C.	300°F.

When economizers are used for heating the feed-water of the boiler, the temperature is usually reduced by about 250°F., and the waste gases pass to the chimney at a temperature of 400° to 450°F. An exit temperature from the boiler flue, before entering the economizer, above 340°C. or 650°F., is indicative of bad work, and is a sign of dirty flues, or of scale-covered boiler plates. When such a temperature is recorded for any boiler, its cause should be at once discovered, and, if possible, there should be no delay in remedying it.

An economizer minimizes, but does not obviate, the losses resulting from too high a temperature of the exit gases; and the boiler is the appliance in

---

[1] *The Working of Steam Boilers*, by E. G. Hiller, 1902.

which all the heat possible should be abstracted from the hot gases. To allow unnecessary heat units to escape into the flues, with the idea that they will be caught and retained by the water passing through the economizer, is not conducive to true economy.

C. CHEMICAL COMPOSITION OF THE WASTE GASES.

a. SAMPLING THE GASES.

The composition of the waste gases passing from each boiler may be ascertained by examining a sample taken from the observation-holes situated just inside the damper of each branch exit flue, and already described under draught and temperature. If an *average* sample of the waste gases passing from a group of boilers is required, this must of course be taken at a point in the main flue, where the gases passing from the individual boilers have travelled some distance together, and have become well mixed. If the sample of exit gases be drawn from the chimney stack, the sampling hole must be placed at least fifteen feet from the ground, since the baffle walls built at the base of the chimney hinder admixture of the gases passing up it, until they have travelled some distance from their entrance point. The sampling holes for drawing samples of the waste gases should be constructed as already described, under Section B; and as it is convenient to be able to make temperature observations at all these points, the wrought-iron pipe used should be 1¾ inches in diameter in all cases, in order to admit the thermometer carrier. Gas samples taken at man-hole covers are wholly untrustworthy, since air always leaks in when sampling is attempted at these places.

For drawing the gases from the flues, three-feet lengths of the glass tubing, sold as "hard glass," ⅜-inch in external diameter, are the most convenient. A large bung 1¾ inches in diameter is fixed upon one of these tubes, and is inserted in the flanged end of the wrought-iron pipe. A second length of glass tube is then connected to the projecting end of the first, by a three-inch length of good *red* rubber tubing, as black rubber is not suited for use with hot gases. It is not advisable to use any apparatus for retaining the soot at this stage of the sampling operation, since the volume of the gas drawn through the tubes may be very large, and asbestos or glass wool speedily become blocked with the soot which collects in it.

The form of sampling apparatus employed depends upon the character of the test, and varies according as one desires a test representing the composition of the gases at a given moment, or an average extending over one or twelve hours. Three forms of sampling apparatus, designed for fulfilling these different conditions, are described below.

I. SNAP-SAMPLES

Fig. 34 shows the most convenient form of apparatus for taking what are called "snap-samples," that is, samples of the waste gases at any given moment of time. *C* is a small rubber finger pump, provided with valves, so that the gases forced through it travel only in the one direction. A pump that passes 35 cc. at each compression is the most convenient size for general use. *B* is a small check valve, and is formed by a short length of black rubber tube $\frac{3}{16}$ inch in diameter, having a central slit longitudinally, and closed at one end with a glass rod. This is enclosed in the glass tube *B*, and serves to prevent all possibility of air leaking past the valves of the pump *C*, into the gas-sample tubes, *A* and *D*. *A* is a Honigman gas burette, holding 100 cc, and graduated in one-tenths, the use of which for CO_2 determinations will be explained in the next section. *D* is a larger gas-sample tube holding 220 cc., and provided with

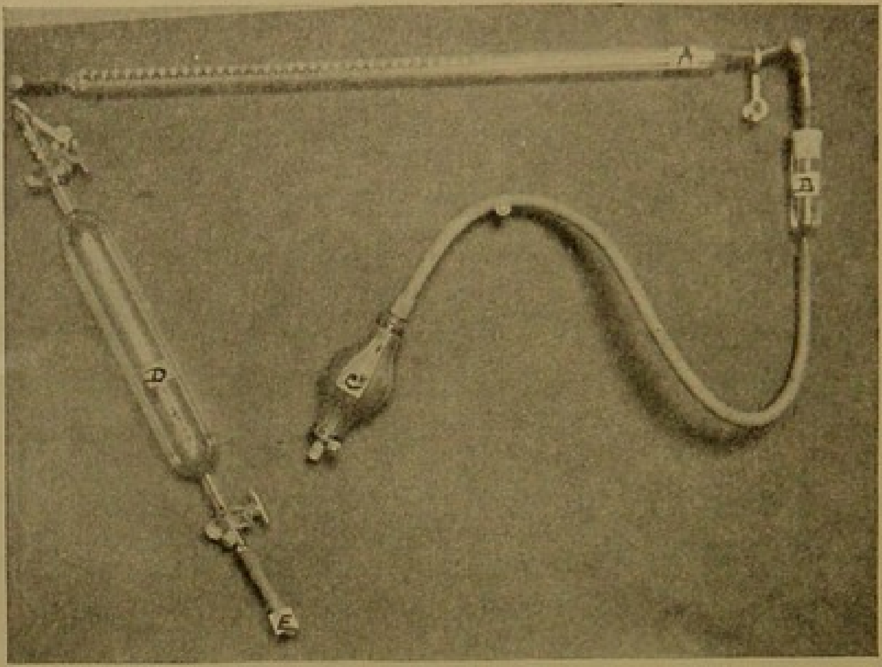

FIG. 34. APPARATUS FOR OBTAINING SNAP-SAMPLES OF FLUE-GASES.

glass stop-cocks at each end. It serves to retain samples of the gas for some hours without change, and is useful for storing reserve samples, or samples to be sent to the expert for complete analysis. These various portions of the apparatus are connected together by rubber tubing, and *D* is connected to the hard-glass tube leading into the flue by the rubber connexion *E*. The sample is taken by pumping the waste gases through the sampling tubes *A* and *D*, until all the air has been expelled, and its place is occupied by the flue gas. Five times the volume of air contained in either tube must be passed through them in order to attain this result; and a simple calculation shows that with a rubber pump, expelling 35cc. at each compression, 46 compressions or suctions will be required to replace the whole of the air in tubes *A* and *D* with waste gases.[1] This number of compressions can be easily effected in one and a-half minutes. Ordinary chemical spring clips are then fixed upon the rubber tubes at each end of the Honigman burette, the stop-cocks on *D* are closed, and the various portions of the sampling apparatus are disconnected. The testing of the gas in the Honigman burette must at once be proceeded with, since rubber connexions are not permanently gas-tight.

The precautions necessary in using this apparatus are—

---

[1] Allowance should also be made for the air contained in the sampling tubes leading into the flues, which may represent another 250 cc.

First. To see that the valve *B* is working properly, and that the two lips of the slit meet and close evenly, when the pump is being compressed in the hand.

Second. To have the interior of *A* and *D* fairly dry before use; and

Third. To see that all the rubber connecting pieces are tight and free from kinks, when the sampling operation is in progress.

This "*dry*" method of sampling is certainly the most convenient of those which can be applied to the sampling of flue gases; and even in unskilful hands it yields accurate results. Unfortunately, it cannot be applied to the withdrawal of samples from the flues over any long period of time.

2. AVERAGE SAMPLES EXTENDING OVER ONE HOUR.

The apparatus shown in Fig. 35 is employed when a sample of the waste gases during a period not exceeding one hour is required. *A* is an ordinary water-jet air pump, sold by chemical apparatus dealers to chemists, for laboratory purposes. *B* is a 220 cc. glass sample tube provided with glass stop-cocks; and *C* is the rubber connexion which serves to join the T-shaped connecting piece to the glass tube leading to the flue. *D* is a rubber connexion ending in a glass jet. The water-jet pump must be connected to a water supply. Should there be none convenient to the place where the average sample is to be taken, the pump must be connected by a syphon tube to a bucket or tank of water placed ten feet above the ground, and a screw clip must be used to regulate the flow of water into the pump. The tube *B* must be filled with mercury, and must be fixed in a suitable support in a vertical position with the jet on *D*, leading into the bottle in which the mercury is stored when not in use. This jet must dip under the mercury level in the bottle when the sampling tube is empty. Water is unsuitable for use in *B*, since absorption of CO_2 occurs, when the liquid and gas are left in contact for one hour.

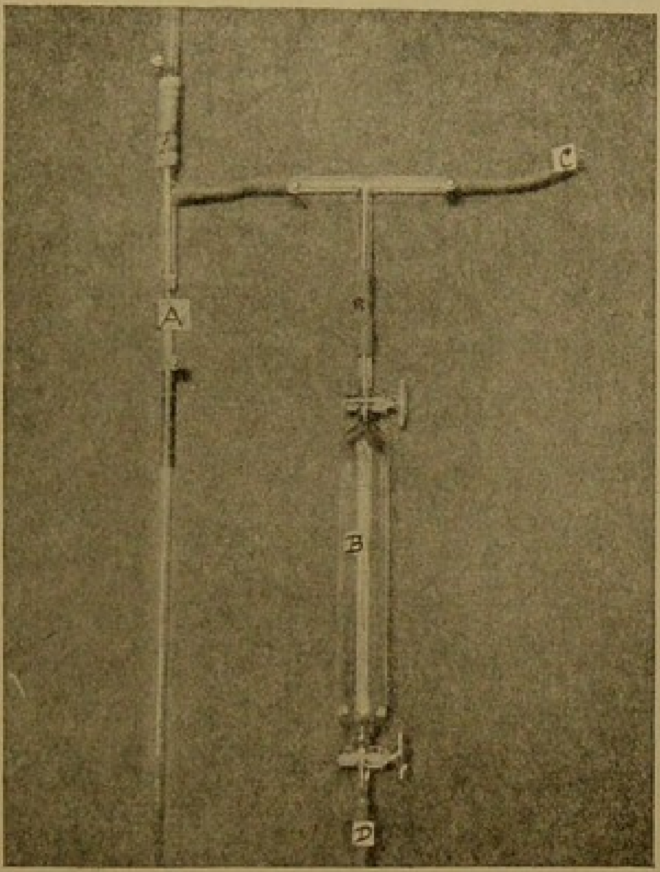

FIG. 35. SAMPLING APPARATUS FOR OBTAINING AVERAGE SAMPLES OF FLUE-GASES DURING ONE HOUR.

The average sample of gas is now obtained in *B* by starting the water-jet pump at such a rate of flow, that a fairly rapid current of waste gas from the flue is carried through the tube *C* and through the T-piece connexion into the pump. The upper glass stop-cock on B is now opened to its full extent, and the lower one is opened sufficiently to allow a slow stream of mercury to pass out of *B* into the storage bottle. The jet on *D* enables the stream of mercury to be regulated with ease; and the rate of flow is arranged so that the vessel *B* shall be empty in one hour, or in the time to be covered by the sampling operation. During the whole of this period a rapid flow of waste-gas is being drawn through the T-piece to the pump; and the gas which enters *B* is therefore a fair average sample of the whole bulk. The precautions necessary in using this apparatus are—

First. To see that the water-pump *A* is working properly, and that there is no danger of back suction of water into *B*, and into the tubes leading into the flue. When the pressure or head of water is too small, this is a possible cause of danger to the sampling operation.

A dirty water supply may also cause trouble, for it will probably lead to stoppage of the pump, owing to lodgment of particles of solid matter in the jet. A small plug of glass wool placed in the suction end of the syphon tube, will obviate this danger.

Second. To see that the mercury bottle is so arranged under *B* that when this tube is filled with gas, the point of the jet shall be dipping in the mercury and shall not be exposed. Otherwise air would diffuse into the sampling tube, if some one were not present to close the stop-cock on *B*, at the exact moment when it became empty. The delivery tubes of the pump *A* should also dip into a vessel of water, for the same reason.

Third. To see that all the rubber connexions are tight and free from kinks, during the sampling operation.

This sampling apparatus, if fixed in a suitable stand, is the most convenient for taking hourly averages of flue gases. By employing two sampling tubes, a second sample of gas may be taken while the chemist or engineer is examining the first ; since, when once started under correct conditions, the apparatus requires no attention until the end of the hour.

3. AVERAGE SAMPLES EXTENDING OVER SIX OR MORE HOURS.

Fig. 36 shows an aspirator which may be used for taking average samples of the flue gases over longer periods than one hour. The cylinder is constructed of sheet zinc, and is 36 inches in length by 6 inches in diameter ; the necks being $1\frac{1}{8}$ inches and $1\frac{1}{2}$ inches in diameter respectively. When filled with water it holds ·588 of a cubic foot (equal to 3·6 gallons or 36 lbs.), and by providing a run-off jet of suitable size, this water can be made to last from two to ten hours. Experiments are necessary to obtain the correct size of jet to use for any given period of sampling; but when once obtained these jets can be marked with the numbers 2 to 10, and all further trouble in this respect can be avoided. The rubber stopper used for holding the jet in the lower (narrow) neck of the aspirator, must be firmly tied in with string or wire, as the pressure upon this stopper when the aspirator is full of water is very great. The top of the aspirator is connected by a rubber stopper and bent tube, to the T-piece shown in the apparatus of the last figure, and the method of obtaining the sample is similar to that described under the previous heading, the large aspirator being simply substituted for the small gas-sampling tube.

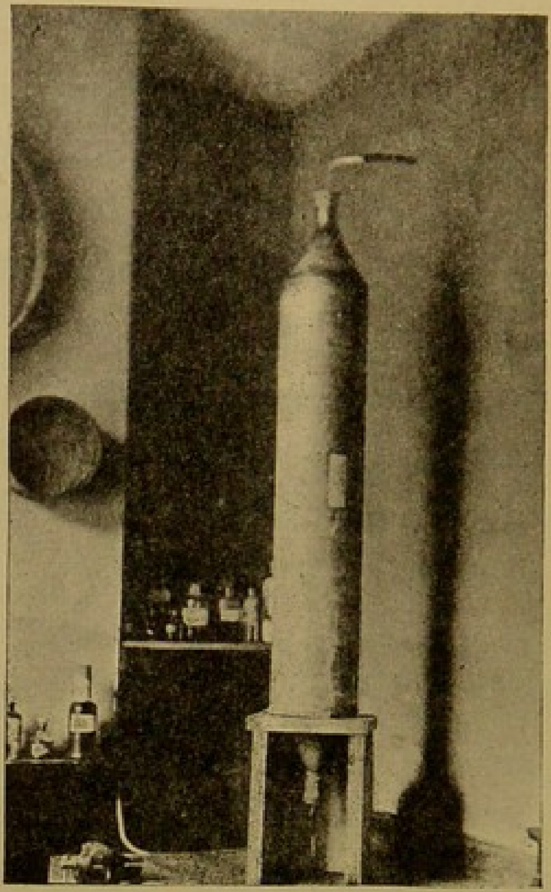

Fig. 36. Sampling Apparatus for Taking Samples of Flue-Gases, over a Period of Six or More Hours.

It is of course impossible to use mercury in such large amounts, and water must be employed for filling the aspirator. A layer of oil can be employed to reduce the CO_2 absorption. This, however, is bound to occur, and therefore it is not advisable to make the period of sampling too long, or to delay testing the sample when once taken. The precautions necessary in using this apparatus are—

First. To see that the water pump is working properly during the whole period, and that no obstructions have lodged in its jet. A constant supply is of course necessary for this use of the water air-pump.

Second. To see that the various rubber connexions are all tight and that none of them are kinked.

Third. To see that the run-off jet of the aspirator is dipping into water, before the whole of the contents have run out.

Owing to the variation in level and pressure within the aspirator, the gas is drawn in more quickly during the first half of the sampling period than during the second, and the sample finally obtained is not, therefore, a true average for the whole period. This effect can be counteracted by connecting a three feet length of $\frac{1}{4}''$ glass tubing to the run-off jet, and by slinging this length of tube with its free end raised in the air, round the upper neck of the aspirator. The flow of liquid then occurs from the upper end of this tube, and by lowering this end three or more inches each hour, the flow of water can be regulated, so that it may be equal for each hour of the sampling period. It is doubtful, however, whether, even under these conditions, a *really reliable average sample* of gases over twelve hours can be obtained; and the average of a number of tests of snap-samples, or of a number of tests of hourly samples taken with the mercury sampling-tube, is to be preferred. In some cases, however, the large aspirator may prove useful and of decided practical value.

b. TESTING THE GASES.

For practical purposes, it is usually sufficient to ascertain the percentage of CO_2 (carbon dioxide) in the waste gases; and only at exceptional times is it necessary in addition to test these gases for oxygen and carbon monoxide.

Three forms of apparatus will be described for attaining these results:—

I. TESTS FOR CARBON DIOXIDE ALONE.

The simplest apparatus which can be employed for making rapid tests of CO_2 in flue gases is the Honigman gas burette, in the modification devised by one of the authors of this book.

The apparatus and method of use is illustrated in Fig. 37. *A* is a Honigman gas burette holding 100 cc.; *B* is a glass cylinder jar, 8″ × 2″ in diameter; *C* is a zinc trough for holding water; *E* is a spring clamp; and *D* is the box, which serves to contain the whole apparatus, and also acts as burette stand. The sample is collected in the Honigman burette, by the dry method described on p. 109; but if it is desired to test the sample contained in one of the larger sample tubes, or in the large aspirator, by this apparatus, the Honigman burette must be filled with mercury, and then connected to the vessel from which it is desired to draw the gas sample. As the mercury runs out, the sample of flue gases will be drawn in. Brine, or a 20 per cent. solution of common salt, may be used to displace the gas in the original collecting vessel. The Honigman burette must be quite filled with the gas, before disconnecting. The burette is now immersed for two minutes in the trough *C*, which is four-fifths filled with water, in

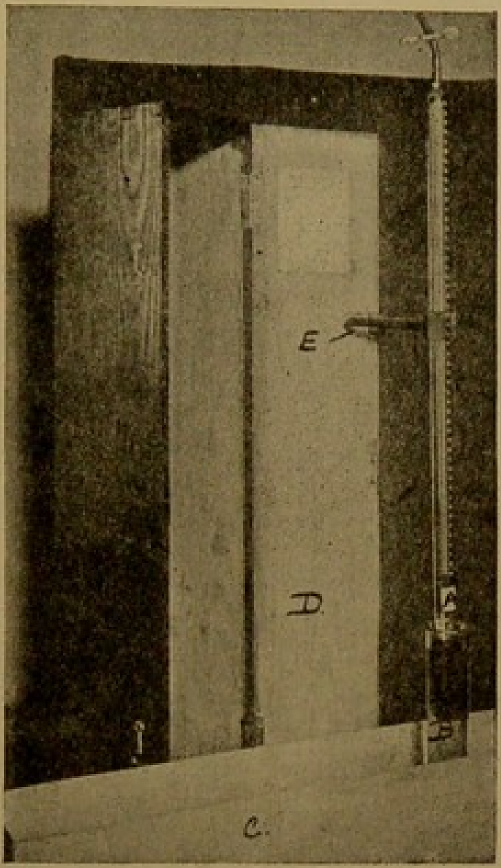

FIG. 37. APPARATUS FOR TESTING FLUE-GASES FOR CO_2.

order to bring the contents of the burette to a standard temperature. The spring clip on the zero end of the burette is then removed, and the burette is clamped in the position shown in Fig. 37, with its lower end immersed in the water contained in the glass jar *B*. The zero mark of the burette is placed level with the brim of *B*, and the upper clip is opened to allow the excess of gas to escape into the air, water being poured into *B* from the trough until the contents of *A* measure exactly 100 cc.

The burette is then removed from the clamp E, and is placed in a slanting position in the trough, with its upper end resting on one of the ends of the same. A small 1-gram. piece of solid caustic potash is taken in the forceps provided for the purpose, and is inserted in the rubber tube at the lower end of the burette. It is then pushed up into the same by a short length of glass rod, this being left in the rubber as stopper.

The burette is now removed from the trough and is gently shaken, the purpose being to dissolve the small lump of caustic potash in the water contained in the burette, and to bring the resultant solution into use as an absorbing liquid.

Two minutes' agitation is usually sufficient for this purpose, and the burette is then again immersed in the water contained in the zinc trough, in order to bring back the contents to the original temperature. The final operation is to withdraw the glass rod from the lower end of the burette, to fix the latter in the vertical position in the clamp, and to read off the volume after levelling the liquid, in and outside, the burette. The loss in volume equals the percentage by volume of CO_2 contained in the sample. This apparatus yields accurate results, and tests with it can be completed within five minutes ; but some little practice is necessary to obtain this accuracy and speed. The precautions necessary in its use are as follows :—

1. The rubber tubing at the upper end of the burette must not be immersed in the water, since if any liquid collects inside it, the expulsion of the excess gas above 100 cc. is rendered exceedingly difficult.

2. No air must be allowed to enter the burette at the lower end, when removing the clip. For guarding against this, it is advisable to squeeze the fingers along the rubber towards the open end, before the clip is opened, keeping the rubber meanwhile under water.

3. Both before and after the absorption of CO_2, the gases must be reduced to the standard temperature—that of the water in the trough.

4. No air must be allowed to enter the tube and burette, when inserting the caustic potash in the solid form. This operation must be carried out under water ; and speed is necessary, as this chemical dissolves most rapidly in water.

5. After each test, the burette, glass jar, and zinc trough must be washed out with clean water, the burette being filled and emptied three times, in order to remove all *KOH* solution. It must then be well drained, before use for the next test.

2. TESTS FOR CARBON DIOXIDE AND OXYGEN.

The Fischer gas-testing apparatus is the most convenient form for use where only two components of the waste gases are to be estimated, and Fig. 38 shows the simplest form of the Fischer apparatus.

