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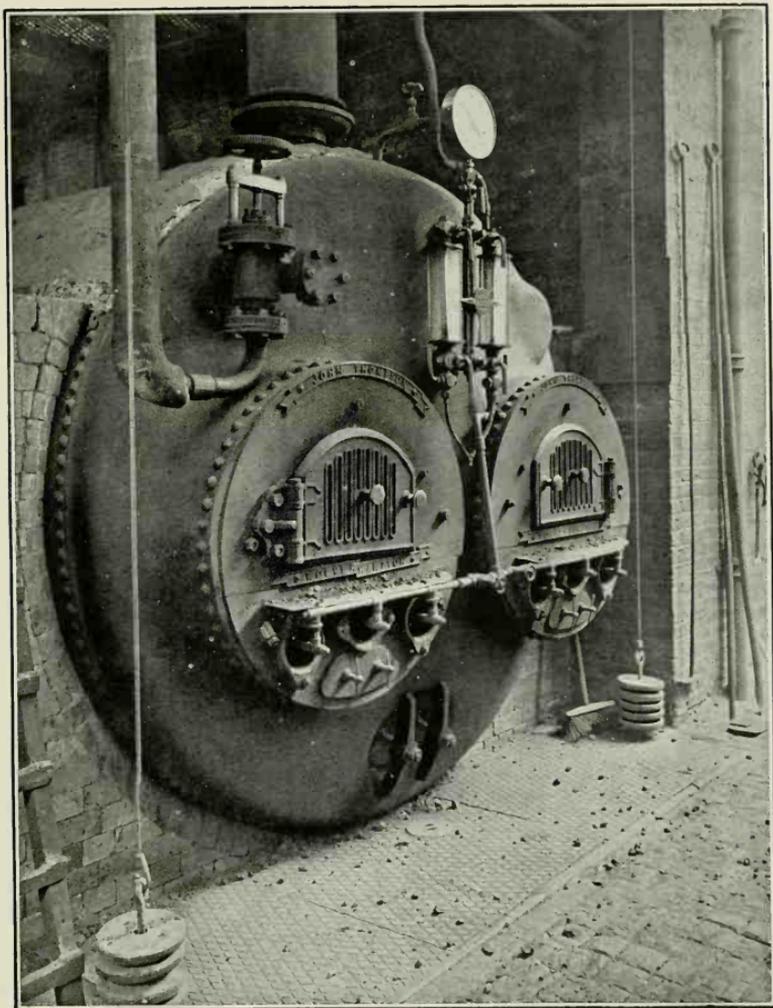


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COKE AND ITS USES

E. W. L. NICOL

COKE AND ITS USES



THOMPSON BOILER FITTED WITH LONDON COKE COMMITTEE'S
COKE-BURNING FORCED DRAUGHT APPARATUS.

PLATE I.

[Frontispiece

COKE & ITS USES:

IN RELATION TO SMOKE PREVENTION
AND FUEL ECONOMY

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PREFACE

Raw coal is at the present time the primary source of heat in almost every British manufacturing and power-supply industry, and the highest authorities are agreed that coal is likely to remain the chief source of heat and power. With a few exceptions of comparatively recent origin, existing steam boilers and furnaces, as well as mechanical stokers, have been designed upon a free-burning coal-fuel basis. Prior to 1913 the use of gas-coke as fuel for steam-raising was, in fact, practically unknown outside the Gas Industry.

In the following book, which is the outcome of many years' specialised experience in adapting coal-fired steam boilers and other heating apparatus to the use of coke, comparisons are frequently drawn between coal and coke, and the performances of coal-fired and coke-fired apparatus, as coal is naturally the standard by which alternative fuels will be judged.

In so far as possible, all statements regarding the relative efficiency and economy of coke as fuel for steam-raising are quoted from independent authorities. This fact should be noted carefully, as the purpose has been to eliminate, where possible, the element of personal prejudice.