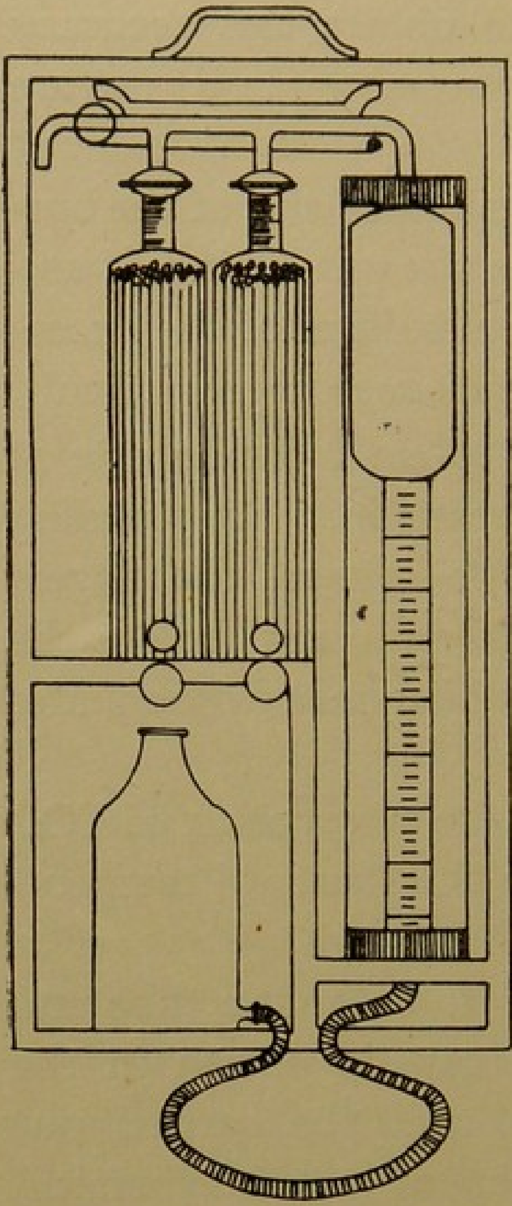

FIG. 38. FISCHER GAS-TESTING APPARATUS.

The essential parts consist of a water-jacketed gas burette, holding 100 cc., and graduated in fifths on the narrow part of the tube; and two absorption pipettes filled with narrow glass tubes, connected to the measuring burette by an overhead T-piece provided with cocks. The absorption pipettes are kept filled with the necessary absorbing reagents. A solution of caustic potash is used for absorbing the carbon dioxide, and one of pyrogallic acid in caustic potash, is employed for absorbing the oxygen. The details of the manipulation of this apparatus are exactly similar to those governing the use of the Orsat-Lunge gas-testing apparatus, and readers are referred to the next section for instruction in its use. The Fischer apparatus is small and compact, and is contained in a case which has a sliding front and back, and measures only 18″ × 9″ × 5″. The necessity for cleaning out the absorption pipettes at intervals, and the presence of liquids, does not render the apparatus so convenient for transport, or so suitable for rough works use, as the Honigman gas burette, in the modified form described in the last section.

3. TESTS FOR CARBON DIOXIDE, OXYGEN, AND CARBON MONOXIDE.

The best form of apparatus for use, when these three constituents of the waste gases are to be estimated, is the well-known Orsat-Lunge gas-testing apparatus. Fig. 39 shows this in its simplest form. Its essential parts are a water-jacketed gas burette *M* holding 100 cc.; and graduated for the first 30 cc. of its volume; three absorption pipettes, *E*, *F* and *G*, connected to the measuring burette by a horizontal T-piece *i*, *i*, and glass stop-cocks, *e*, *f*, *g*; and a rubber finger-pump *K* and water-bottle *I*, for bringing about the transfer of the gas sample from one vessel to another.

The absorbing solutions used are caustic potash, pyrogallic acid in caustic potash, and ammoniacal cuprous chloride, in the order named, for the CO_2, O, and CO respectively.

The solutions should be of the following strengths—

Caustic Potash.—A solution of Sp. Gr. 1·20. The absorption pipette requires about 150 cc. to fill it to the requisite level for use, and this amount of

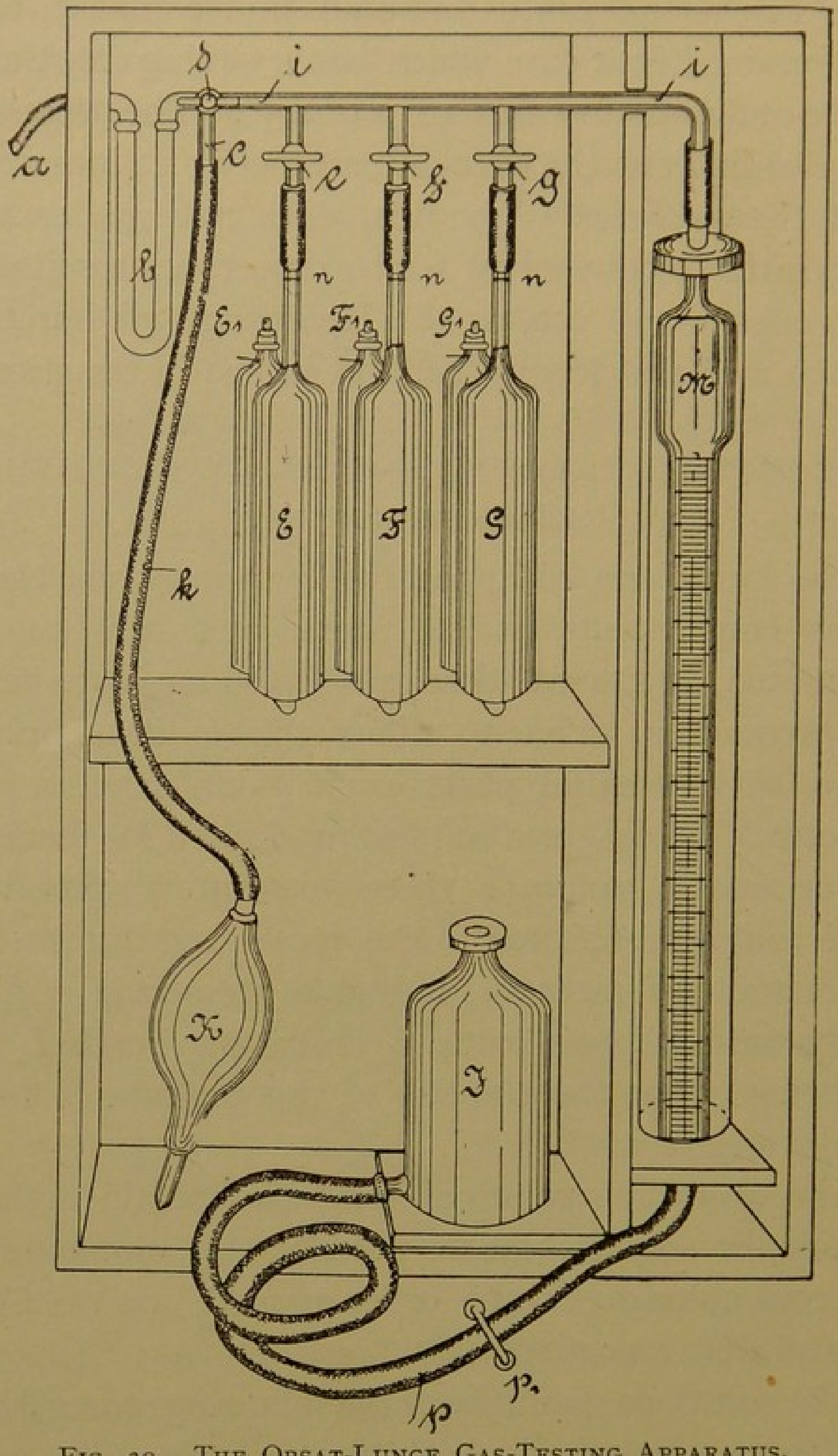

Fig. 39. The Orsat-Lunge Gas-Testing Apparatus.

solution is obtained of the desired strength by dissolving 23 grams of caustic potash in 140 cc. water. One stick of caustic potash of the usual thickness weighs about 14 grams; and it is most convenient to determine the weight of one stick, and then to obtain the required weight in future by dissolving 1½ or 1⅔ sticks in 140 cc. water. It is not advisable to make a large quantity of the solution and to store it, since a solution of this strength is apt to cause glass stoppers to stick fast in the necks of bottles; and if kept in a corked bottle CO_2 absorption occurs.

Pyrogallic Acid.—A solution of 20 grams of pyrogallic acid, in caustic potash solution of 1·20 Sp. Gr. The caustic potash solution (150 cc.) is first prepared as above, and after cooling, it is poured on to the weighed amount of pyrogallic acid, contained in a small flask. This must be kept corked while solution occurs, and the whole must then be transferred without any unnecessary exposure to the air, to the second absorption pipette. The solution of pyrogallic acid in caustic potash is of a dark brown colour, and it deepens rapidly in tint, owing to oxygen absorption and to the formation of coloured organic products.

Ammoniacal Cuprous Chloride.—250 grams of ammonium chloride are dissolved in 750 cc. of water, and 200 grams of cuprous chloride ($Cu_2 Cl_2$) are added. The whole is agitated in a closed flask or bottle, until only a slight amount of insoluble oxychloride remains. The solution is a brown liquid, which does not change much if kept out of contact with the air. When required for use, 35 cc. of ammonium hydrate (Sp. Gr. ·91) are mixed with 105 cc. of this solution, and the whole is transferred at once to the absorption burette. As this solution absorbs carbon dioxide and oxygen, as well as carbon monoxide, it loses strength rapidly on exposure to air; and even when confined in the absorption burette, it changes much too quickly in composition. If the gas-testing apparatus is only in occasional use, it is therefore wise to empty the third absorption pipette after each test.

Filling the Pipettes.—The pipettes after thoroughly washing and filling with the glass tubes, are fixed in position on the stand, and a funnel is attached by a rubber tube, to the top opening of the back limb. The requisite volume (150 cc.) of solution is now poured quickly into the pipette through the funnel, and the opening at the upper end of the back limb is closed, either with a small rubber stopper, or with one of the caoutchouc balloons sold specially for this purpose.

The front end of the pipette is now connected to the T-tube by a short length of rubber tubing. These joints are apt to prove troublesome, and the writer has found the following the best method of making them. Red rubber tube of special quality, with walls ⅛″ thick is employed. A piece 1¼ inches long is wet internally, and is slipped entirely over the upper end of the absorption pipette. When the latter is placed in position in the stand, the short length of rubber tube is now gently worked up again by twisting, until it is half on the glass tube from the stop-cock, and half on the absorption pipette. The wetting of the internal walls facilitates this slipping motion. The ends of the two glass tubes should almost touch when the pipette is in position, in order to lessen the risk of loss of gas by permeation through the walls of the rubber tube. The rubber is then firmly bound in position by thin copper wire. When these joints have to be broken, it is most simple to cut through the rubber with a sharp, thin-bladed knife ; since with the lapse of time the rubber sticks to the glass, and the pipette may be broken in trying to remove it while the pipette is in the stand.

Making the Test.—After filling and connecting each of the absorption pipettes in the manner described, the water-bottle *I* is filled with a 20 per cent. solution of common salt, slightly acidified with HCl, and coloured pink with methyl orange, and is connected to the measuring burette by the rubber tubing *p*. By raising the bottle *I*, and opening the cock *S*, the air is expelled from the burette, and it is filled to the 100 cc. mark with brine. The clip *P* is then closed, the bottle is lowered, and the cock *g* is carefully opened, in order to draw the *KOH* solution in the pipette *G* up to the containing mark *n*. The stopper *g*, is of course removed during this operation. If by any mischance *KOH* solution gets into the tube above the mark *n*, or into the T-tube, it must be washed back into *G* by some of the brine from *M*. In the latter case, it will be advisable to remove the cock *G*, and wash it well with water; since otherwise it may stick fast and render a new T-piece necessary. After filling the absorption pipette *G* to the mark *n* with *KOH* solution, the stopper *g*, is replaced; and the process is repeated with *F* and *E* respectively. In operations of this kind, it will be found most convenient to open the cock to the full extent, and to regulate the suction by pinching the rubber tube *p* between the finger and thumb; since by this means a more regular and slow approach of the liquids in the absorption pipettes, to the *n* mark on the capillary tube can be maintained. The absorption pipettes, when filled to this mark, should have about one inch of liquid in the back limb, and if caoutchouc balloons are employed for closing the openings E_1, F_1, G_1, these should be removed and made quite empty. These balloons will then simply fill and empty, as the liquid in the pipettes rises and falls in the hinder limb, and all contact of the absorption liquid with the air will be avoided. The apparatus is now ready for use.

The sample of gas to be examined is drawn into the apparatus through the tube *a* and the U-tube *b*. The latter is filled with glass wool, and contains a little water in the bend, its purpose being to retain any particles of soot that may be present in the gas sample. The finger-pump *K* is provided in order that by aid of this and the three-way cock at *S*, the air in the U-tube *b* and connecting tube *a* may be displaced by the gases to be examined, before admitting the sample into the measuring burette.

When the sample has been collected in a sample tube by the dry method (see p.109), a 20 per cent. solution of common salt must be employed, to take the place of the 100 cc. of gas transferred to the Orsat apparatus. The simplest plan in effecting this transfer is to immerse the tube in a large beaker containing the brine, and after connecting the upper end to *a* to open the lower stop-cock, which must of course be kept under the surface of the liquid while the 100 cc. is drawn into *M*. This is effected by opening the stop-cock *S*, so that the gas has access into *i*, and by lowering the bottle *I*, and opening the clip p_1. Rather more than 100 cc. of gas is drawn into *M*, the tube *p* is then pinched between the finger and thumb, and the cock at *S* is turned so that the connexion between *i* and the other outlets is closed. The bottle *I* is now raised, the pressure on *p* with the finger and thumb is released, and the imprisoned gas is reduced to 100 cc. by water pressure alone. The tube *p* is again pinched tight, close to the bottom of the measuring burette, and the cock *S* is turned so that the capillary tube *i* and measuring burette *M* are connected with the air for five seconds, the tube *k* and finger-pump *K* being removed for this purpose.

The 100 cc. of gas contained in *M* are now at atmospheric pressure, and the absorption can commence. *S* is closed as before, the bottle *I* is raised, and the cock *G* is opened, so that the sample passes into the first absorption pipette containing KOH. If stoppers are used to close E_1, F_1, and G_1, these must be removed as each pipette is brought into use;

with caoutchouc balloons this is unnecessary. When the whole of the 100 cc. has passed into *G* it is allowed to remain ten seconds, and is then drawn back into *M* by lowering the bottle *I*. This transfer of the gas to *G* is repeated three times, and the absorbing liquid in *G* is then drawn up to *n*, the cock *g* is closed, and after levelling the brine in *I* and *M*, the volume of gas in the latter is read off. The diminution represents the percentage of CO_2 in the sample.

This process of transfer and absorption is now repeated in the pipettes *F* and *E*; and in a similar manner, by measuring the diminution in volume, the percentages of oxygen and carbon monoxide are obtained. After the last absorption the cock *S* is turned, so that the capillary tube *i* is in connexion with the air, and the residual gas, which is pure nitrogen, is expelled from the apparatus; this is then ready for a fresh test.

The Orsat-Lunge apparatus, when once in good working order, is fairly easy to manipulate, and yields accurate results; but the absorption pipettes are somewhat troublesome to clean and fill, and should the stop-cocks on the capillary tube stick tight, much time and energy may be fruitlessly lost in trying to loosen them.

The precautions necessary in using this apparatus are—

1. *Leakage.* A measured volume of inert gas should be left for ten minutes, *under pressure* in the measuring burette and pipettes, at weekly intervals; any diminution in volume will, of course, indicate

leakage. The residual gas from a previous test (which as pointed out above is almost pure nitrogen) is the best inert gas to employ for this test.

2. *The glass stop-cocks* should be removed at intervals, the cocks and sockets thoroughly cleaned with soft paper, and after coating with a thin film of washed lard, or other suitable lubricant, they should be replaced. This treatment must also follow any mishap with the absorbing liquid in *G*, since KOH solution of 1·20 Sp. Gr. is noted for its power of causing two glass surfaces to bind fast.

3. *Volume Measurements.*—All measurements of volume in the burette *M* must be made with the brine at the same level within and without the burette, and the tube *p* at such times must be free from kinks. The water in the jacket tube around *M* must cover the whole of the burette, and must be changed occasionally.

4. *The Absorption Pipettes.*—These must be emptied, cleaned, and refilled with fresh absorbing solutions at regular intervals; the cuprous chloride solution being that which requires most frequent renewal. For the accurate determination of carbon monoxide in reasonable time, it is in fact necessary to have two cuprous chloride pipettes in use, and to employ the fresher solution for absorbing the last traces of the gas. Owing to the evolution of CO_2 from this solution, after it has been used for some time in the Orsat apparatus, the CO tests are always somewhat untrustworthy, unless made with freshly prepared cuprous chloride; and for works use it is not

advisable to carry out this determination. The percentage of carbon monxide in the waste gases can in such cases be fairly accurately estimated by use of the following formula—

$$x = 100 - (N + C + O),$$

where N equals the percentage of nitrogen, O equals the percentage of oxygen, and C equals the percentage of carbon dioxide by volume in the waste gases. For waste gases from fuels containing much hydrogen this formula yields incorrect results, however, since portion of the 20·8 per cent. of oxygen is used up in burning the hydrogen, and thus disappears from the volume of resultant gases owing to its condensation as water. This causes a variation of 2 per cent. or more in the volume of nitrogen, which in the above equation would then be 81·2 in place of 79·2. For a coal containing 4·80 per cent. H, 7·30 per cent. O, and 5 per cent. moisture, the calculated figures show that 81·5 per cent. N would be present in the flue gas.

4. AUTOMATIC CO_2 RECORDING INSTRUMENTS.

Three forms of automatic apparatus for determining and recording the percentage of carbon dioxide in waste gases are now being manufactured and sold. These are known as the "*Ados Recorder*," the "*Arndt Econometer*" and the "*Composimeter*" respectively. Only brief descriptions of these will be given here, since they are patented instruments, and their construction and method of use are very

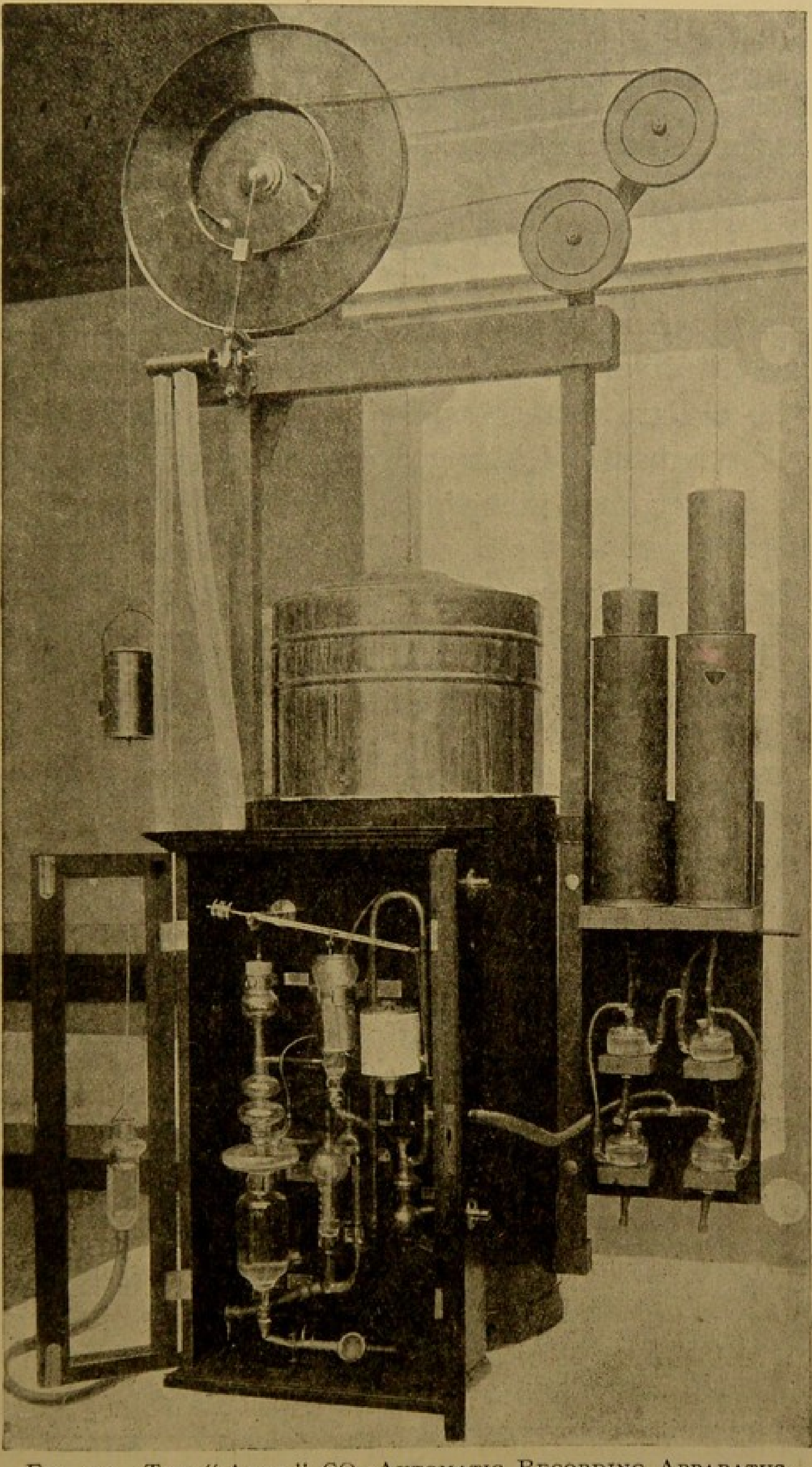

FIG. 40. THE "ADOS" CO_2 AUTOMATIC RECORDING APPARATUS.

fully explained in the pamphlets published by their manufacturers and selling agents.

The Ados Recorder.—This apparatus, which is illustrated in Fig. 40, depends upon the absorption of CO_2 by a solution of potassium hydrate, an automatic arrangement being utilized for forcing a measured volume of the flue gases, at stated intervals of time, into the absorbing vessel. The volume measurements of the gas, remaining after the CO_2 is absorbed are then transferred by a lever and arm attachment to a pen, which marks the result upon the recording paper carried on a revolving drum. Fig. 41 shows the diagram obtained over twelve hours with this apparatus, the vertical lines representing the volumes of unabsorbed gas; and the test being made ten times in the hour, or every six minutes. The gases are drawn from the flues by independently-worked suction pumps, so that a large sample is available for each test.