No apology is made for attempting to treat the subject in non-technical language, as it is believed that by so doing a larger public will be served, and the dual object—to promote efficiency in fuel practice and to eliminate smoke—will be the better and sooner attained.

The use of coke as fuel for gas-producers is not included. Its use for this purpose as well as other purposes not specifically dealt with,

is well established and has no direct bearing upon the problem of mitigating the coal smoke nuisance.

As it has not been possible to refer in the text to all the sources of information which have been consulted in the course of compilation, it is desired to make full acknowledgment to the *Fuel Economy Review*, published by the Federation of British Industries, of which free use has been made, and to the editors and publishers of the *Times Engineering Supplement*, the *Manchester Guardian*, and the technical journals associated with the gas industry for permission to use extracts from articles contributed to their pages.

Finally, my best thanks are due to Mr. Thomas Goulden, M.Inst. C.E., late Chief Engineer to The Gaslight & Coke Company, for his encouragement and advice, and for his valuable help in revision. I am also indebted to Mr. Alwyne Meade, author of *Modern Gasworks Practice*, for suggesting that this book should be written, and for his helpful criticism of the manuscript.

E. W. L. N.

LONDON, October 1923.



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COKE AND ITS USES

CHAPTER I

INTRODUCTION

COKE may be described as a form of fuel obtained by heating or "carbonising" coal or other carbonaceous material in vessels from which air is excluded, whereby its volatile constituents are driven off in gaseous form. During the process of destructive distillation or carbonisation four substances are produced—gas, watery liquid (called ammoniacal liquor) and tar, while the solid residue of coke is left in the retort. This is a very old observation, and as a point in the history of applied science it is interesting to know who first submitted coal to destructive distillation.

According to one authority, it appears we must credit a German chemist, named Johann Joachim Becher, with the first recorded observation of the process in 1680, although in 1656 Evelyn described in his diary "a project, by Sir John Winter, of charring sea-coale, to burne out the sulphure and render it sweet, the resulting cinders, deprived of their sulphure and arsenic malignity, making a clear, pleasant chamber fire."

In 1681 Henry Serle, in conjunction with the German chemist Becher, was granted a British patent for "a new way of making pitch and tarre out of pit-coale, never before found out or used by any other." According to Dr. Lunge, in his work on coal-tar and ammonia, Becher wrote: "In Holland they have peat and in England pit-coals; neither is very good for burning in rooms, or for smelting. But I have found a way, not merely to burn both kinds into good coke, which not any more smokes nor stinks, but with their flame to smelt equally well as with

wood. That I have demonstrated with pit-coal at the Hague and here in England, at Windsor, on the large scale. It is also noteworthy, that, equally as the Swedes make their tarre from fir-wood, I have made from pit-coal a sort of tarre which is equal to the Swedish in every way. I have made proof of it on wood and ropes, so that even the King has seen a specimen of it, which is a great thing in England, and the coal from which the tarre has been taken out is better for use than before."

The conversion of coal into coke for use in iron smelting was first carried out on a large scale in this country, and in Germany, about the middle of the eighteenth century.

Even at that early date it is recorded of one Stauf, who carried on a coking industry in Germany, that he had the wisdom to condense the volatile product, producing oil, lampblack and sal-ammoniac.

About forty years later (1789), in his *Chemical Essays*, Bishop Wilson recorded the following observation: "Those interested in the preparation of coal would do well to remember that every 96 ounces of coal would furnish 4 ounces at least of oil, probably 6 ounces might be obtained; but if we put the product so low as 5 ounces from 100, and suppose a coak oven to work off only 100 tons of coal in a year, there would be a saving of 5 tons of oil which would yield about 4 tons of tar; the requisite alteration in the structure of the coak oven, so as to make them a kind of distilling vessel, might be made at a very trifling expense."