The "Ados" apparatus is now in use in a very large number of works in this country and on the Continent. If carefully used, and kept in good order, it yields a very valuable check upon the firing of the boiler plant; and by its aid, considerable economies in fuel can be effected. The results obtained, however, with the "Ados" apparatus, should be checked by independent CO_2 tests at stated intervals; since an error in the percentage of CO_2 may otherwise be perpetuated through a whole series of the automatic records. The caustic potash solution also requires frequent change for the maintenance of accuracy; and the apparatus could hardly be left to the charge of an ordinary boiler engineer.

Arndt's Econometer.—This automatic apparatus differs from the *Ados Recorder,* in that the principle is gravimetric, not volumetric. The percentage of CO_2 in the flue gases, is deduced from the variations in weight of a fixed volume; this weight, of course, increasing with increased percentage of CO_2. The apparatus, without any recording attachment, is

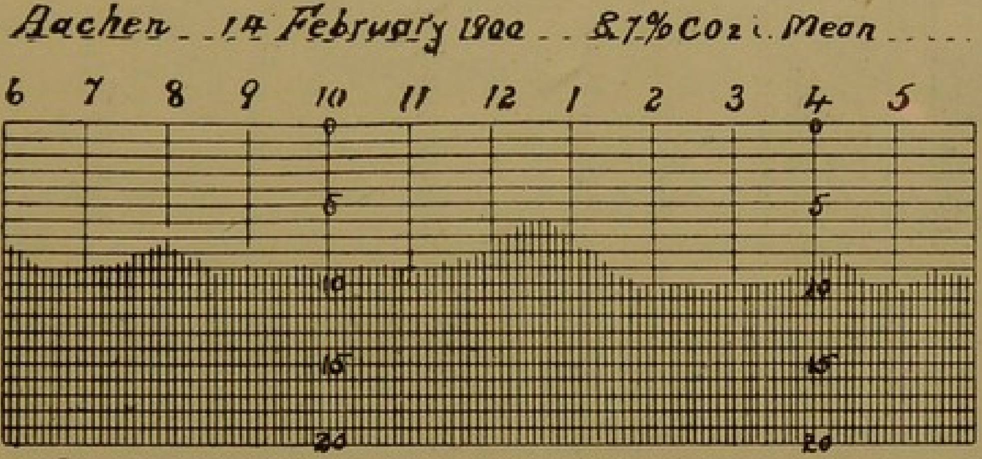

FIG. 41. RECORD OBTAINED OVER TWELVE HOURS WITH THE "ADOS" CO_2 RECORDER.

shown in Fig. 42. A small steam-jet aspirator is utilized in order to draw the flue gases through the glass globe hung on one arm of the balance, enclosed in the glass case; and the weights are so adjusted on the pan attached to the other arm of the balance, that the percentage of CO_2 can at once be read off on the scale over which the pointer moves.

The reading on this scale, therefore, always indicates the percentage of CO_2 in the flue gases at the moment of observation; and this is of course a most useful result. If desired, an automatic recording attachment can be connected to the pointer, and the result can be rendered available for future reference in the form of a continuous curve. The *Econometer* is in use in a certain number of works on the Continent, but it has not been so much employed in this country. It is less troublesome to keep in order than the "Ados" apparatus; but as in the case of that instrument, the results obtained required to be checked at stated intervals, by tests made independently with other apparatus.

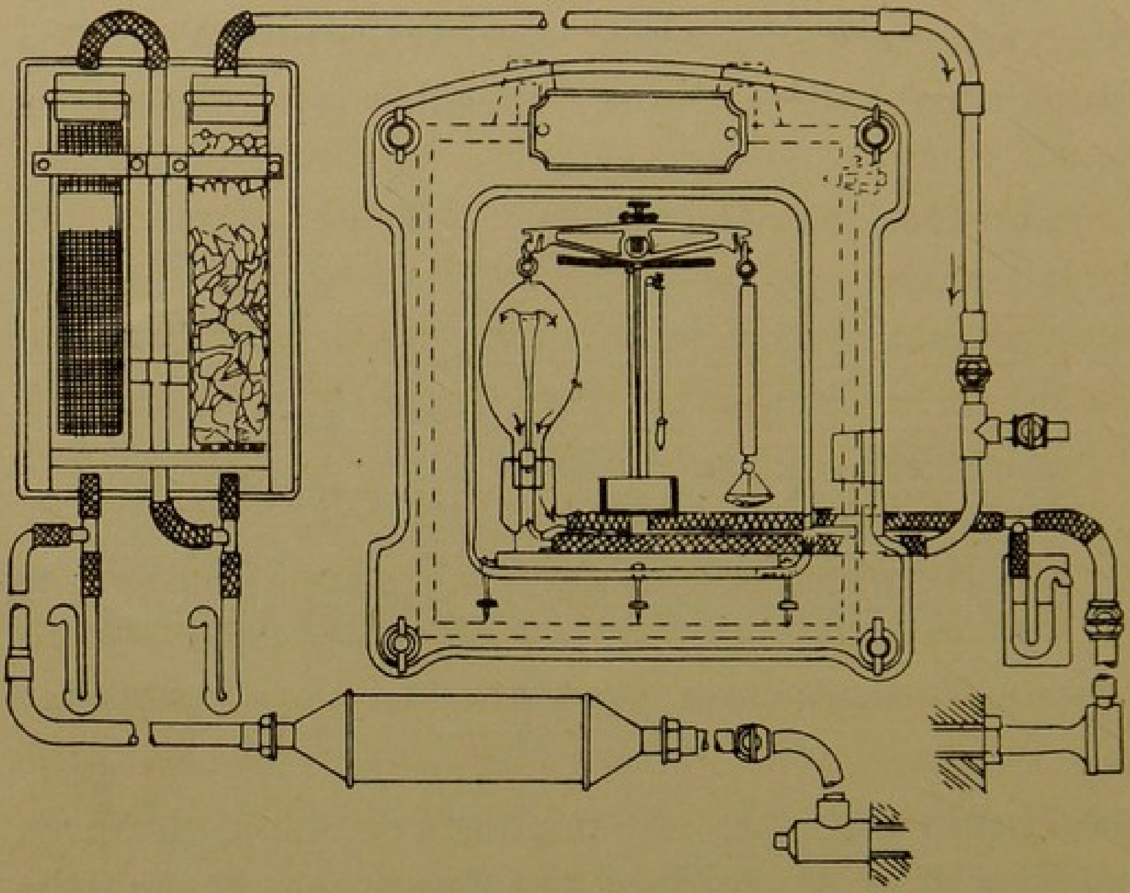

FIG. 42. THE ARNDT ECONOMETER.

The Gas Composimeter.—This automatic CO_2 apparatus is little known in the United Kingdom, but is in use in America. Its principle differs from that of the Ados and Arndt instruments; the variations in pressure due to absorption of the CO_2, and consequent reduction in volume of the flue gases, being the basis of this method of determining the percentage of CO_2 in the flue gases. The Authors unfortunately are not able to give an illustration of the apparatus, which has recently undergone modification, but it is similar in principle and in some details of its construction to the "*Pneumatic Pyrometer*" invented by Uehling and Steinbart, and now used in many American blast-furnace plants for temperature determinations. The first cost of the *Gas Composimeter* is higher than that of the other instruments; but it is believed by the writers to be accurate in its records, and to require little attention when once fixed in position.

It must be remarked here, however, that instruments depending upon the variations in the specific gravity of the gases will be liable to yield incorrect results when much carbonic oxide (CO) is present in the flue-gases; and for this reason the *Ados Recorder* and the *Gas Composimeter*, which are not liable to error from this cause (since the CO_2 is directly absorbed, and the remaining gases are measured in volume), are to be preferred for works use.

5. THE SIGNIFICANCE OF THE GAS TEST RESULTS.

All heat passing away with the waste-gases to the chimney is lost from the fuel-user's point of view, and therefore the highest efficiency can only be obtained by reducing the volume and the temperature of these gases, to the lowest limit consistent with proper combustion of the fuel in the furnace. The temperature observations are made as already described in section B of this Chapter; the requisite check upon the volume of the waste-gases is furnished by the CO_2 tests, carried out as described in Section C. 1–4.

Air is composed, in round numbers, of 21 per cent. oxygen and 79 per cent. nitrogen by volume, or 23 per cent. O and 77 per cent. N by weight. When coke is burnt in the exact volume of air requisite to produce carbon dioxide gas, the latter will occupy the same volume as the oxygen from which it has been formed; and perfect combustion under such conditions yields a gas containing 21 per cent. CO_2 and 79 per cent. nitrogen. Under proper conditions this percentage can be approached in actual practice, with coke or anthracite combustion furnaces. When bituminous coal is burned, the hydrogen of the hydrocarbons carries off some of the oxygen to form water, and the maximum CO_2 percentage that can be obtained with such fuel is about 19 per cent.; while 16 per cent. represents the highest obtainable in actual practice.

Percentages of CO_2 below this maximum indicate that more air is being passed through the furnaces than is required for the combustion process; and the diminished CO_2 percentage is the measure of this excess air. Thus 15 per cent. CO_2 with bituminous fuel represents $\frac{19}{15} = 1{\cdot}27$ times the requisite volume of air, or a 27 per cent. excess; while 8 per cent. CO_2 represents $\frac{19}{8} = 2{\cdot}37$ times the requisite volume, or 137 per cent. excess.

The temperature at which the exit gases pass into the chimney next requires consideration. Since the draught of the chimney depends upon the specific gravity of the waste gases in relation to that of the surrounding atmosphere, and this, again, depends upon their temperature, it is obvious that there is a point below which heat cannot be abstracted from the flue gases without endangering the draught, and therefore the efficiency, of the whole boiler installation. This point, for chimneys of normal height and capacity, is about 400°F. (205°C.), and it is therefore unwise to cool the exit gases below this temperature. Where artificial draft is employed (either forced or induced) this difficulty has not to be faced ; and in such cases there is no objection to abstracting all the heat possible from the flue gases, before they pass into the atmosphere.

The Authors believe that in time artificial draught will be much more widely used than at present, for boiler and furnace work. The difference in cost between natural and artificial draught (if the interest on capital outlay and loss of heat, necessitated by a tall brick chimney, be properly debited to the natural draught account) is much less than is generally recognized by boiler engineers. Moreover, the draught obtained from chimneys, however tall and large, is excessively variable, and is too dependent upon the wind and state of the atmosphere, to be well adapted for the scientific working of large boiler plants. The change from natural to artificial draught which is now occurring in the control of the lead chamber process, for manufacture of sulphuric acid, is indicative of what may occur at a later date, in the more scientifically managed steam generating plants of this country.

However, at present, natural draught is usually employed, and a certain loss of heat in the exit gases is absolutely necessary. This necessary loss can be ascertained by the following calculations.

One pound in weight of average fuel requires theoretically about 12 pounds of air for its complete combustion, and yields about 13 pounds of waste gases. The specific heat of these waste gases varies according to the percentage of CO_2 and H_2O they contain, and for a gas containing 15 per cent. CO_2 Poole gives the specific heat as ·323. But, as already pointed out, 15 per cent. CO_2 represents a 27 per cent. excess of air by volume in the waste gases, and the total weight in this case will therefore be increased by 12 × ·27 = 3·2 pounds, or from 13 to 16·2 pounds.

Assuming that these 16·2 pounds of waste gases pass to the chimney with a final temperature of 350°F. (or 176°C.), the heat loss will amount to 16·2 × ·323 × 160 = 837 centigrade units; or to 11·1 per cent. of the total heat value of the coal, when this is equivalent to 7,500 centigrade units. This then represents the heat necessary for creation of the chimney draught. Its loss can never be avoided, and converted into *£ s. d.*: it must be regarded as the price paid for so-called "natural draught."

Supposing, now, that in place of a temperature of 350°F., the waste gases pass to the chimney at 656°F. (346°C.), the usual temperature when economizers are not installed. The loss then becomes 16·2 × ·323 × 330 = 1,726 centigrade units, equal to 23 per cent. of the total heating value of the fuel. The loss grows still larger when, in place of 15 per cent. CO_2 being found in the exit gases, only 8 per cent. CO_2 are present. The excess of air is now equal to 137 per cent., and the weight of waste gases becomes 29·4 pounds per pound of fuel burnt. The specific heat of exit gases containing only 8 per cent. CO_2, according to Poole, is ·316, and the loss therefore rises to 29·4 × ·316 × 330 = 3,066 centigrade units. This is equal to 40 per cent. of the heat value of the original fuel.

These figures and calculations show the great importance of the heat losses in the waste gases, and the necessity for gas analysis as a check, upon the volume of air passing through the boiler furnaces.

In Table III of the Appendix, the percentage of fuel loss arising from the heat losses in the waste gases has been presented in tabular form, for various temperatures and percentages of CO_2.

The specific heats used in these calculations have been calculated on the assumption that a bituminous fuel containing 57 per cent. fixed carbon, 30 per cent. volatile matter, and 13 per cent. ash, has been utilized in the boiler furnace, and that the calorimetric value of this fuel is 7,500 centigrade units (equal to 13,500 B.Th.U.). The Sp. Heats obtained are much lower than those given by Poole, and it is evident that further experimental work is required on this subject.

It has also been assumed that this fuel when fired contained 5 per cent. moisture. Since the latent heat of steam is equal to 536 calories, a further loss of heat is due to the evaporation and specific heat of the aqueous vapour, produced from the burning fuel. In the case under consideration, this will amount to $(636 \times \cdot05) + (\cdot479 \times \cdot65 \times 330) = 39\cdot7$ centigrade units, ·479 being taken as the specific heat of aqueous vapour under constant pressure.

The analysis of the waste gases may also indicate a further source of loss. When boilers are heavily worked, and draught is deficient, carbon monoxide may be found in the waste gases. This is especially the case when smoke is being produced—that is, when fresh coal is being thrown on the fires. Under such conditions, the carbon and hydro-carbons do not meet at once with sufficient oxygen to convert the carbon into carbon dioxide, and unless a secondary air supply be provided, the monoxide is produced. Reference was made in Chapter I (see p. 27) to the great difference in heat values of carbon burnt to CO, and burnt to CO_2. The difference in centigrade units is 5,684, and when 1 pound of ordinary fuel containing 72·6 per cent. carbon is burnt with deficient air supply, the loss of heat from this cause amounts to $5{,}684 \times \cdot726 = 4{,}126$ centigrade units, or to 55 per cent. of the total heat value of the fuel. Even under normal working conditions, a small percentage of carbon monoxide will often be present in the gases just above the fires; but if the secondary air supply, which ought to come in at the bridge, is properly regulated, the oxygen necessary to convert this monoxide into dioxide will be provided at this point, and the final stage of the combustion of the carbon will be completed without loss of heat.

The tendency in practice is, however, to work with a large excess of air, and the heat losses in actual practice are much more largely due to the heat mechanically carried away by waste gases, than to imperfect combustion and formation of carbon monoxide.

The heat losses due to these causes in boiler installations, as usually worked, are much greater than is generally recognized by boiler engineers; and there is no doubt that in many cases these losses rise to over 30 per cent. of the total heating value of the fuel. Even when economizers have been installed there is still need for a careful check upon the composition of the waste gases; for although the temperature cannot be reduced below 350°F. (175°C.) the volume of the gases by careful work may be reduced to the limit represented by 15 per cent. CO_2, which it has been shown, represents the minimum loss, and is equal to 11·1 per cent. of the total heat value of the fuel.

Supposing, now, that in place of 15 per cent. CO_2, only 8 per cent. are present in the waste gases. The heat wasted under these conditions rises to $29{\cdot}4 \times {\cdot}316 \times 160 = 1{\cdot}496$ units, or to 20 per cent. of the fuel value, and the loss is practically doubled.[1] Boiler engineers must not therefore assume that the possession of an economizer plant, relieves them from the necessity of keeping a careful eye to the composition of the exit gases.

In order to ascertain the best working conditions for each boiler, tests should be made at 15-minute intervals with the Honigman apparatus, over a period of two or three hours under normal working conditions; and the best position of the dampers and other air regulating devices should be definitely settled for each stage of the firing process. Permanent marks should then be placed on the dampers and air slides, to render it easy for the fireman to renew these positions as required during his work. The results can then be checked, by connecting one of the recording instruments to the flues of this boiler, and by noting the CO_2 percentages over a 24-hours' run, or a week's work. As already stated, perfect combustion and maximum efficiency can only be attained when sufficient draught is provided; and this must be the first matter to receive attention if the original test results are below the maximum desired. Given adequate draught, it is simply a matter of careful testing and damper regulation to obtain from each boiler the maximum efficiency. If the interest of the stokers be aroused in the subject, by paying them a weekly premium, based on the CO_2 test results, the improved "experimental" results will be rendered permanent and will soon

---

[1] See p. 140 for explanation of these factors.

be made manifest in a reduced consumption of fuel for the maintenance of steam. In the absence of such inducement to better work, it is to be feared that the results obtained will remain "experimental."

The highest efficiency is, however, unattainable if the boilers are being over-worked ; and one of the first steps towards improvement in many steam-raising plants in this country, is that an addition of between 20 per cent. and 30 per cent. should be made to the number of boilers installed, or that a system of forced draught should be adopted for raising the evaporative capacity of the existing installation.

Appendix.

I. PATENT ABSTRACTS.

INTRODUCTORY NOTE.

The Authors have not attempted in this section to deal with all the Patent literature of Smoke Prevention. A selection has simply been made of the Patents granted in recent years in England, Germany and America, for fuel-consuming appliances designed to promote more perfect combustion.

The English Patents chosen deal chiefly with devices for supplying secondary air; the German, with improved methods of grate or furnace construction; and the American, with improved forms of mechanical or automatic stoking appliances. The numerous English mechanical stoking appliances have not been specially described in this section, because the general principles underlying their construction have been dealt with in Chapter II; and these mechanical stokers are now in such general use, and so widely known, that their special description at this date, in a book intended for practical engineers, is somewhat superfluous.

The Authors make no comment upon the value or validity of the various Patents described in this section of their work, but the information as to the correct conditions for perfect fuel combustion, given in Chapters I, II and III of this book, will enable readers themselves to judge of the value, or otherwise, of these inventions.

A. ENGLISH PATENTS.

No. 2,478 of 1899

This Patent is in the name of John McNaull Wilson, and its essential feature is the use of a spray of saltpetre solution, above the burning fuel, at the times when smoke emission from the chimney is to be expected—that is, after firing. Figs. 43 and 44 are diagrams of a boiler furnace provided with the Wilson apparatus, the first in sectional elevation, and the second in sectional plan.

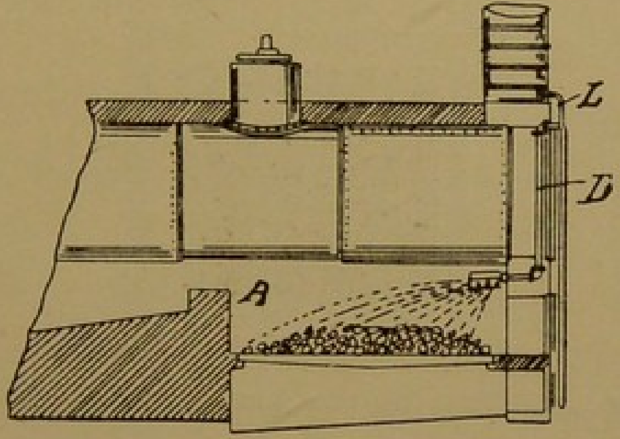

Fig. 43. The Wilson Spray Apparatus.

These diagrams are self-explanatory. Air under pressure, or steam, may be used for producing the spray, and any other chemical compound that contains oxygen may be substituted for saltpetre.

APPENDIX I

The Patent-claims of the Wilson Patent are as follows—

1. The method of preventing smoke from furnaces, which consists in introducing into the fire box above the fire and so to combine with the unconsumed products of combustion therein, a chemical reagent which yields gases which are supporters of combustion, and air, as set forth.

2. The method of preventing smoke from furnaces, which consists in introducing into the fire box above the fire and so as to combine with the unconsumed products of combustion therein, a chemical reagent in a finely divided condition, which yields gases which are supporters of combustion, and air, as set forth.

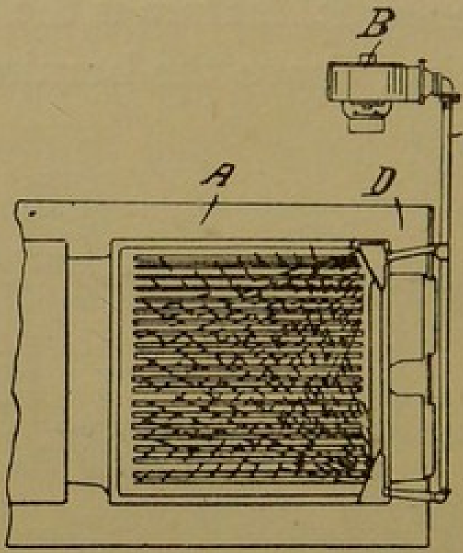

Fig. 44. The Wilson Spray Apparatus.

3. The method of preventing smoke from furnaces, which consists in introducing into the fire box above the fire and so as to combine with the unconsumed products of combustion therein, a chemical reagent in the form of spray, which yields gases which are supporters of combustion, and air, as set forth.

4. The method of preventing smoke from furnaces, which consists in introducing into the fire box above the fire and so as to combine with the unconsumed products of combustion therein, a solution of a chemical reagent which yields gases which are supporters of combustion, and spraying said reagent by a jet or blast of air within the firebox, as set forth.

5. The method of preventing smoke from furnaces, which con-

sists in distributing in the fire box above the fire and so as to combine with the unconsumed products of combustion therein, a finely divided chemical reagent which yields gases which are supporters of combustion, by a jet or blast of hot air, as set forth.

6. The method of preventing smoke from furnaces, which consists in introducing together into the fire box above the fire and so as to combine with the unconsumed products of combustion therein, a chemical reagent which yields gases which are supporters of combustion, and hot air, as set forth.

7. The spraying nozzle herein described having the two compartments, the upper compartment opening into the furnace through a series of orifices in which the solution pipes terminate as set forth.

8. The spraying nozzle herein described having a wide orifice for the passage of air into the furnace and a series of orifices above the same in which terminate pipes conveying a solution from a suitable reservoir.

The Wilson Patent is being exploited by the Wilson Smokeless Process Ltd., and this company in November, 1903, stated that about fifty boilers in the United Kingdom had been provided with the apparatus. A considerable number of boilers in Belgium, France, Sweden and India have also been fitted with the Wilson spray.