In 1781 the Earl of Dundonald took out a patent for making pitch, tar, oils, cinders, etc., from coal, and, down to the present time, patents in ever-increasing numbers have been granted for improved processes and apparatus designed to facilitate the carbonisation of coal, or with a view to produce a soft coke or smokeless fuel more readily adaptable to existing fireplaces.

One process which, at the time of writing, has stood the test of commercial exploitation and made steady progress is that carried on during the past 120 years at gasworks. Known as the high-temperature process of coal carbonisation, it has been reduced to an exact science by gas engineers. But long before the introduction of coal gas as an illuminant the necessity of converting coal into coke arose from the need of a

substitute for charcoal as fuel for metallurgical purposes, the timber on which the charcoal supply was dependent being at that time largely depleted.

In this connection it is recorded that the iron from which the railings of St. Paul's Cathedral were made was among the last to be smelted by means of wood charcoal in the county of Sussex.

A few of the advantages gained by carbonising coal are, briefly, as follow :

1. A fuel of higher calorific intensity is obtained, because it has lost its volatile constituents, which, although themselves possessing considerable calorific power, not only absorb heat during the process of decomposition and volatilisation, but are easily wasted. Thus, when raw coal is used as fuel, a considerable portion of the heat is necessarily used to distil or decompose it, and the net quantity of heat available for useful purposes is, therefore, diminished.

2. Valuable chemical by-products are obtained, as well as gas and fuel oils which can be burnt smokelessly and efficiently.

3. The residual coke burns without smoke.

4. It does not "run" or "cake" in the fire, thus permitting a free air supply and, consequently, more regular combustion.

5. The volatile sulphur is driven off during carbonisation at high temperature and recovered as a by-product, thus largely eliminating an objectionable element always present in raw coal.

6. The resulting coke requires only the minimum excess of air (30 to 50 per cent.) to effect its complete combustion, whereas, in ordinary practice, bituminous coal is unavoidably allowed a quantity greatly in excess (100 to 200 per cent.) of that theoretically necessary.

From the industrial user's point of view, this latter advantage is by far the most important, as it tends directly, and very materially, to improve the efficiency of steam raising and other heating operations. The proportion of volatile matter contained in a solid fuel is in fact a measure of the difficulty of burning it efficiently without the formation of smoke and consequent waste. Bituminous coal contains as much as 35 per cent. volatile matter, including 3 to 5 per cent. hydrogen; gas

coke contains only 1 to 3 per cent. volatile matter, and only a trace of hydrogen.

Where metallurgical coke is the primary product, the process of carbonising coal is conducted in so-called "Beehive" ovens, and in coke ovens. At gasworks coal is carbonised in various types of retorts, gas being the primary product, and coke the most important secondary product.

Field's *Analysis* of the accounts of the principal British gas undertakings (which unfortunately does not give the calorific power of the coal used) gives the average gas, coke and tar produced per ton of coal carbonised by one of the Metropolitan Gas Companies for the year 1922, as follows: 13,406 cubic feet of 495 B.Th.U. gas; 11.36 cwt. of coke available for sale; 9.8 gallons of tar. A rough and ready, but reliable, comparison between this and the average method of utilising the country's coal resources for steam production, from the thermal efficiency point of view, is therefore possible.

Taken together, the coke and tar, on the above basis, would evaporate in a steam boiler, approximately, 13,400 lb. of water from and at 212° Fahr., without the formation or emission of visible smoke.

The average evaporation obtained in many industrial coal-fired steam plants is as low as 4.5 lb. per lb. of coal; in others it is more than double this quantity. Assuming an average evaporation of 6 lb., the weight of water evaporated per ton of coal would be 13,440 lb.; so that, in addition to the ammoniacal liquor (about 30 gallons) recovered in the process of carbonisation, the gas evolved, at least to a very large extent, may be regarded as a net gain to the nation, as compared with the wasteful method of burning coal directly as fuel by ordinary means which, almost inevitably, causes the formation and emission of smoke.