No. 19,631 of 1900

A Patent granted to Green & Howe for "Improvements connected with the Combustion of Fuel in Furnaces." The essential feature of the Green apparatus is that of a bridge supply of hot air. The supply of air is under control, and can be regulated by the fireman according to the body of flame and smoke passing from the furnace grate. Fig. 45 shows a longitudinal section of the grate of a Lancashire boiler provided with the Green apparatus. The lower part of the bridge chamber, *c, c, c*, is simply a heating chamber for the air which passes through it ; the upper part, *d, d*, is a mixing chamber, in which the hot air and smoke-laden gases from the fire-grate mingle, and produce perfect combustion ; e^1 is a movable door to the air-heating chamber *c*, and is operated by the lever and handle *f*.

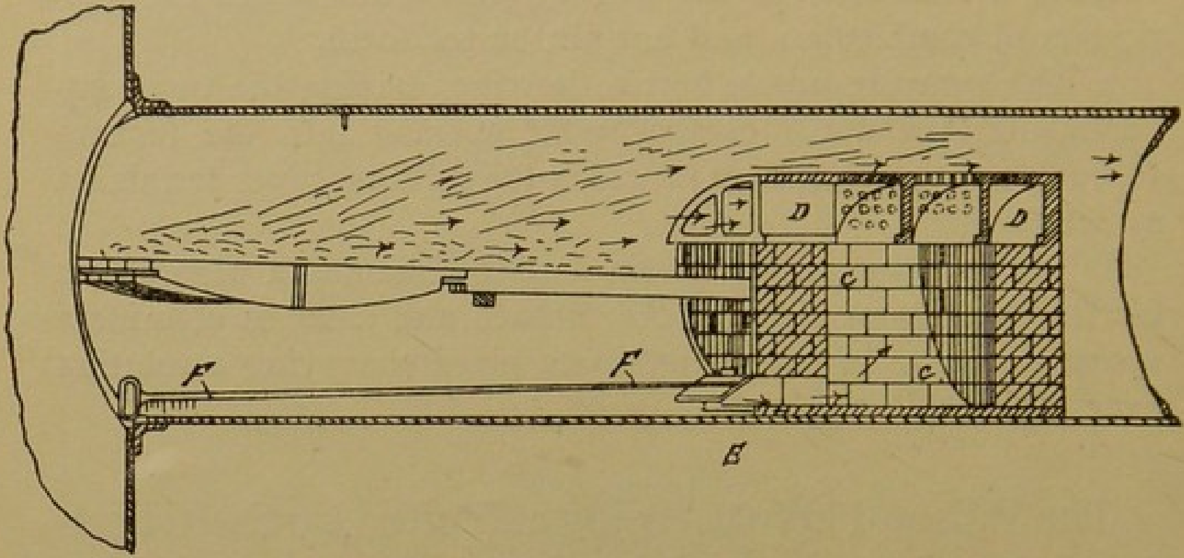

FIG. 45. THE GREEN AND HOWE BRIDGE CONSTRUCTION.

The claims of Patent 19,631 are as follows—

1. The herein described improvement connected with the combustion of fuel in furnaces, namely, supplying heated air and gases of combustion from the fire, into a chamber at the bridge, in which the air and gases mix, and then passing such gaseous mixture through perforations in the roof of the bridge, over which the main body of the gases of combustion pass ; for the purposes set forth.

2. The herein described improvement connected with the combustion of fuel in furnaces, namely, supplying heated air, gases of combustion from the fire, and cold air in regulated quantities into a chamber at the bridge ; wherein said airs and gases mix, and the mixed fluid issues in streams, upwards into the gases

of combustion passing longitudinally from the bridge; for the purposes set forth.

3. In a furnace, the combination of a chamber *c* with a perforated bridge roof, and hollow fire bars, *h*, communicating between said chamber and the ashpit for supplying hot air to said chamber; substantially as set forth.

4. In a furnace, a hollow chamber *c* formed as the bridge, as described, the upper portion of which is in the form of a hollow bridge *d*, having a perforated roof d^1; as herein set forth.

5. In a furnace adapted for promoting complete combustion and preventing the formation of smoke, a hollow bridge *d*, having a perforated roof d^1, and a perforated or open front end or wall next the grate; as set forth.

6. In a furnace, the chamber *c*, the hollow bridge *d* with openings d^1 in its roof, and openings d^2 in its front wall or end, hollow or air heating fire bars *h* communicating between the ashpit and said chamber, and an opening *e* and regulatior e^1, communicating between the ashpit and said chamber; as set forth.

The Green Patent is being exploited by the British Smoke Consumer Co., and a large number of firms have adopted the apparatus.

NO. 535 OF 1901

This Patent is granted to J. C. PARKER for "IMPROVEMENTS IN STEAM GENERATORS." The greater part of the Patent Specification relates to improvements and modifications of the tube design and setting, in ordinary water-tube boilers, but its essential feature from the smoke-consuming standpoint is the provision of a secondary combustion chamber behind the grate, with a special supply of heated air. Fig. 46 is a sectional elevation of the Parker improved boiler setting; and in this *A* and *A* represent the secondary combustion chambers, in which the combustion of the furnace gases is completed *before* they come into contact with the first rows of tubes. The three baffle plates *B*, *B* and *B*, cause the gases to take a zig-zag course in ascending through the tubes of the boiler. The secondary air supply comes in at *C* and *D*.

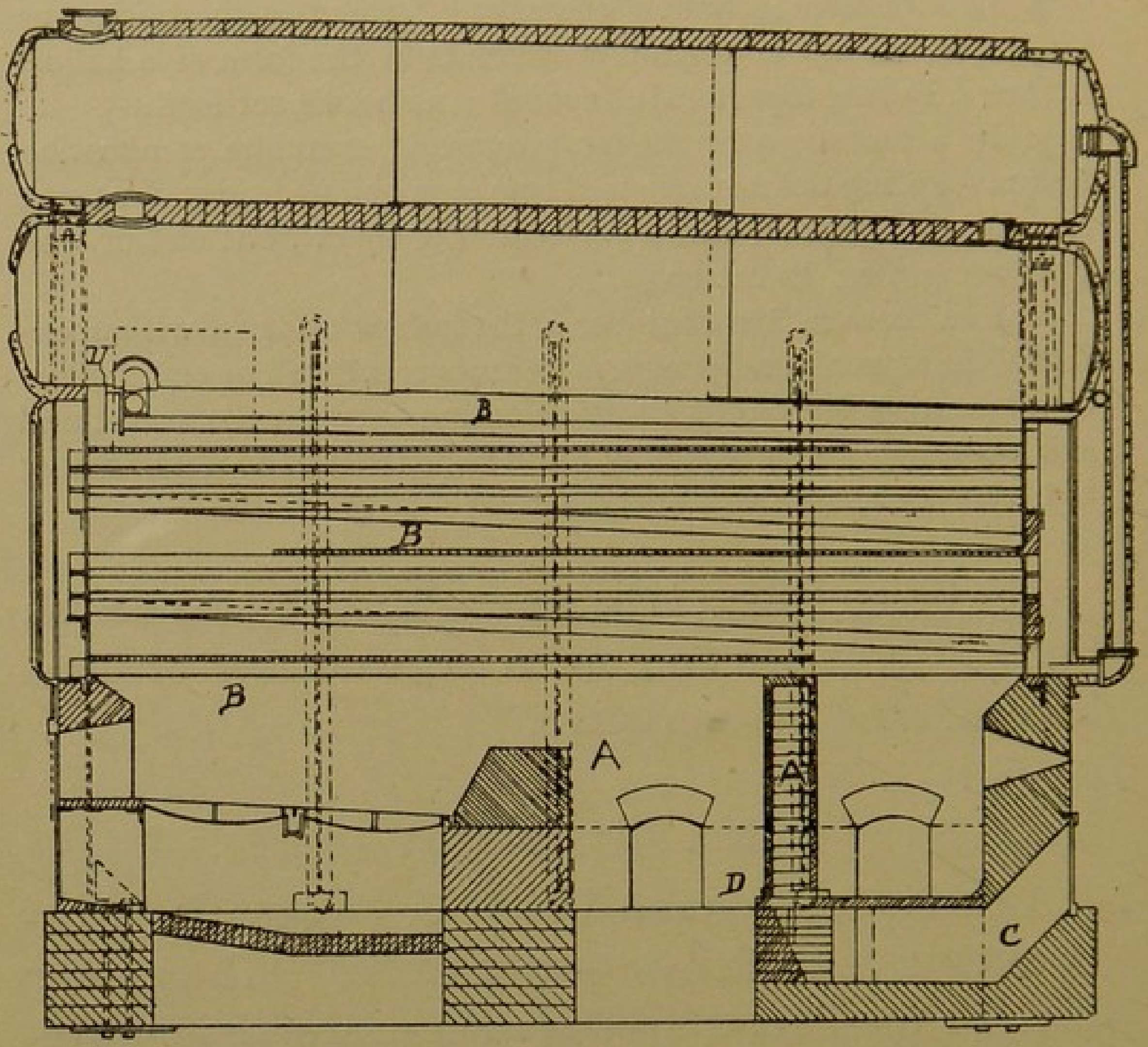

FIG. 46. THE PARKER WATER-TUBE BOILER SETTING.

Claim 13 of the Parker Patent relates to this feature of the boiler setting, and is worded as follows–

13. In a water tube generator, a furnace, with grate bars, a bridge wall at the rear of said grate bars, a chamber at the rear

of said bridge-wall, vertical air ducts 44, of refractory material, perforated in the walls thereof, in said chamber, having vertical slots 88 between said ducts for the passage of flame and air therethrough, air passage *a*, and air door 45, substantially as specified.

No. 3,050 OF 1901

A Patent in the name of JOHN ALVES and THE BRITISH FUEL ECONOMIZER AND SMOKE PREVENTER, LTD., for Improvements in Smoke Consuming Apparatus.

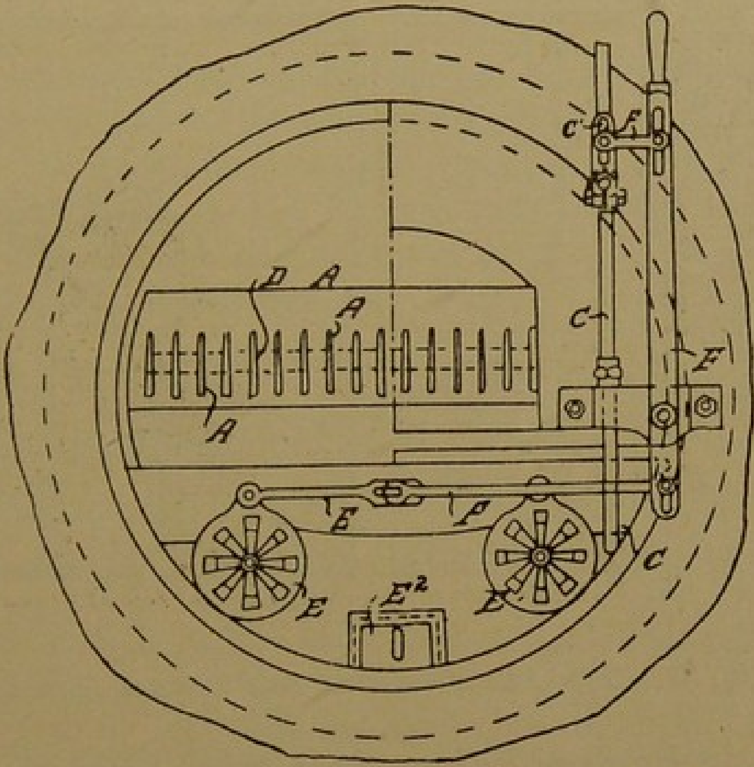

FIG. 47. THE ALVES BRIDGE AIR SUPPLY APPARATUS.

The essential feature of this apparatus is a bridge supply of air and steam, under the control of the fireman. The steam can be super-heated if desired, and the air supply can also be heated by passing through channels in the bridge-wall. Fig. 47 shows a front elevation of a boiler furnace provided with this apparatus, and Fig. 48 is a longitudinal sectional elevation of the bridge-end of the same. E *e* is the air supply channel, which can be closed by the lever F; *a*, *a*, are the air admission slots in the bridge-wall; D is the steam pipe which supplies the injectors, and E^1 is the chamber in which the air supply is heated before injection into the furnace gases.

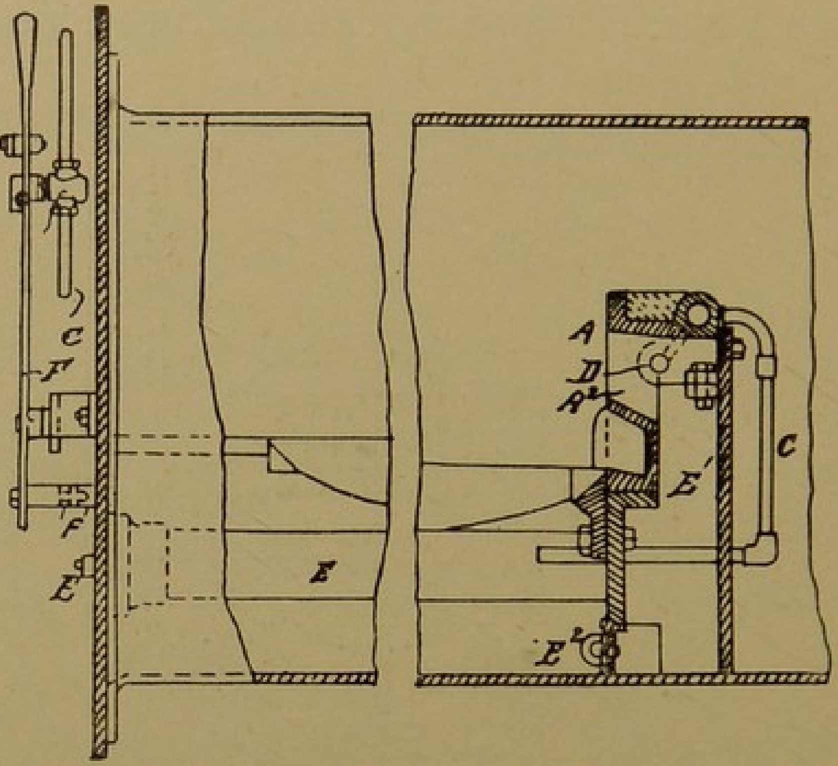

FIG. 48. THE ALVES BRIDGE AIR SUPPLY APPARATUS.

The claims of this Patent are as follows—

1. In smoke-consuming apparatus for steam-boiler and other furnaces wherein heated-air, under the influence of steam-jets, is supplied to the furnace, a bridge formed with alternate sets of passages, one set serving for the conduct and heating of the air prior to its meeting the steam-jets, and the other set serving for the conveyance of the heated-air to the furnace after the same has come under the direct influence of the said steam-jets, substantially as herein described.

2. In smoke-consuming apparatus for steam-boiler and other furnaces wherein heated-air, under the influence of steam-jets, is supplied to the furnace, a bridge provided with conduits or passages *a* open at each end to a chamber E^1 and serving to conduct and heat the air passing therethrough alternating with slots or passages a^1 for the conveyance of heated-air to the furnace under the influence of steam-jets, substantially as set forth.

3. In smoke-consuming apparatus for steam-boiler and other furnaces wherein steam-jets are employed to inject streams of air through slots or perforations formed in the bridge, simultaneously regulating the supply of steam, and air to the bridge, substantially as herein described.

4. In smoke-consuming apparatus for steam-boiler and other furnaces wherein, under the influence of steam-jets, heated-air is supplied to the furnace through a slotted or perforated fire-bridge, a steam superheater constructed and arranged substantially as herein described and whereby its removal for repair or renewal without disturbing the bridge is facilitated.

No. 2,893 of 1901

This Patent is granted to H. W. Miller for "Improvements in Furnaces of Steam Boilers"; especially of Water-tube Boilers. The essential

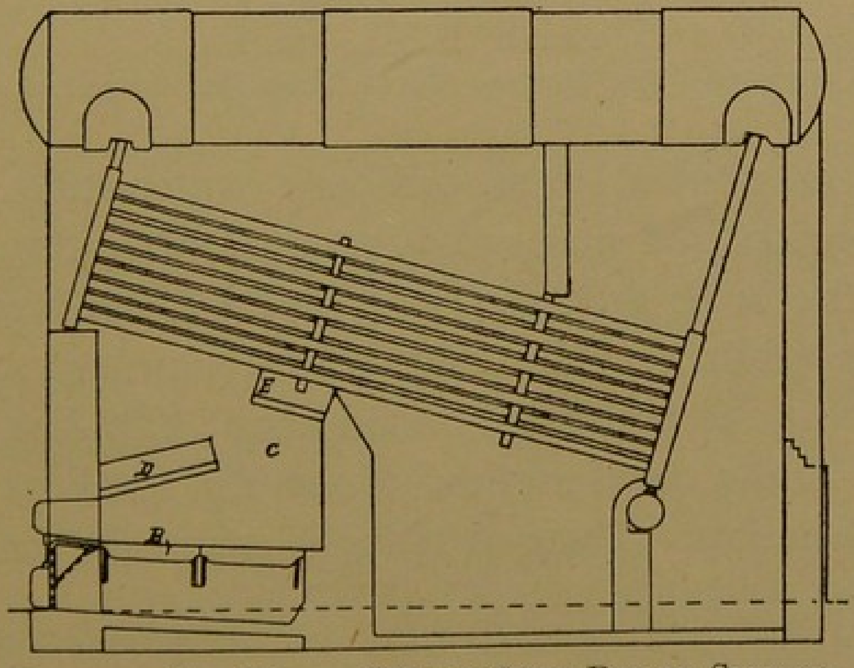

Fig. 49. The Miller Water-Tube Boiler Setting.

feature of the Patent is the plan for forming a large combustion chamber or chambers lined with some non-conducting and refractory material, above the furnace grate, in which the hot gases and air can mix and produce complete combustion, before contact with the colder water-tubes of the boiler.

Figs. 49 and 50 show the Miller improved setting, as applied to an ordinary water-tube boiler, in longitudinal and cross-sectional elevation. The two fire-brick arches, D and E, form the lower and upper walls of this combustion chamber, and the tubes of the boiler are raised about two feet higher than in the usual method of setting, to allow for its construction. There is only one claim in the Miller Patent, and it is worded as follows—

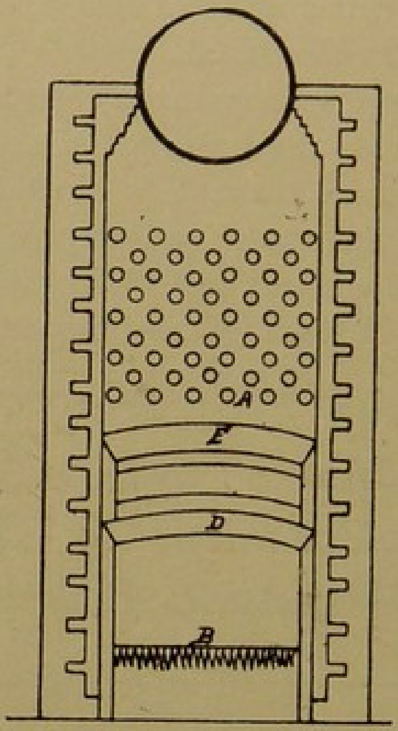

FIG. 50. THE MILLER WATER-TUBE BOILER SETTING.

> In water-tube boilers the provision of a firebrick lined com-

bustion chamber between the fire and the tubes, formed of two arches at different levels, and the provision of a second chamber in which the temperature of the gases is high enough for combustion to be completed, substantially as and for the purpose herein described.

The Miller Patent Water-tube boiler setting is in use at the Kensington and Notting Hill Electricity Supply Works, at Glasgow Electricity Works, and also at Messrs. Crompton's works at Chelmsford, with satisfactory results.

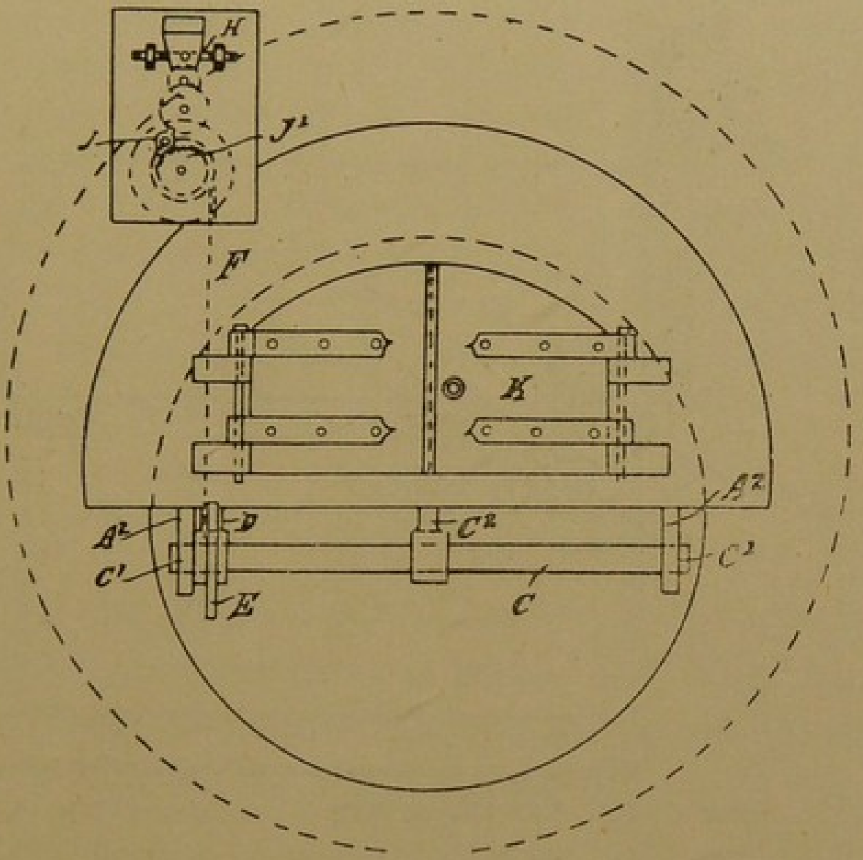

FIG. 51. THE CLARK AUTOMATIC AIR REGULATION MECHANISM.