Considered from another view-point, the commercial value of a ton of coal, treated at the gasworks, may be said to be enhanced threefold, largely by the expenditure of labour; while the by-products recovered are necessary to the maintenance and development of British agriculture and industry.

CHAPTER II

VARIOUS PROCESSES OF COAL CARBONISATION

COKE is a generic term applied generally to all descriptions of coke, *e.g.* metallurgical or by-product coke, foundry coke and blast furnace coke, and gas coke, just as the term "coal" is used to indicate fuels of such widely different composition and characteristics as anthracite, or anthracitic coal, and all the various kinds of bituminous, coking and non-coking coals. Coke is made not only from coal, but also from peat, petroleum and pitch; but while it is solely with gas coke that we are at present concerned (the other kinds of coke mentioned not being available as a substitute for coal), a brief description of the various processes of coal carbonisation may help the reader to distinguish between the different kinds of coke and the particular uses for which they are specially designed and produced.

Coke has been described as a form of fuel obtained by heating or "carbonising" coal or other carbonaceous material, in closed retorts, whereby its more volatile constituents are driven off in gaseous form. It contains, as its chief constituent, fixed carbon, together with the mineral matter or ash of the original coal. Coking or caking coal—that which on heating becomes semi-fluid—is the most suitable for the manufacture of coke. Used alone, non-coking coal produces, ordinarily, a powdery coke or "breeze," but coal of this description is now largely used "blended" in various proportions with coking coal, the resultant coke being in every respect quite satisfactory as regards purity, strength and density—important factors in metallurgical coke. Even anthracitic coal has in this way been incorporated in the coke mass. Anthracite has little value from the gas-making view-point; but, blended with coking coal, waste anthracite or anthracitic coal might also be utilised to augment the output of coke.



BEEHIVE COKE

A method of carbonising coal—now little practised—was originally carried on by a process similar to that employed in making charcoal from wood. The coal was stacked around one or more wide-open brick chimneys, and covered with slack, and, finally, with wet coke-dust or breeze, except at certain air-holes. The mound thus formed was then ignited from above and gradually burnt downwards, giving off ammoniacal liquor and combustible gas and tar, which were allowed to escape unburnt, or only partially burnt—truly a ghastly waste of valuable products. The “burning” process concluded, all air-holes were covered over to exclude air and arrest combustion, the cooling of the mass being hastened by quenching with water.

The “Beehive” coke oven was probably a direct development of this primitive system. Erected in batteries of four or more ovens, the horizontal section of the Beehive oven is square, and the vertical section is dome-topped and similar to that of a bee-skep. The oven, being first heated by means of a coal fire, is charged through the doorway at the side. This doorway, and also an opening at the top, are kept open to allow the escape of the dense volumes of smoke evolved by the partial combustion and distillation of the coal. As soon as the emission of smoke ceases, these openings are closed and the oven is allowed to cool down. After a period of twelve to fifteen hours, or longer, according to circumstances, the coke is extracted and finally quenched. A more recent development of the Beehive coke oven permits of the recovery of by-products. Beehive coke, which was long considered to be the best, and, in fact, the only coke suitable for certain metallurgical processes, is distinguished by its characteristic grey or silvery appearance, a result of its being cooled away from contact with air. Although still extensively produced in the United States, it is now largely, if not entirely superseded in this country by coke made in coke ovens, the chief characteristic of which is extreme hardness. This feature is necessary in order to enable it to support, without crushing, the weight of the charge of metal in the blast furnace or cupola.