NO. 12,938 OF 1901

A Patent granted to A. M. CLARK (for C. H. Gould, of Melbourne) for an IMPROVED SMOKE PREVENTER and Fuel Economizer. The essential feature of this patent is the provision of Automatic Apparatus for controlling the air supply to the furnace. Clockwork mechanism is used for opening and closing the slides or valves which regulate the air supply; this being delivered through the dead-plate of the furnace grates, just inside the furnace doors. The mechanism is so adjusted that the slides are fully open directly after charging fresh fuel, and they gradually close as the volatile gases in this fuel are distilled off and burnt. Figs. 51 and 52 show a plane elevation of a boiler front, and a sectional side view of the grate, fitted with the Clark Automatic Air-supply mechanism.

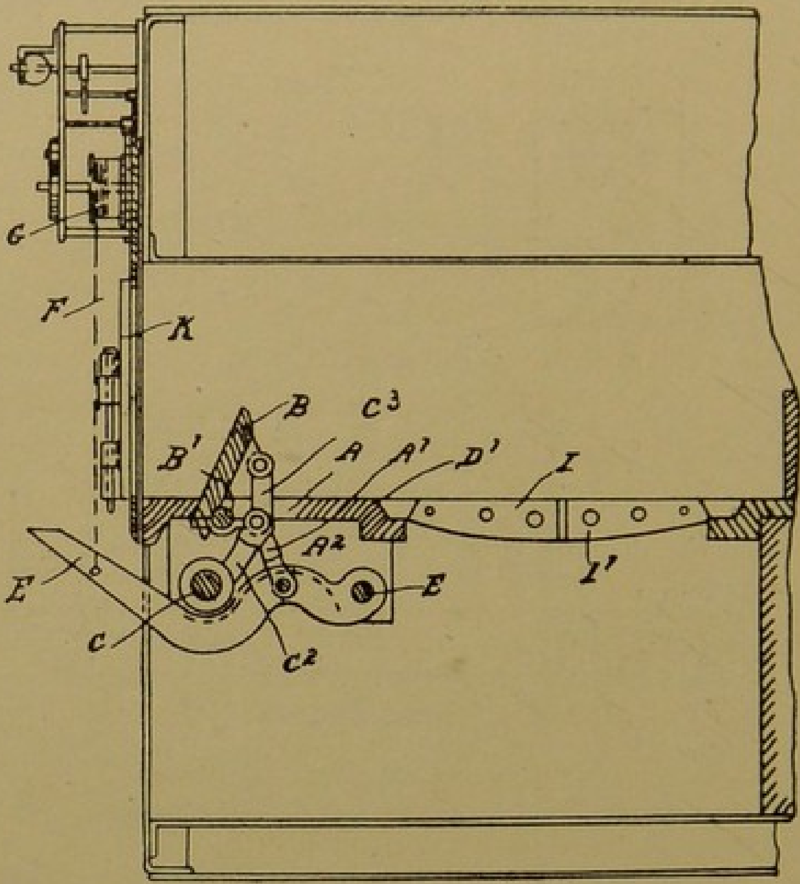

Fig. 52. The Clark Automatic Air Regulation Mechanism.

The following are the claims of this Patent—

1. An improved smoke preventer and fuel economizer for furnaces consisting of a hinged or pivoted door or valve as B fitting an opening as A in the dead plate, said door or valve being controlled by clock mechanism or a clock train in order to close the door or valve in a predetermined time substantially as described and shown.

2. An improved smoke preventer and fuel economizer for furnaces consisting of a dead plate as A^1 having an opening as A in it, a pivoted door or valve as B adapted to fit such opening, jointed levers C^2 and C^3, rock shaft C lever E and jointed levers D D^1 combined with a clock mechanism or clock train time regulating gear, substantially as described and shewn.

3. In an improved apparatus of the type specified the combination of the clock mechanism with the regulating device or governor H *h* substantially as and for the purpose described.

4. The improved smoke preventer and fuel economizer for furnaces constructed, arranged and operated substantially as herein described and as illustrated in the drawings.

No. 14,597 OF 1901

This Patent is granted to HORNSBY, ROBERTS AND JAMES for "IMPROVEMENTS IN STEAM GENERATORS." The essential feature of the Patent is the provision of a fire-clay backing to certain parts of the tube construction in water-tube boilers, in order to obtain a higher degree of temperature and better combustion of the volatile gases. Fig. 53 is a sectional elevation of a boiler provided with these additions, D being a fire clay-tile backing to the lowest row of tubes *c*, and E being a hanging row of tiles or bricks on that portion of the lowest row of tubes, which is just above the bridge-wall of the furnace. The claims of this patent are worded as follows—

1. In a steam generator of the kind described the combination of tiles and hanging fire bricks on the top portion of the tubes immediately over the furnace and bridge wall, substantially as, and for the purpose, described.

2. In a steam generator of the kind described making the front header and the pocket which is riveted to the underside of the steam and water drum wide enough to take two or more rows of connecting nipples, substantially as described and illustrated.

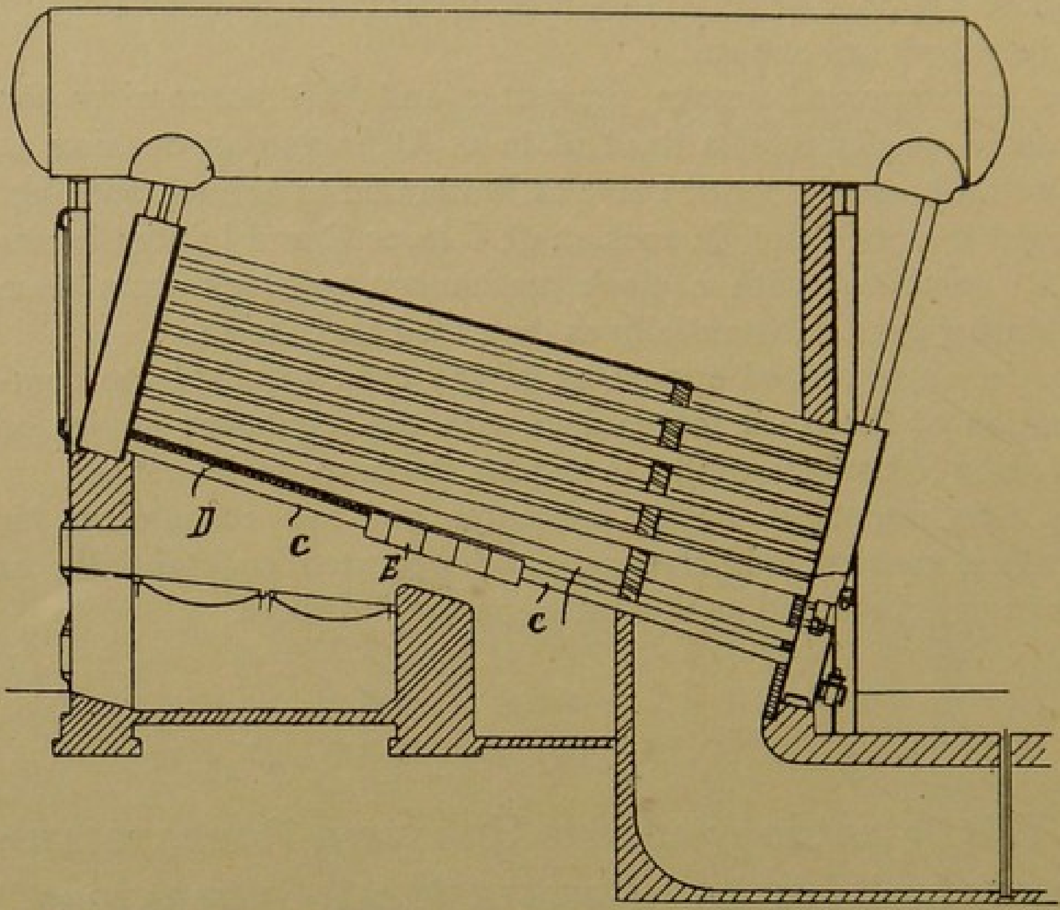

Fig. 53. The Hornsby Improved Setting for Water-Tube Boilers.

3. The improved steam generator hereinbefore described and illustrated in the accompanying drawing.

No. 24,514 of 1901

A Patent in the name of R. Thomson, for "Improvements in and relating to the Combustion of Fuel in Furnaces and Kilns." The object of this invention is to obtain *perfect* combustion of the fuel and volatile gases, without the excess of air, that is usually employed, to attain this end. The essential feature of this Patent is the plan of feeding the fuel and the air for its combustion in a downward direction on to a hearth, or on to a bed of heated fuel ; the products of combustion then escape in an upward direction. The change of direction of the heated air, which is supplied under forced draught, and the method of feeding the fuel, is held to effect a much better mixing of the volatile gases and air, than is obtained by the usual system.

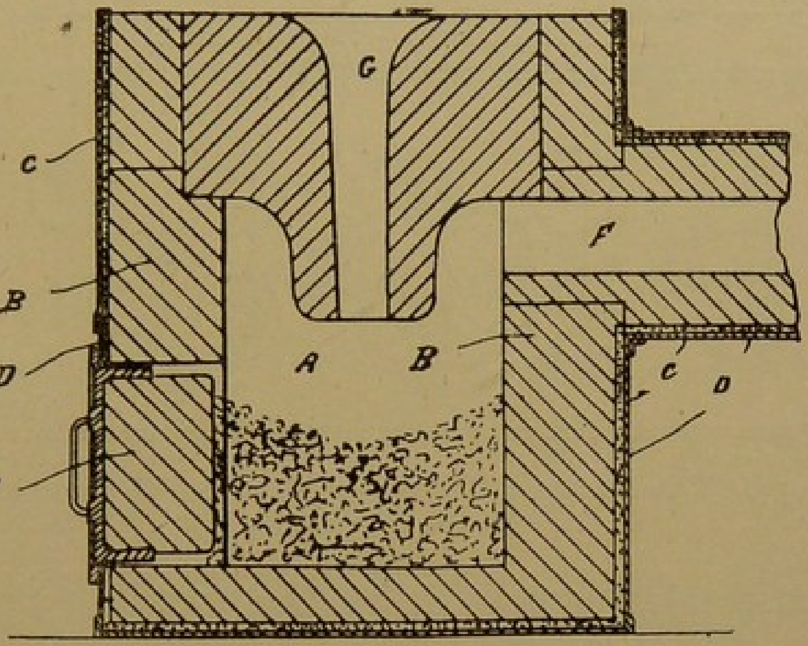

FIG. 54. THE THOMSON IMPROVED FURNACE CONSTRUCTION.

The improved method can be applied with equal success to solid and to liquid fuel, also to fuel in the powdered form. Figs. 54, 55 and 56, show the details of the furnace construction employed, for applying this method of firing to a Lancashire boiler.

An external furnace on wheels extends across the front of the boiler, and projections from this fit into the two boiler tubes. The openings *g g*, *g* into the furnace, are used for the supply of fuel and air to the hearth of the combustion chamber, *a*, and the gases pass away from this by the openings *f* and *k*.

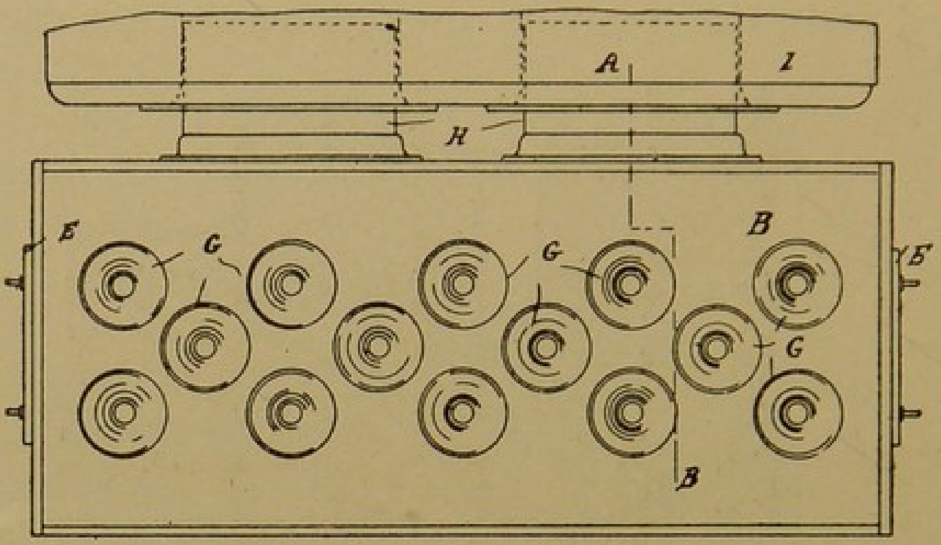

Fig. 55. The Thomson Improved Furnace Construction.

The ashes and clinker are removed by the end doors, *e*, *e*.

The wording of the claims of the Thomson Patent is as follows—

1. The method of effecting combustion of fuel, consisting in feeding the fuel in small regulated quantities into a furnace chamber, along with one or more downwardly directed streams of air on to a hearth of incandescent material, from which also all products of distillation and combustion are emitted upwardly whereby the fuel and all its combustible products are thoroughly commingled with sufficient air in a region of sufficiently high temperature to effect complete combustion.

2. A furnace for the combustion of solid, liquid or pulverized fuel, comprising a furnace chamber having a hearth carrying incandescent fuel or other material, one or more suitable air

inlets over the hearth through which fuel also is fed so that it is thoroughly brought into contact with the air supply during distillation or vaporization while surrounded by incandescent material, escape of waste gases taking place upwardly in a direction opposite to that of the inflowing air.

3. In a furnace as claimed in Claim 2, an air inlet orifice or tube, bell mouthed outwardly at its upper extremity, and of such length as will give the requisite direction to the stream of air flowing through it.

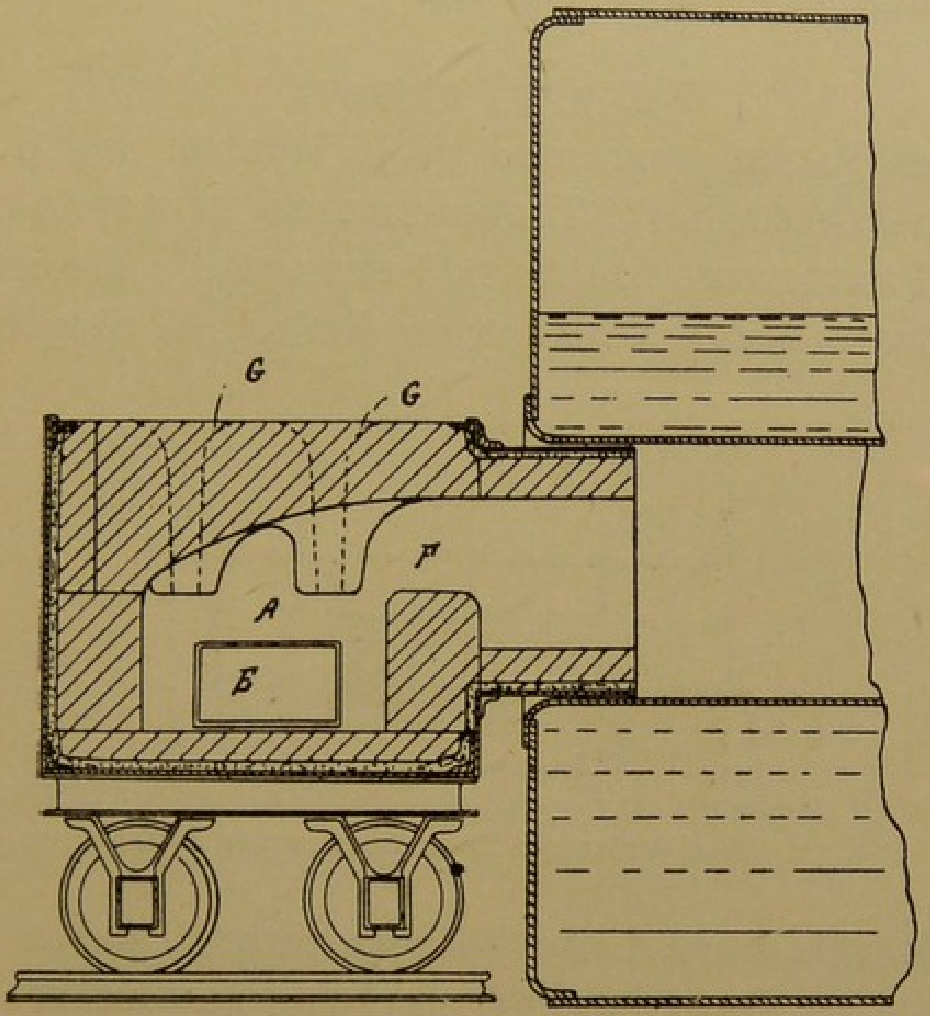

FIG. 56. THE THOMSON IMPROVED FURNACE CONSTRUCTION.

4. In a furnace as claimed in Claim 2, air inlets as claimed in Claim 3, together with outlets for the products of combustion so proportioned in relation to the air inlets as to produce the maximum induced draught, substantially as described.

5. In the process of combustion claimed in Claim 1, delivering

liquid fuel into the air inlet passages in such a way that vaporization takes place in the air stream.

6. In a furnace as claimed in Claim 2, spraying liquid fuel on to the sides of the air inlet orifice, or delivering it on to a rod within such orifice, whereby vaporization takes place from the hot lower walls of said orifice or rod, and thorough commingling with air is also effected.

7. The improved furnaces hereinbefore described with reference to the accompanying drawings.

NO. 7,373 OF 1902

This Patent is granted to J. WILSON and G. S. KEMP-WELCH, for "IMPROVEMENTS IN APPARATUS FOR PREVENTING SMOKE IN FURNACES." Its essential features are a hollow fire-bridge, of chequered brickwork, named the "Regenerator," and a gas-producing apparatus for supplying gas for heating this hollow bridge at stated intervals, during the combustion process.

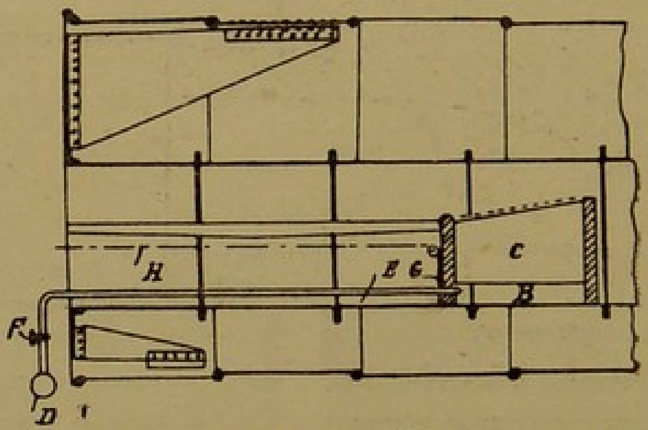

FIG. 57. THE WILSKEMP FUEL ECONOMIZER APPARATUS.

Fig. 57 is a sectional elevation of a Lancashire boiler fitted with the Wilson and Kemp-Welch apparatus, and Fig. 58 is a sectional plan of the same. The hollow bridge C is connected with the gas-producer by the main-pipe *d* and branches *e*, *e*.

When no air is being drawn through *e*, the cocks F, F are opened, and the bridge chequer-work is raised to a high temperature, by the ignition of this gas in its interstices. When firing is going on, the gas supply is turned off, the air inlet *g*, is opened by means of the lever H, and heated air is supplied above the bridge, for combustion of the smoke and volatile gases passing off from the furnace grate.

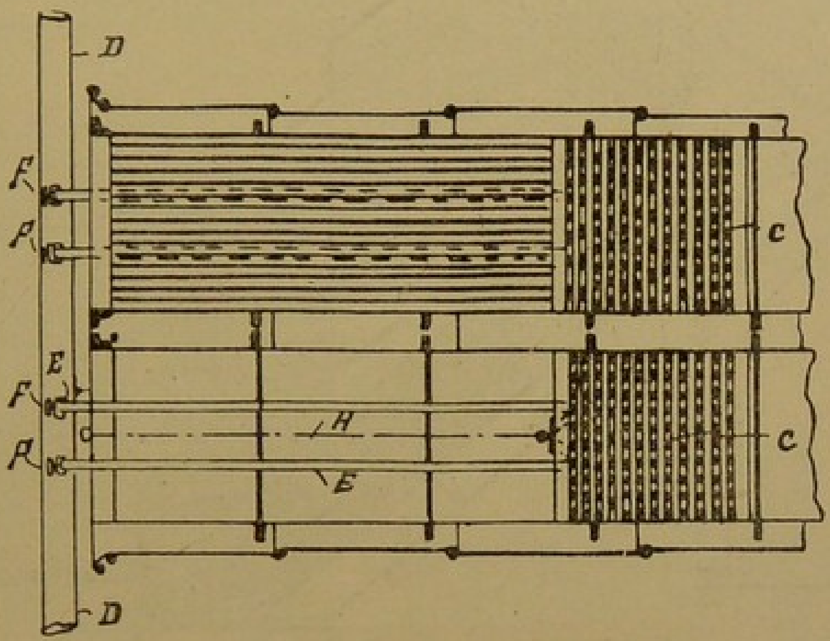

FIG. 58. THE WILSKEMP ECONOMIZER APPARATUS.

The claims of this Patent are as follows—

1. The combination with a furnace of a regenerator supplying air at the back of the fire substantially as described.
2. Apparatus for preventing smoke in furnaces substantially as described and illustrated in the drawings.

The Wilson and Kemp-Welch Patent is being exploited by the Wilskemp Smoke Consumer and Fuel Economizer Syndicate, Ltd., and the apparatus is stated to be in use on several boiler plants with successful results.

B. GERMAN PATENTS.

No. 79,015 of May, 1894

This Patent is in the name of G. W. Kraft, of Dresden, and relates to an inclined grate method of firing. Fig. 59 is a sectional elevation of the same.

At the upper end of the inclined grate A, there is fixed the charging hopper B, which is movable and slides vertically, so that a larger or smaller portion of the grate may be covered by its lower end. The angle of the grate and hopper is selected so as to give a regular feed of the coal to the lower part of the grate; and this feed of course increases as the

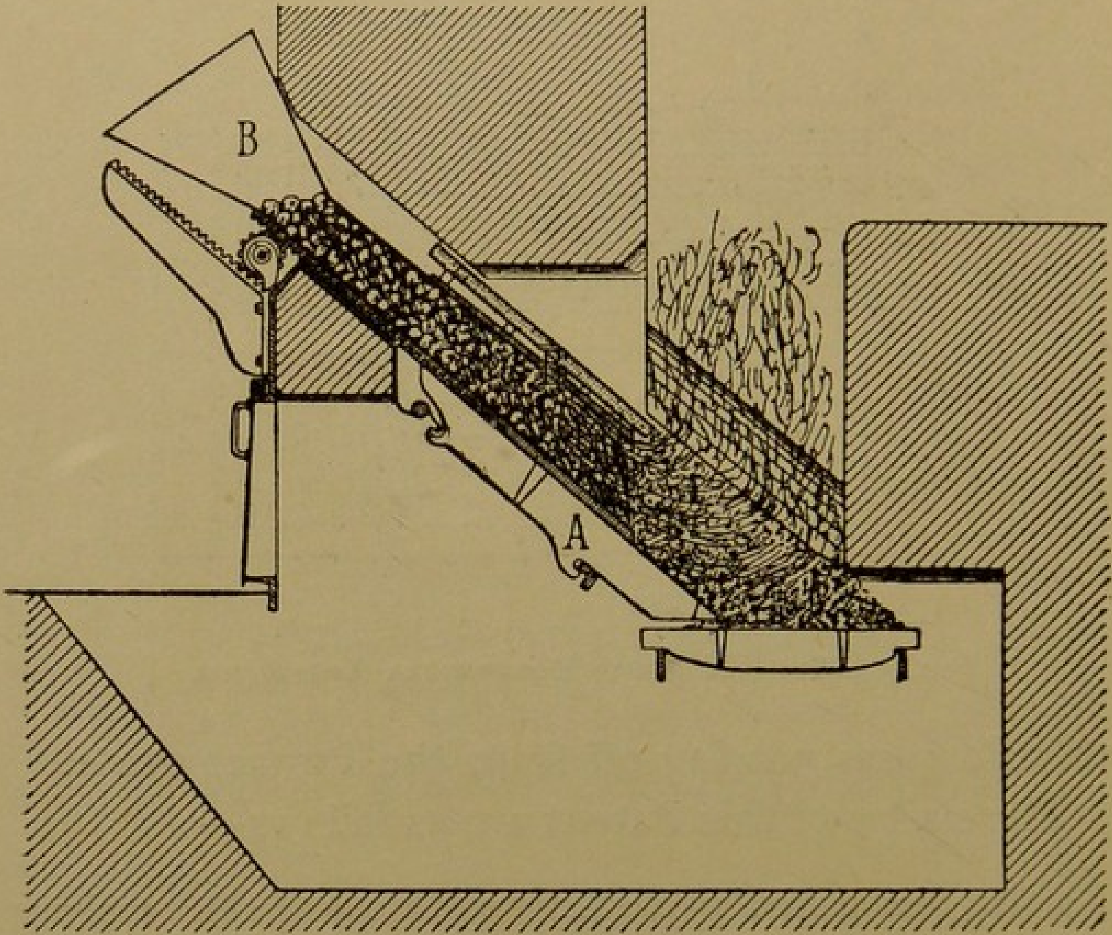

Fig. 59. Kraft's Inclined Grate Furnace Construction.

charging hopper is withdrawn, and a larger portion of the grate surface is rendered available for the combustion process. Any mechanical device

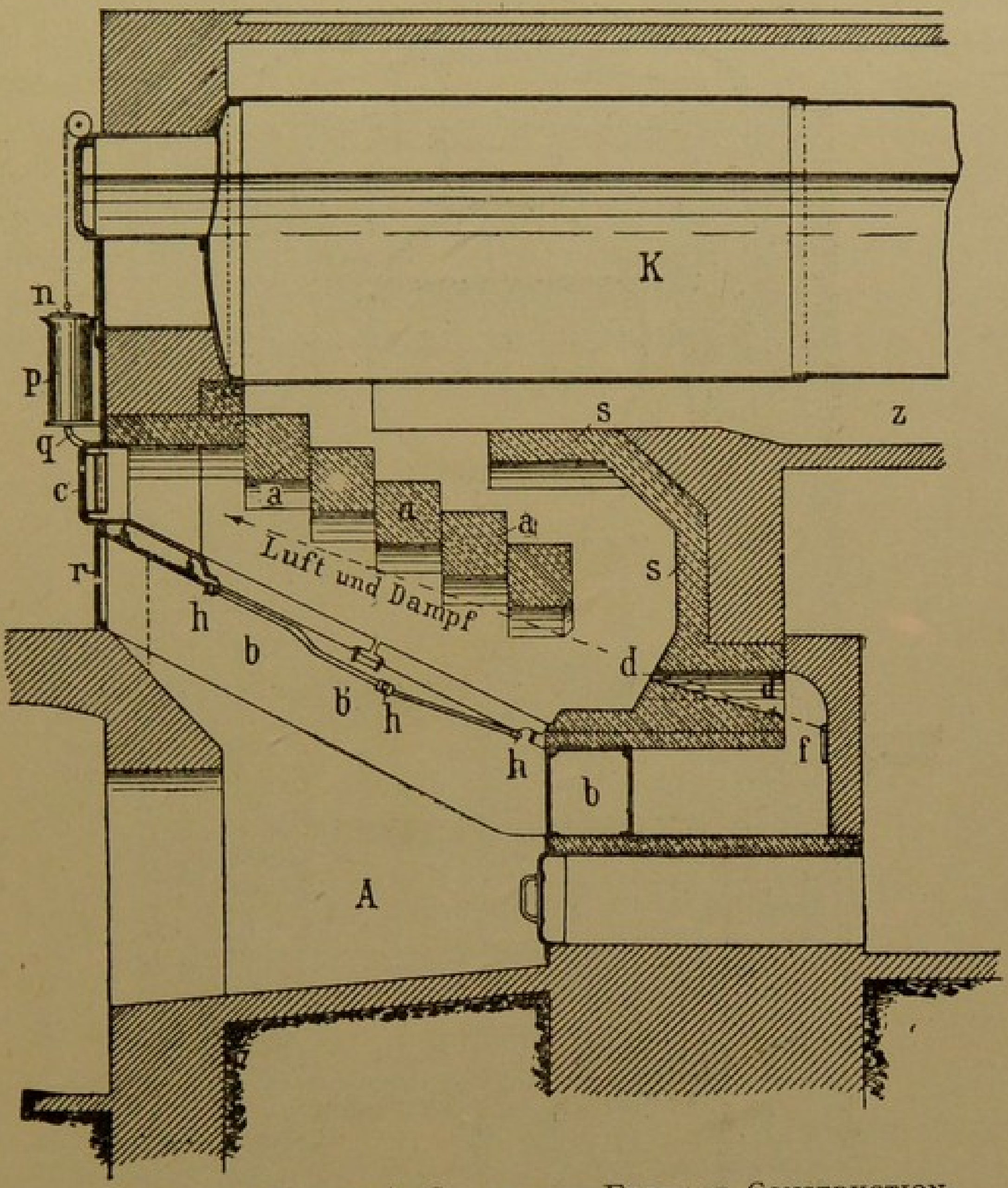

Fig. 60. Krippel's Grate and Furnace Construction.

may be utilized for moving the charging-hopper, and causing it to rise or descend in the grate.

The Patent claim is as follows—

A grate for burning poor fuel, distinguished by a movable charging hopper, that can be withdrawn from the furnace, and which may be utilized to increase or lessen the size of the grate, and therefore of the fire.

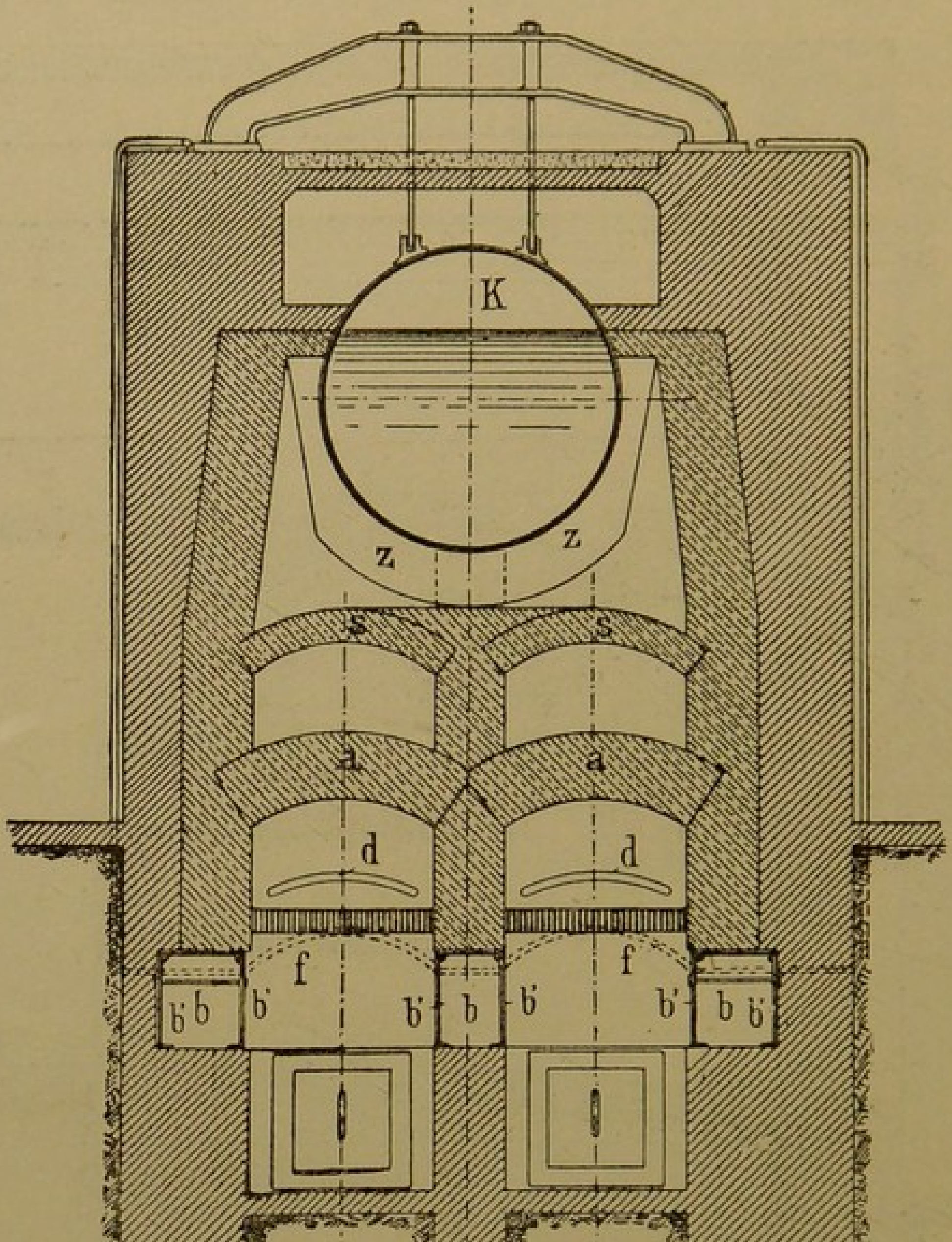

Fig. 61. Krippel's Grate and Furnace Construction.

No. 91,332 of 1896

A Patent granted to A. Krippel, of Vienna, and illustrated by Figs. 60 and 61.

The claim of this Patent is as follows—

A furnace and smoke-consuming apparatus, distinguished by an automatic air supply device actuated by the furnace door. On opening the furnace door *C*, the sliding damper is raised, and air is admitted either to the bridge, or to the ash-pit of the furnace, by channels *b b b*, in which it is heated by contact with iron walls. This heated air then passes through the fuel on the grate, or through the openings *d d* in the bridge, and promotes the combustion process.

In the latter case, it passes as a current of heated air above the grate, in a contrary direction to that of the half-burnt gases, and the arched wall above the grate is built in step-fashion, to promote the better mixture and combustion of the mixed gases. Fig. 60 is a side, and Fig. 61 a front sectional elevation of this type of furnace construction, applied to a cylindrical boiler.

No. 96,185 of 1897

The Patentee of this improved furnace is C. H. C.

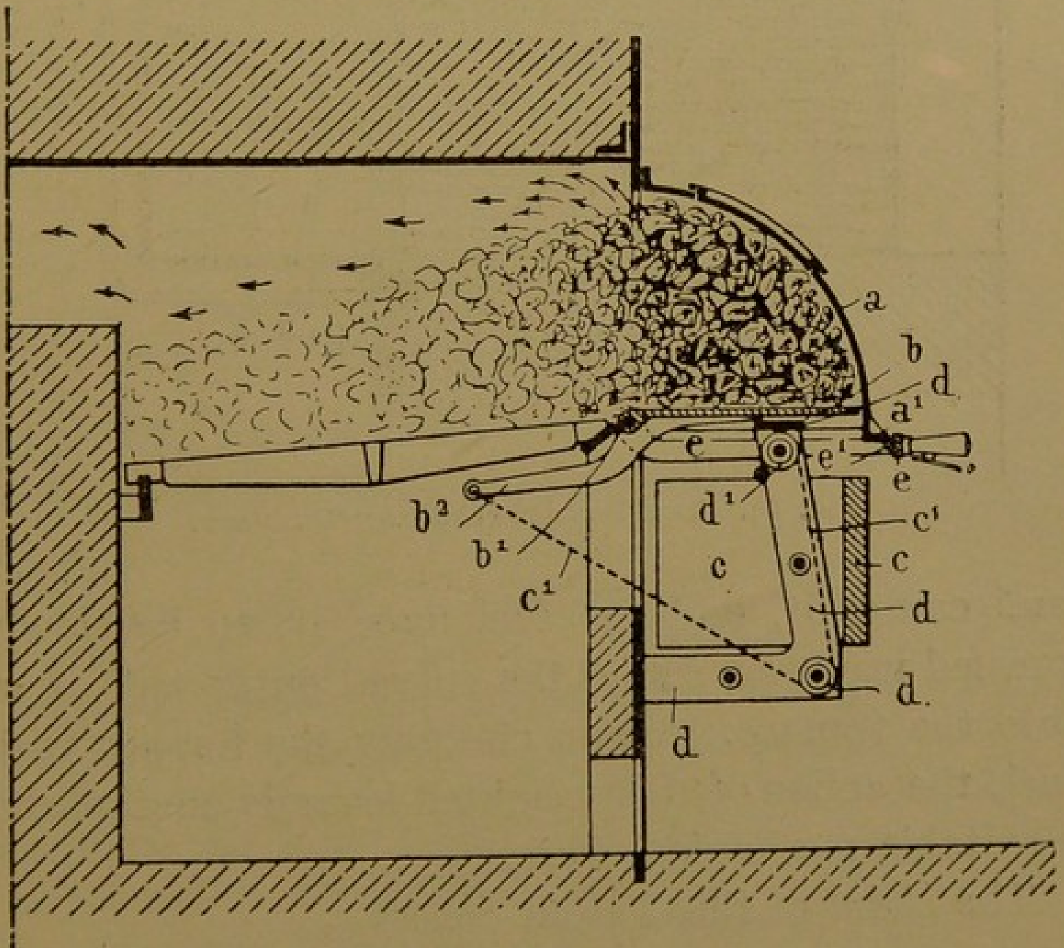

Fig. 62. The Bock Grate and Furnace.

Bock, of Hamburg, and the Patent relates to an automatic device for feeding the fuel slowly and regularly on to the fire. The apparatus is illustrated in Figs. 62 and 63, which represent a sectional elevation and sectional plan of the furnace respectively. A box (*a*) projecting from the front of the furnace has a hinged false bottom *b*, which is kept in position by the weighted lever b^2. The weight *c* keeps the bottom *b* from falling downwards, and causes it, and the fuel upon it, to be slowly pressed upwards, round the curved outer wall of *a*, into the furnace. When charging the hopper with fuel, the action of this weighted lever is checked by a suitable mechanical device.

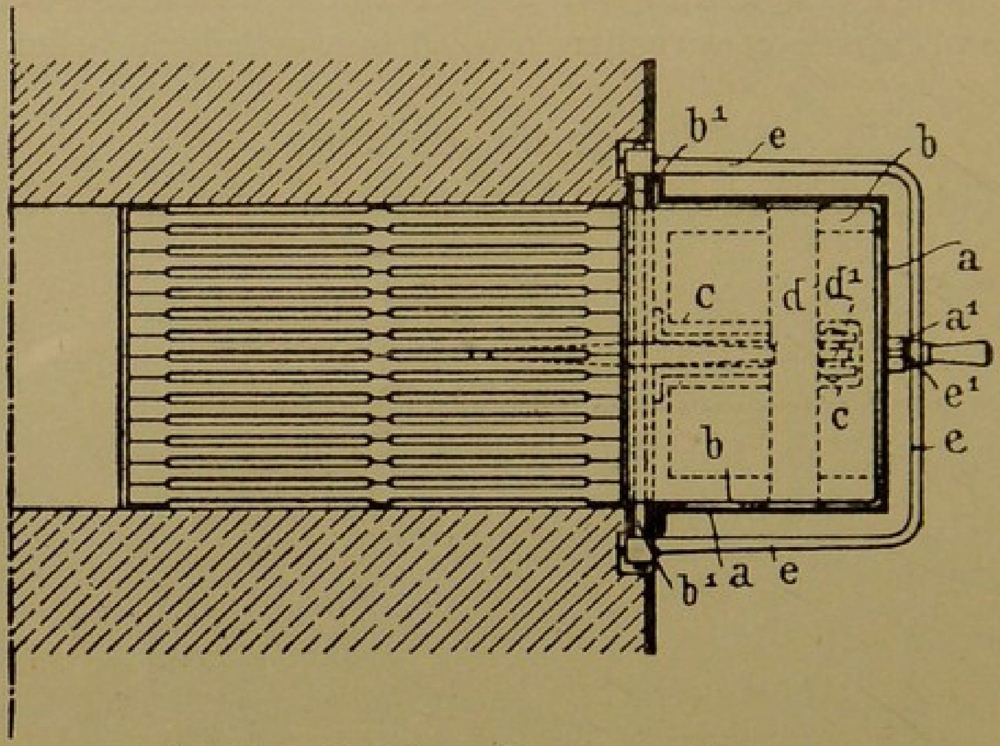

Fig. 63. The Bock Grate and Furnace.

The claim of this Patent covers—

Grates for furnaces of all kinds, provided with a projecting fuel-box, characterized by a movable bottom, and a mechanical device for carrying the fuel resting on this false bottom gradually into the zone of combustion.

No. 112,156 of 1899

This Patent was granted to W. Dürr, of Munich, and relates to improvements in the provision of a secondary air supply, for boiler furnaces with inclined grates.

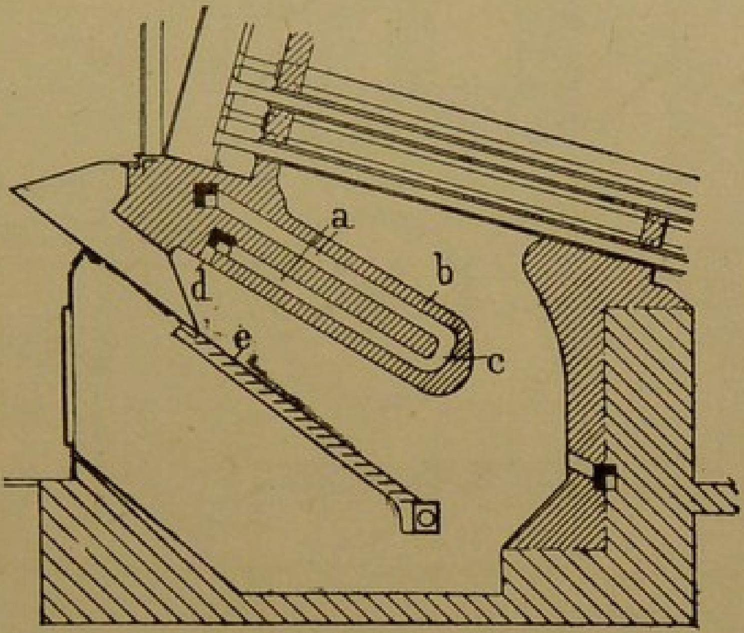

Fig. 64. The Dürr Furnace Construction.

Fig. 64 is a sectional elevation of this improved furnace construction, and requires no detailed explanation.

The Patent claim covers—

The use of a hollow arch over the inclined grate of the furnace, for heating the secondary air supply, the passage of the air through the channels in this hollow arch being in an opposite direction to that of the heated gases outside it.

No. 114,909 of 1899

A Patent granted to A. Piontek, of Braunschweig, for an improved form of external revolving hearth furnace for boiler firing. Fig. 65 is a sectional elevation of this furnace; and in this F represents the fuel charging hopper, B an inclined grate, C the revolving hearth, A the combustion chamber, and D a space which becomes filled up with half-consumed carbonized fuel and ashes. The movement of the revolving hearth C, of course carries the fuel from B towards D, and also assists in the movements of the carbonized fuel and ashes towards the bottom and front of the ash-hole; and all these features of the design are covered by the wording of the Patent claim.

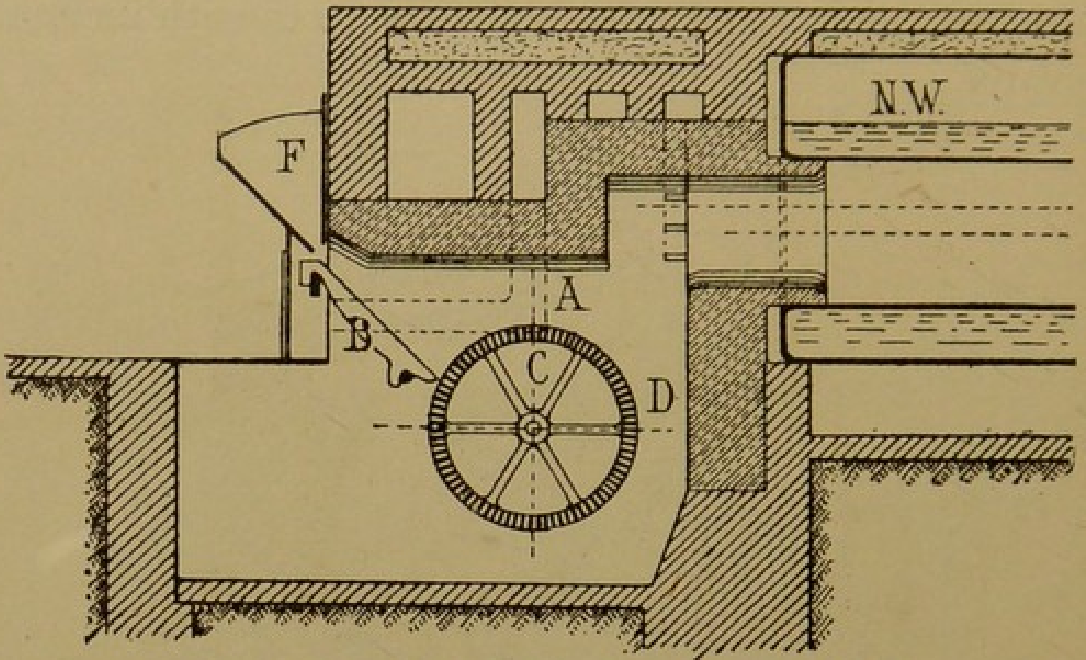

FIG. 65. PIONTEK'S REVOLVING HEARTH GRATE.