OVEN COKE

The principle of making coke in modern coke ovens is the same, but the process is much quicker and more economical, while the resulting coke is now considered better than, or at least equal in quality to Beehive coke. The coal is first crushed to a fairly uniform size. It is then washed, in order to eliminate impurities, and pressed into rectangular moulds containing several tons. The cake thus formed is pushed into the heated oven and carbonised at a high temperature—about 2000° Fahr.—for a period of from fifteen to twenty-four hours. In a modern coking plant, the gas evolved from the coal is used partly for heating adjacent ovens, any surplus being “stripped” for benzol, and either used as fuel for steam raising, or sold to gas-supply undertakings. In many instances, however, surplus gas is unavoidably allowed to flow to waste. While the primary product is metallurgical coke, the by-products recovered, in addition to benzol, include sulphate of ammonia, tar oils and other gas-tar products and pitch.

The weight of the charge in each oven, together with the preliminary compression, the high temperature and long period of “burning,” combine to produce in oven coke that characteristic hardness which renders it eminently suitable for metallurgical purposes, but less suitable for other purposes which necessitate a relatively free-burning fuel.

Metallurgical coke must be as free as possible from any impurities which might have an injurious effect upon the metals in the production of which it is used. Of these impurities the most objectionable are the sulphur and phosphorus usually present in the coal in the form of “brasses” or pyrites. It is for the elimination of these impurities that the preliminary crushing and washing processes are primarily designed. Being usually made from unwashed coal, gas coke is, therefore, unsuitable for use either as a heating or as a reducing agent in cupola or blast furnace operations. These two operations require coke not only free from impurities, but of different degrees of porosity, known respectively as “foundry” and “furnace” coke, and in each case of sufficient strength to withstand the attrition taking place in the furnace.

By whatever process it is produced, coke varies considerably not only in its chemical and physical characteristics, but also in external appearance ; but it may generally be accepted that, with the same kind of coal, the higher the temperature and the longer the period of carbonisation, the harder and less easily combustible it will be.

Hard oven coke, suitably graded, is, however, extensively used in the United States as fuel for closed heating and cooking stoves. The large scale on which coking operations are carried on in that country may be realised by the fact that, at one group of coking plants, some 13,000 tons of coal are carbonised per twenty-four hours.

LOW-TEMPERATURE COKE

A modification of the coke-oven process, designed with a view to produce a semi-coke or smokeless solid fuel, and, at the same time, an increased quantity of liquid fuel or other products, the low-temperature process ¹ of coal carbonisation, has for some time been carried on experimentally on a relatively small scale. This process, however, has, so far, failed to satisfy commercial requirements. The temperature maintained during the relatively short period of carbonisation is of the order of 1000° Fahr. ; and instead of being reduced to 1 or 2 per cent., as in oven or gas coke, the volatile content of low-temperature coke is not less than 10 to 12 per cent. It is obvious, therefore, that for a given output of gas, the quantity of coal carbonised by this process would have to be greatly increased, while the output of gas per retort would necessarily be reduced. The low-temperature process has not hitherto found favour with gas-supply authorities as an economic method of producing gas.

GAS COKE

While oven coke is a primary product, and its quality is the first consideration, gas coke is considered a secondary product ; and any attempt to improve its adaptability to special purposes is necessarily

¹ For further particulars of this process the reader is referred to *Low-Temperature Carbonisation*, by Dr. C. H. Lander, Government Director of Fuel Research.

subservient in importance to the production of gas. As carried on at gasworks, the process of coal carbonisation is in fact designed to produce the maximum number of potential "therms" in gaseous form. With this end in view, the coal is charged into retorts and heated, or carbonised, at a temperature of about 2200° Fahr. for a period of eight to twelve hours, after which there remains in the retort a quantity of coke equal to about 70 per cent. of the original weight of the coal.

The proportion of coke to coal may, however, be substantially reduced by "steaming" the incandescent coke before its removal from the retort.