No. 116,063 OF 1900

This Patent was granted to H. BÖTTGER, of Dresden, and relates to an improved method of feeding coal or slack on to the grate of a boiler or other furnace, without admission of air. Figs. 66 and 67 show the arrangements of parts for effecting this object.

d is a heavy hinged door which when closed, as in Fig. 66, acts as support for the hinged door *b*, supporting the charge of fuel in the hopper *a*. *d* can either be opened by hand or by automatic mechanism, and then takes the position shown in Fig. 67. The swing bottom *b* of the hopper *a* then falls back, and the charge of fuel falls on to the inclined step-grate. A balance weight *c*, attached to a lever acting on *b*, causes the two doors *b* and *d* to close, before all the fuel has dropped out of *a* on to the

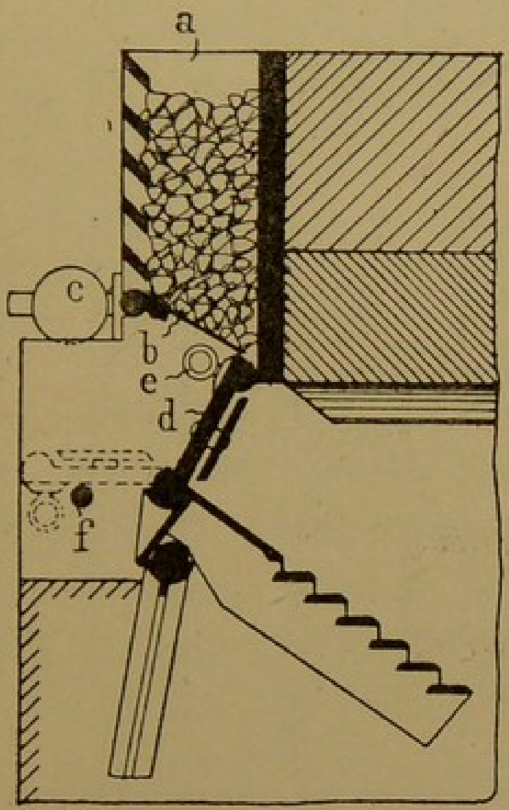

Fig. 66.
The Böttger Automatic Feed Grate.

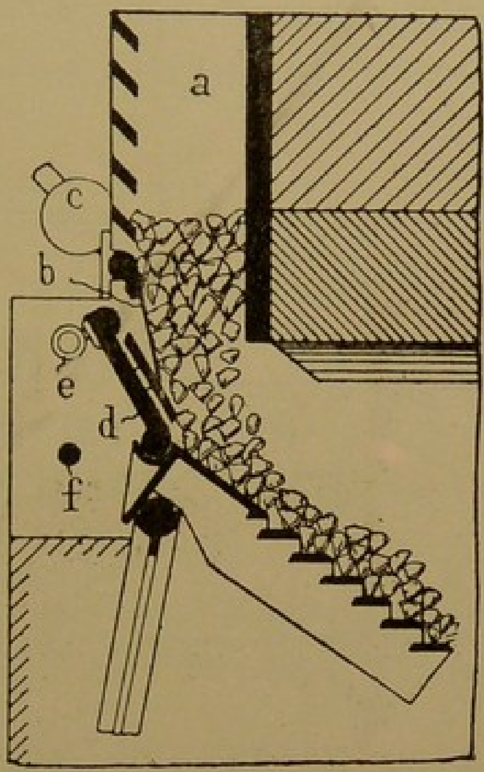

Fig. 67.
The Böttger Automatic Feed Grate.

grate. The Patent claim covers all these details of construction.

No. 123,300 of 1901

This Patent relates to a system of under-feed firing; and was granted to K. F. Schumann, of Hosterwitz. Fig. 68 is a sectional elevation of this type of furnace. The charge of fresh fuel is placed in the charging chamber *c*, where it is subjected to a preliminary heating. When a fresh charge of fuel is required on the grate of the furnace, the hollow slide box *d* is pushed back by means of the lever, until it occupies the position indicated by

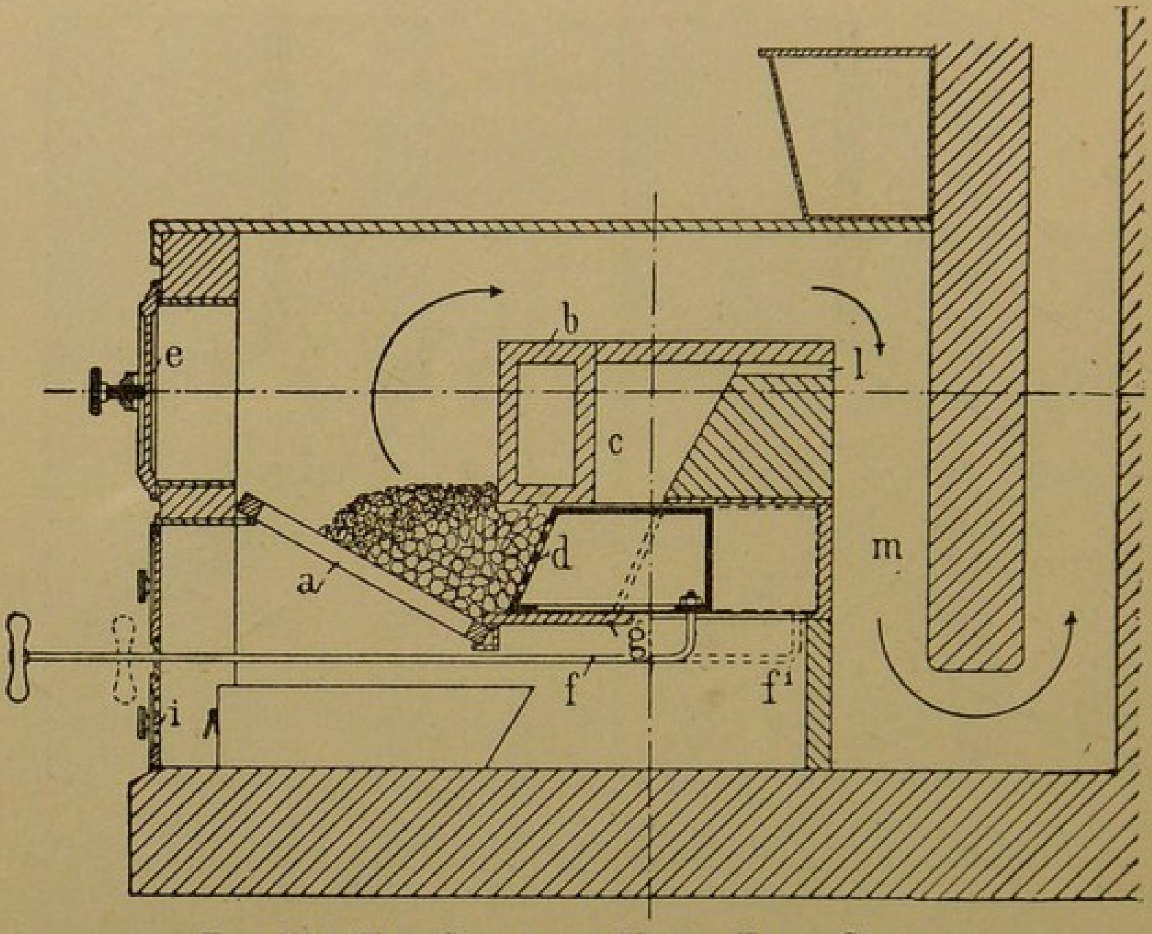

Fig. 68. The Schumann Under-Feed Grate.

f^1 g^1. The charge of fuel in *c* then falls in front of *d*, and on returning this to its original position, the fuel is brought on to the grate *a*, underneath and behind the hot mass of carbonized fuel and ash already there.

The gases liberated from the fresh fuel are therefore compelled to pass through the glowing body of fuel above them, in order to reach the combustion chamber of the furnace, and a more perfect combustion is claimed for this method of combustion and charging.

The Patent claim covers these details of construction and the results obtained.

C. AMERICAN PATENTS.

The smoke devices of America differ somewhat from those of this country, owing to the difference of boiler practice and the difference of fuel.

Those selected for description will include modifications of the old Juckes chain grate, furnaces of the under-fired type, and the step grate.

The Coxe Stoker (Fig. 69) for hard or Pennsylvania anthracite, is of the chain-grate variety.

It consists of a chain, carrying a series of transverse flat-topped bars, on to which the fuel is fed from a hopper. The air supply is provided by a fan, which delivers air into a sheet-iron box, under the chain. This box is divided by partitions in such a way, that whereas the division B secures the full supply, there is a moderate pressure in A, and diminished pressures in C, D, etc., to the end of the grate, the air supply being thus regulated to the thickness of the fire. The final box only passes air to cool the ash, and to burn the carbonic oxide, from the thicker parts of the fire. With a brick arch over the fire, to compel all the gases to travel the full length of the grate before escaping to the boiler, it was found by Mr. Coxe that an evaporation from and at 212°F, of 10·14 to 11·12 pounds, per pound of combustible was obtained. This stoker merits careful attention. The air regulation is what reason demands it should be, and there appears to be no cause why it should not suit bituminous fuel, and thus render the chain grate one of the foremost of apparatus. As already pointed out, the usual chain-grate apparatus is extremely faulty, owing to want of the air regulation plates, which are essential to a horizontal chain grate.

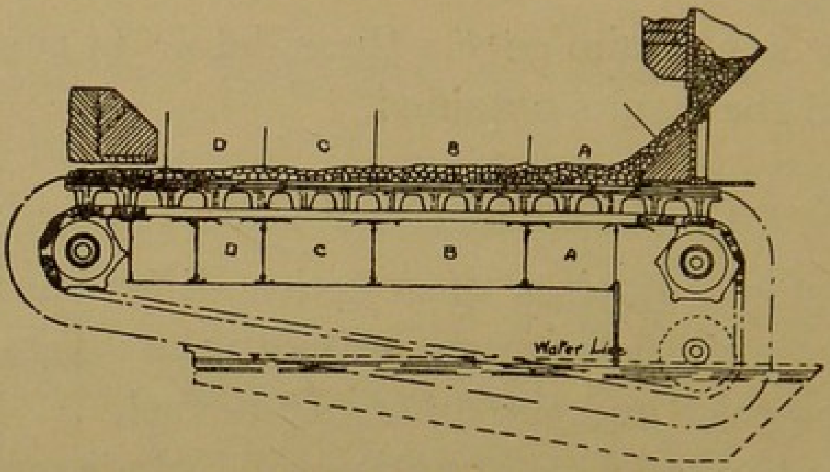

Fig. 69. The Coxe Chain Grate Stoker.

The extended use of under-fired shell boilers in America, has favoured the stepped grate type of furnace. One of these, mechanically operated, is the Roney Stoker.

A slider in the bottom of the coal hopper, pushes the coal upon the grate, which has an angle of 37° from the horizontal. The grate bars are of the flat step variety, and rock from a horizontal position, to one inclined downwards. The rocking of the bar causes the fuel to gravitate downwards, filling up weak places in the fire, and gradually transferring the ash to a dumping plate at the foot of the inclined grate. The bar movement also serves to keep an open fire. A brick coking arch covers the upper end. It is important to note that the gravitation effect is only possible with inclined grates, and this is one great advantage of externally-fired boilers not possessed by any of the internally-fired variety. Where a fire can be caused to pack itself, and close up bare spots automatically, a better economy is possible than can easily be secured in any horizontal grate.

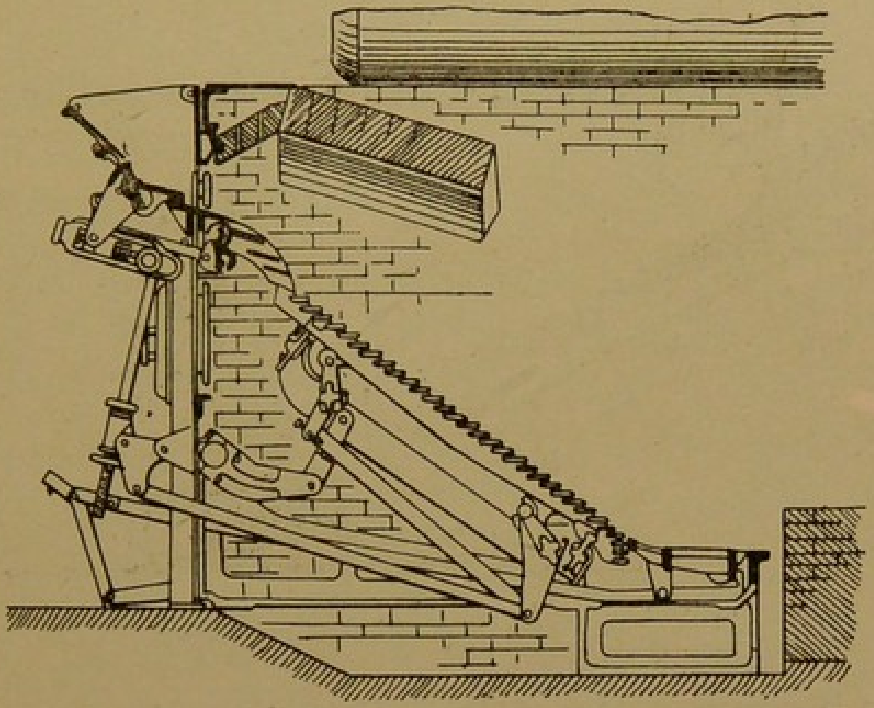

Fig. 70. The Acme Stoker.

The Acme Stoker, Fig. 70, is another of the inclined grate variety, with an angle of 32°. Coal is fed over the small upper coking grates, under a brick arch. The fire-bars of the inclined grate are arranged so that alternate bars rise above the general level, move downwards, and return below level, so helping the fire to travel gradually towards the dumping grate at the foot. The whole grate can be lowered in front to a flatter position, so that hand firing can be carried on through the door, which is below the grate when mechanical firing is in progress. The grate when fully charged and ignited, can then be raised to the full angle and mechanically operated as usual.

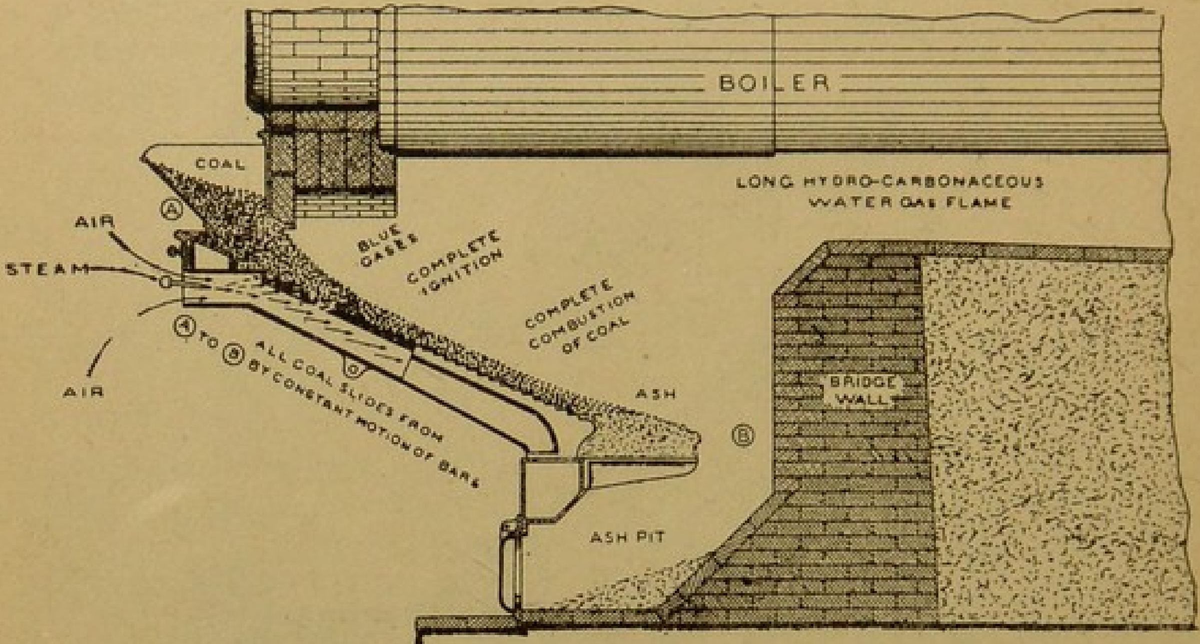

Fig. 71. The Wilkinson Stoker.

The Wilkinson Stoker (Fig. 71) has a grate with a flat angle of 25°, and it consists of hollow bars through which air flows to the fuel. The air may be drawn in by a steam jet in each bar. Movement of the bars alternately to and fro, feeds forward the fuel. Value is placed on the use of steam, and in the illustration the idea of the makers of this furnace is set forth, showing that the incandescent fuel on the grate is supposed to be utilized to split up the steam into its elements, and thus to transfer the combustion to a long locus of flame beneath the boiler. The firebrick arch of this illustration could probably be extended with advantage. The grate of course tends to give an even fire, and the final ash is dropped below, as shown. The Wilkinson Stoker is claimed to burn anthracite or bituminous coal. It is important that anthracite should not be allowed to burn into bare patches on the grate, and it is therefore necessary that the fire should have a self-closing action, without too much disturbance taking place. American hard anthracites should be disturbed as little as possible during combustion, being in this respect like the dry bituminous, or " self-stoking," coals of this country.

THE UNDERFEED STOKER, of Walbrook, London, is shown in Figs. 72 and 73. In this machine, coal is fed up a long central trough, by means of a tapering helix, and it becomes partly coked before it rises from the top. The sides of the trough sometimes have a lateral movement, which slightly crushes the rising coking fuel.

As the fuel rises, it falls over on each side, upon the two inclined grates, of longitudinal hollow flat plate bars, under and through which air is blown. This air passes out parallel with the bar faces, and thus mixes better with the fuel, and does not so readily escape upwards untouched. The plates have a rocking movement, which helps the fuel downwards to the long side troughs, whence it can be raked when all is burned to ash. These underfeed stokers generally may be said to resemble a pair of step grates set back to back, with the fuel supply at the common ridge between them. They are then, to some extent, a compound of a coking system and a gravity or inclined grate system, and the air supply is directed so as not to escape too readily and create bare patches in the fire. These underfeed laterally sloped grates, appear to afford something of the gravity effect, with a grate longitudinally horizontal, and they can be employed where the highly-inclined step grates cannot be accommodated, as in the furnaces of Cornish or Lan-

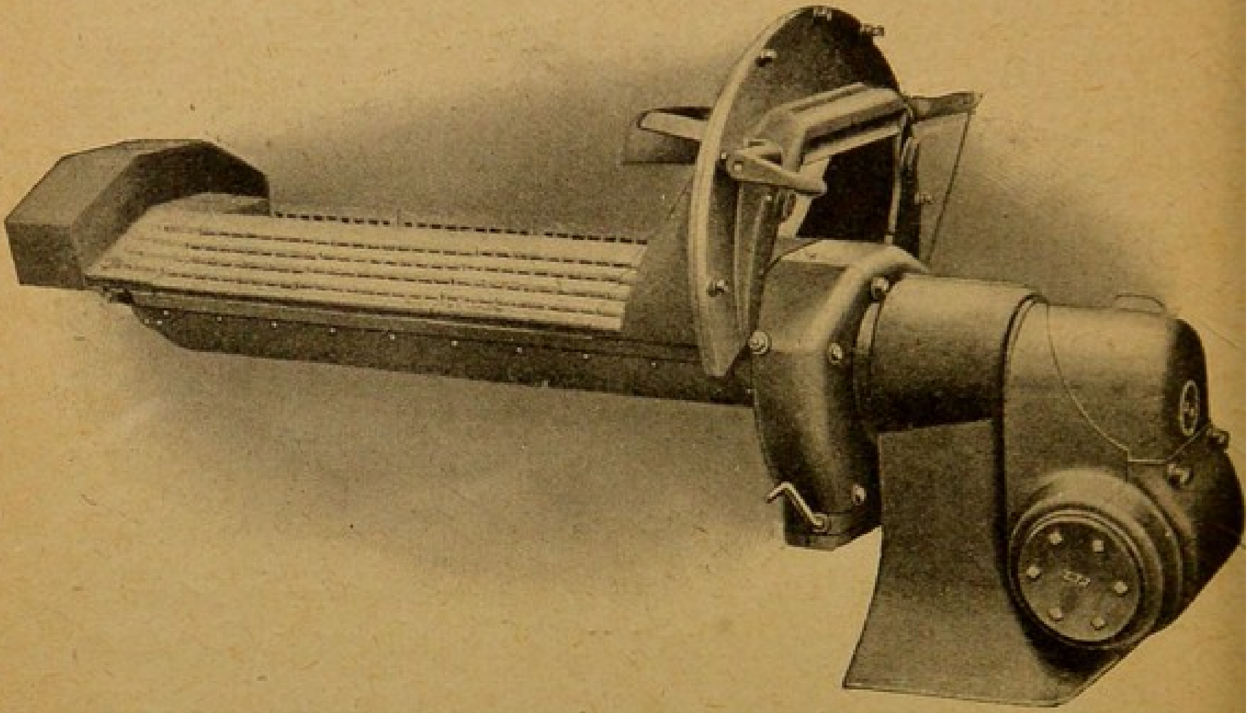

FIG. 72. THE UNDERFEED STOKER.

cashire boilers. They are used always with assisted draught. Under-firing cannot be said to have proved a success until, by means of gravity, the fuel was made to travel over the grate surface, and this was only secured by inclining the grate surface transversely as shown. By this lateral sloping alone could a really inclined grate be secured in an internally fired boiler. In Fig 73 the fuel is marked G; D is the trough in which works the helix which feeds forward the coal; F F^1 are the first air inlets supplying air to the fuel at E, just above the moving sides of the hopper, which crush the fuel when it begins to coke as it approaches the heat. Air enters through the slots in the bar edges as at B, and air is forced by a fan to the undergrate space A, C.

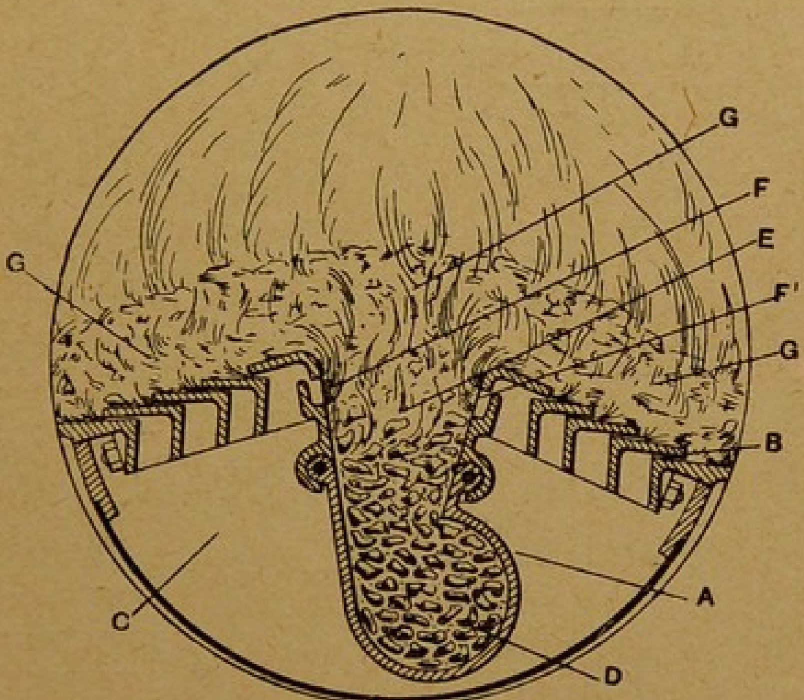

Fig. 73. The Underfeed Stoker.

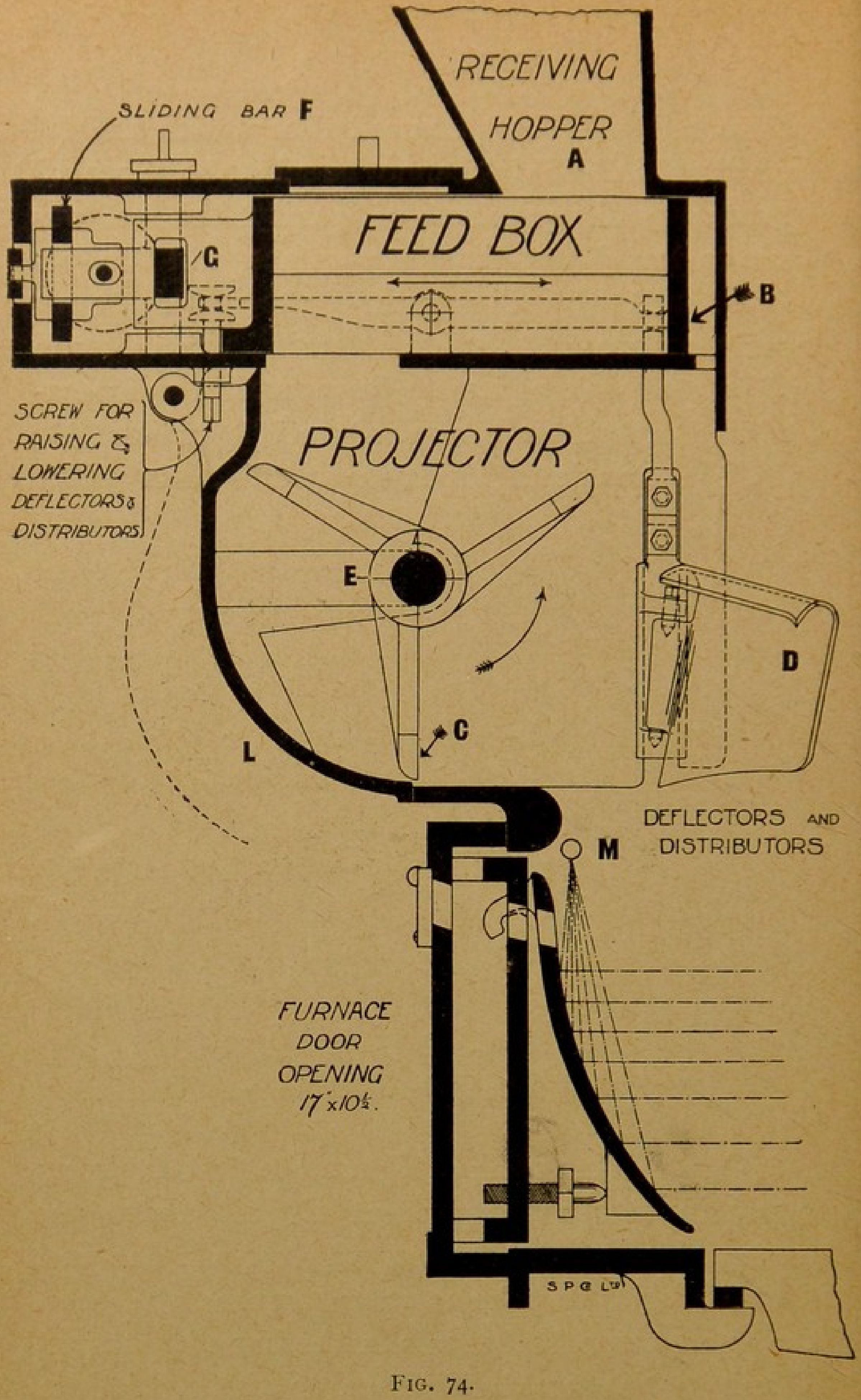
RECEIVING HOPPER
A
SLIDING BAR F
G
FEED BOX
B
SCREW FOR RAISING & LOWERING DEFLECTORS & DISTRIBUTORS
PROJECTOR
E
D
C
L
DEFLECTORS AND DISTRIBUTORS
M
FURNACE DOOR OPENING 17" x 10½".
S P C Lᵀᴰ

Fig. 74.

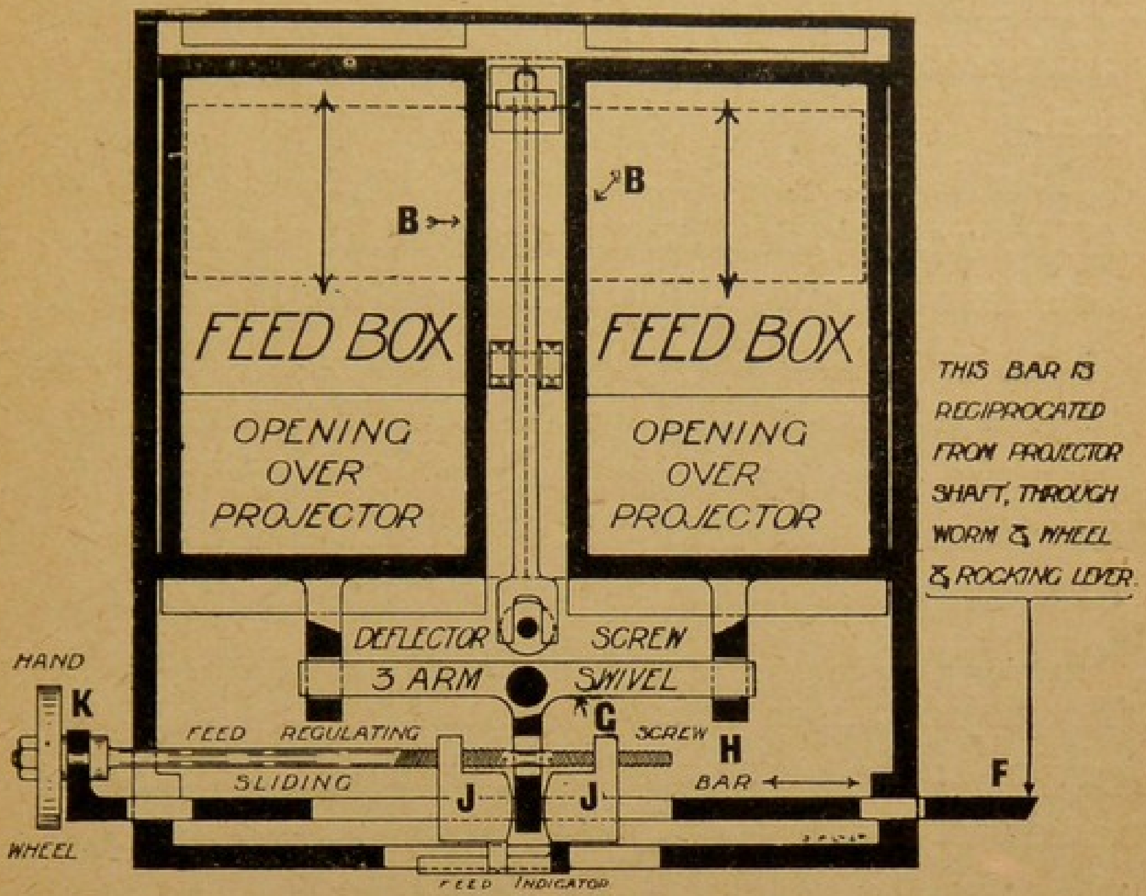

FIG. 75.

THE "E.S.E." PATENT MECHANICAL STOKER

REFERENCE.

A—Coal receiving hopper.
B.—Sliding feed boxes.
C.—Three arm projector.
D.—Deflectors and distributors.
E.—Projector shaft, 300 revs. per minute.
F.—Sliding bar with blocks J.
G.—Three arm swivel, working boxes B.
H.—Feed regulating screw to set blocks J.
J.—Feed regulating blocks on bar F.
K.—Feed regulating hand wheel.
L.—Projector casing relief door.
M.—Jet pipe, for clearing dead plate.

Gravity grates fail when their angle is too flat for the quality of the fuel. Coals of the coking variety will sometimes hang upon the bars. Hence the advisability of a variable angle to suit changes of fuel.

The E.S.E. Stoker, of Blackburn, Lancashire (Figs. 74, 75), consists of a sprinkling gear which acts first to sprinkle the coal upon the right side of the grate from dead-plate to bridge. Then the apparatus pauses, and the left side of it comes into operation and feeds fuel on the other half of the fire, thus mechanically imitating side firing, and providing always that one side of the furnace shall be bright while the other is giving off gases freely. The object aimed at is to keep a fairly constant gas output to be consumed by aid of the surplus air admitted at the door, and of the temperature provided by the clear, red half of the fire.

Appendix II

TABLES.

Fuel Analyses, Losses and Costs

TABLE I

APPROXIMATE ANALYSES, CALORIFIC VALUES (CALCULATED AND OBSERVED), PRICES, AND COMPARATIVE COSTS OF VARIOUS ENGLISH AND WELSH COALS.

From Liverpool Engineering Society Paper, by J. B. C. Kershaw, on "Fuel Economy," November 18, 1903.

General Description of Coal	1 Particular Description of Coal	2 Per cent. Moisture	3 Per cent. Ash	4 Per cent. Coke	5 Per cent. Volatile Matter	6 Per cent. Fixed Carbon	7 Calorific Value (Observed)	8 Calorific Value (Calculated)	9 Price per Ton d/d in Bunkers s. d.	10 Calorific Value per Penny of Cost
Hard South Wales Coals	Eaglebush	1·05	14·25	86·70	13·30	72·45	7503	—	17 9	35·2
	Dynevor Duffryn (1)	1·35	10·75	86·40	13·60	75·65	7935	—	18 2	36·7
	Standard Merthyr (1)	1·21	·85	84·50	15·50	75·65	7942	7950	21 0	31·5
	Standard Merthyr (2)	1·27	2·45	85·40	14·60	72·95	7717	7641	21 0	30·6
	Cwmmer Main (1)	1·46	10·00	87·50	12·50	77·50	7935	7855	17 3	38·3
	Cwmmer Main (2)	1·45	5·55	87·60	12·40	82·05	8280	8247	17 3	40·0
	Dynevor Duffryn (2)	1·25	8·10	84·10	15·90	76·00	7987	8028	19 1	34·8
	Dynevor Duffryn (3)	1·20	9·75	87·40	12·60	77·65	7762	7875	19 1	33·0
	Pontardame Smokeless (1)	2·66	8·40	87·90	12·10	79·50	7875	7995	17 3	38·0
	Pontardame Smokeless (2)	4·48	15·25	88·20	11·80	72·95	7537	7398	17 3	36·3
	Pontardame Smokeless (3)	3·65	13·05	87·40	12·60	74·35	7650	7583	17 3	36·9
	Ocean Small Steam	3·13	13·95	87·00	13·00	73·05	7590	7511	15·10	39·9
	Loughor & Mynydd Newydd	2·20	17·05	86·00	14·00	68·95	7360	—	9 6	64·5
	Werfa	1·34	14·95	90·00	10·00	75·05	7331	—	11 11	51·2
Soft Bituminous Coals	Cannock Seam	10·62	23·05	70·15	29·85	47·10	6382	—	6 9	78·7
	Kingswinford Slack	11·54	12·45	72·10	27·90	59·65	7297	—	8 6	71·5
	North Hetton (1)	2·51	13·80	69·00	31·00	55·20	7590	—	11 10½	53·2
	Madeley Washed Slack	3·20	6·20	66·70	33·30	60·50	8365	8041	10 6	66·3
	Stopford Slack	7·83	9·45	66·10	33·90	56·65	7590	—	7 5	85·2
	Bowley Washed Slack	2·76	5·85	67·40	32·60	61·55	8365	8123	10 6	66·3
	North Hetton (2)	2·94	11·40	69·70	30·30	58·30	7790	7658	11 10½	54·6
	Wigan (1)	4·94	16·85	69·90	30·10	53·05	7192	7089	8 3	72·6
	Wigan and Skelmersdale (1)	6·76	16·50	71·20	28·80	54·70	7245	7203	8 4	72·4
	Wigan (2)	3·56	14·50	70·10	29·90	55·60	7537	7369	8 6	73·8
	Wigan and Skelmersdale (2)	3·76	14·20	69·60	30·40	55·40	7590	7370	8 4	75·9
	Digby Bright Peas	10·44	6·50	63·50	36·50	57·00	7935	7703	7 9	85·3
	Shipley Peas	7·72	7·75	66·00	34·00	58·25	7891	7764	7 11	83·0
	Marchay Rough Slack	7·80	3·05	64·70	35·30	61·65	8314	8214	8 8	79·9
	Manners Peas	7·44	10·75	66·40	33·60	55·65	7675	7490	7 5	86·2

NOTES.—(1) The results in columns 3, 4, 5, 6 and 7 are all based on the sample dried at 110°C.
(2) Columns 7, 8 and 10 give the calorific values in centigrade units.
(3) The samples marked 1, 2 and 3 are different samples of the same coal.
(4) The first twelve samples are from a South Coast Electricity Supply Station, and the costs delivered in bunkers are correspondingly high.

TABLE II

HEAT IN B. TH. UNITS CARRIED AWAY BY WASTE GASES, PER POUND OF FUEL BURNT.[1]

Specially calculated for "Smoke Prevention."

Temperature °F	Percentage of CO_2 in Exit Gases											
	4	5	6	7	8	9	10	11	12	13	14	15
100	1095	884	739	639	562	503	456	418	385	358	334	314
200	2190	1769	1479	1279	1125	1007	913	836	770	716	669	628
300	3285	2654	2219	1919	1687	1510	1369	1254	1155	1074	1003	942
400	4380	3539	2959	2559	2250	2014	1826	1673	1540	1433	1338	1257
500	5475	4424	3699	3199	2812	2518	2283	2091	1925	1791	1672	1571
600	6570	5309	4439	3839	3375	3021	2739	2509	2310	2149	2007	1886
700	7665	6193	5179	4478	3937	3525	3196	2927	2695	2507	2341	2200
800	8760	7078	5919	5118	4500	4028	3652	3345	3080	2865	2676	2514

---

[1] Calculated for a Bituminous Fuel containing 73 per cent. C, 4·8 per cent. H, 7·3 per cent. O, and 13 per cent. ash in dry state, and 5 per cent, moisture when charged. Specific heat of exit gases (calculated) lies between ·239 and ·245.

TABLE III

PERCENTAGE OF FUEL WASTED, BY HEAT LOSSES IN EXIT GASES, AT VARIOUS TEMPERATURES.[1]

Specially calculated for "Smoke Prevention."

Temperature °F	Percentage of CO_2 in Exit Gases											
	4	5	6	7	8	9	10	11	12	13	14	15
100	8·1	6·5	5·4	4·7	4·1	3·7	3·3	3·0	2·8	2·6	2·4	2·3
200	16·2	13·1	10·9	9·4	8·3	7·4	6·7	6·1	5·7	5·3	4·9	4·6
300	24·3	19·6	16·4	14·2	12·5	11·2	10·1	9·2	8·5	7·9	7·4	6·9
400	32·4	26·2	21·8	18·9	16·4	14·9	13·4	12·3	11·4	10·6	9·8	9·2
500	40·5	32·7	27·3	23·6	20·8	18·6	16·8	15·4	14·2	13·2	12·3	11·6
600	48·6	39·3	32·8	28·3	24·9	22·3	20·2	18·5	17·1	15·9	14·8	13·9
700	56·7	45·8	38·2	33·1	29·1	26·0	23·5	21·6	19·9	18·5	17·2	16·2
800	64·8	52·4	43·7	37·8	33·2	29·7	26·9	24·7	22·8	21·2	19·7	18·5

---

[1] Losses calculated for a coal containing 7,500 Centigrade units, equal to 13,500 B. Th. Units.

APPENDIX II

TABLE IV

ACTUAL LOSSES INCURRED IN MOST BOILER PLANTS AS AT PRESENT WORKED, DUE TO LOW PERCENTAGE OF CO_2 IN THE WASTE GASES.[1]

	Wasted Fuel		
Tons of Coal Burnt per Day of 24 Hours	Tons per Day	Tons per Year of 330 Working Days	Money Value of Loss per Year £
10	1	330	132
25	2½	825	330
50	5	1650	660
75	7½	2475	990
100	10	3300	1320

[1] *The Engineer*, May 2, 1902.

NOTE.—The above table is based on the assumption that a 10 per cent. loss, of heat and fuel, which might be avoided, is occurring with the exit gases, and that slack at 8*s*. per ton delivered in bunkers is being burned under the boilers. The money value of the loss will of course increase with coals of higher value.

Appendix III.

MISCELLANEOUS EXTRACTS.

A. GOUTEL'S FORMULA FOR CALCULATING THE CALORIFIC VALUE OF FUELS, FROM THE RESULTS OF THE APPROXIMATE ANALYSIS.

Formula.

$$P = 82\,C + a\,V.$$

P = Calorific value in Centigrade units. C = per cent. fixed carbon. V = per cent. volatile matter. a = a variable coefficient, depending upon the amount of ash and moisture in the fuel.

Using the formula $V^1 = \frac{V \times 100}{C + V}$, the following values are obtained for a.

V^1 =	5.	10.	15.	20.	25.	30.	35.	38.	40.
a =	145.	130.	117.	109.	103.	98.	94.	85.	80.

Comptes Rendus, Sept., 1902.
Sc. Abstracts, No. 252, 1903.

B. EXTRACTS FROM MR. C. E. STROMEYER'S 1902 MEMORANDUM TO THE MANCHESTER STEAM USERS' ASSOCIATION.

It is evident, therefore, that far greater losses can be incurred by bad stoking with excess of air than with too little air, and there is, therefore, no harm in aiming to attain perfect combustion, more particularly as smoke at once reminds one that the combustion is growing too imperfect. This advice does not apply to gas-fired boilers. Gas, being smokeless, would not be visible, though it travelled up the chimney unburnt. Gas firing has, therefore, always to be regulated by analyses of the waste products.—P. 9.

Perfect combustion is of far more importance, both as regards the efficiency of a boiler and the power to be got out of it, than is, within limits, either the amount of heating surface, or its arrangement.—P. 32.

C. RULES FOR SAMPLING FUEL.[1]

As each barrow load or fresh portion of fuel is taken from the pile or store heap, a count is kept of the number used, and *the whole contents of each tenth or twentieth barrow, or portion,* are placed on one side, in a cool place, under cover. Care must be taken that the barrow or portion selected for the sample, does not contain an unfair proportion of lumps or smalls.

At the end of the day, or period, for which the sampling is to be carried on, the heap of fuel obtained for sampling purposes, as described above, is transferred to a sampling plate, and the larger lumps are all crushed down to walnut size. Should no sampling plate be available, four of the iron plates used for covering man-holes and boiler-flues may be utilized to obtain a *hard clean* surface on the floor of the boiler-house, and the crushing down of the sample may be carried out on these plates, with any heavy and flat lump of iron at hand. The heap of fuel, after this first crushing, is thoroughly mixed by turning over and over with a spade. The heap is then flattened down, two lines are made across it at right angles with the edge of the spade, and two of the four opposite sections are selected to form the reduced sample.

The lumps in this are again crushed, the sample is again mixed, and the quartering operation repeated, until about 8 or 10 lbs. of fuel only remain, with no lumps that will not pass through a $\frac{1}{4}$-in. sieve. Two 1 lb. tins, with ordinary or patent lids, are filled from this remaining heap of fuel, after thoroughly mixing the same with the hands or with a small shovel. One of these tins is to be sent per parcels post to the fuel expert for analysis; the other is to be kept for reference in case of dispute.

---

[1] From Liverpool Engineering Society Paper on *Fuel Economy*, Nov. 18, 1903.

INDEX.

INDEX

Butler & Tanner, The Selwood Printing Works, Frome, and London.