VERTICAL COKE

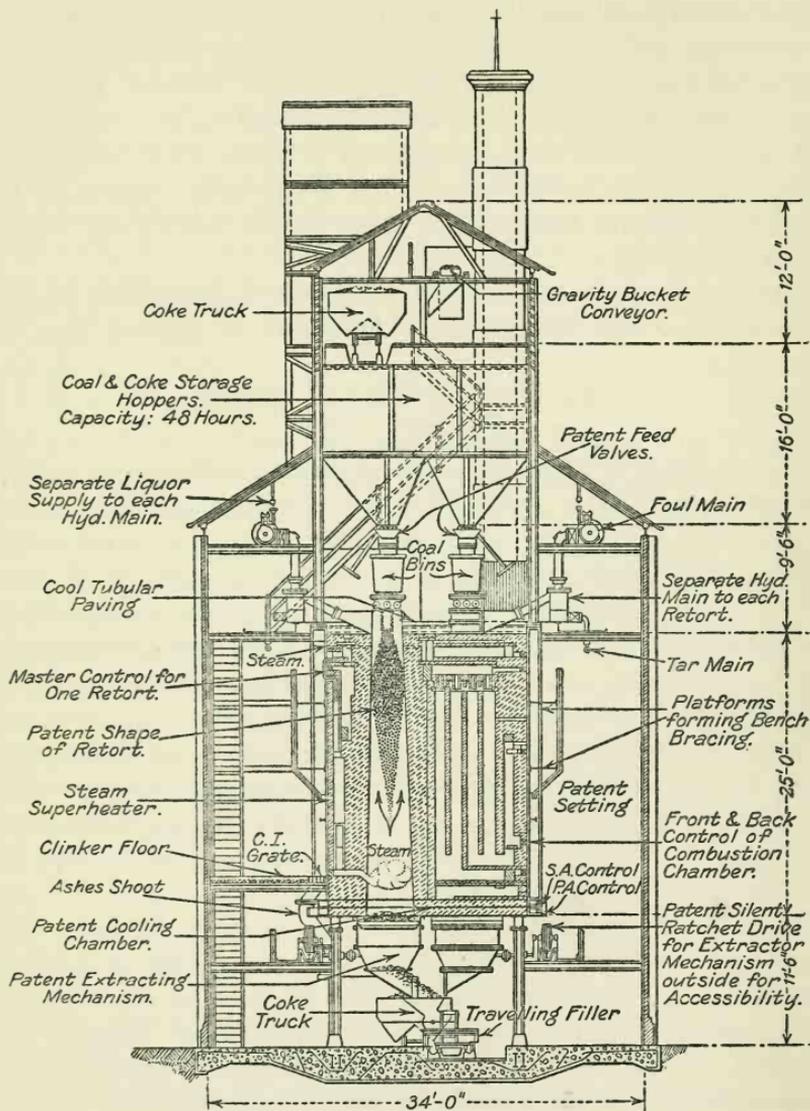
Various types of retorts are used—horizontal, inclined, and vertical. The last-named type is designed for either intermittent or continuous operation, and receives the coal at the upper end from overhead storage bunkers. The retort is heated to a working temperature of about 2200° Fahr. through a system of external flues, by means of gas produced in a coke-fired gas-producer. The coal, as it gravitates through the retort, is carbonised, and the coke thus formed is gradually cooled as it descends towards the lower or outlet end of the retort.

Being tapered internally, this type of retort allows the coal to swell during the process of carbonisation, thus producing coke which, usually, is comparatively light and porous; and, moreover, it possesses the advantage of producing practically cold coke, thus eliminating the necessity of quenching with water.

The physical structure of vertical coke depends, however, very largely upon the characteristics of the coal from which it is made. Durham coal has been considered by some engineers as unsuitable for use in vertical retorts owing to the fact that it tends to "hang up" in the retort. Other coals produce coke of extremely low density which, owing to its bulk, is not suitable for use in apparatus, such as small hot-water boilers, having restricted fuel capacity.

Blends of Durham (up to 40 per cent.) and other gas coals have,

COKE AND ITS USES



Cross Section through Retort House.
(Looking towards Hoist.)

FIG. 1.—VERTICAL GAS RETORT. GENERAL ARRANGEMENT.
(Dempster & Sons Ltd.).

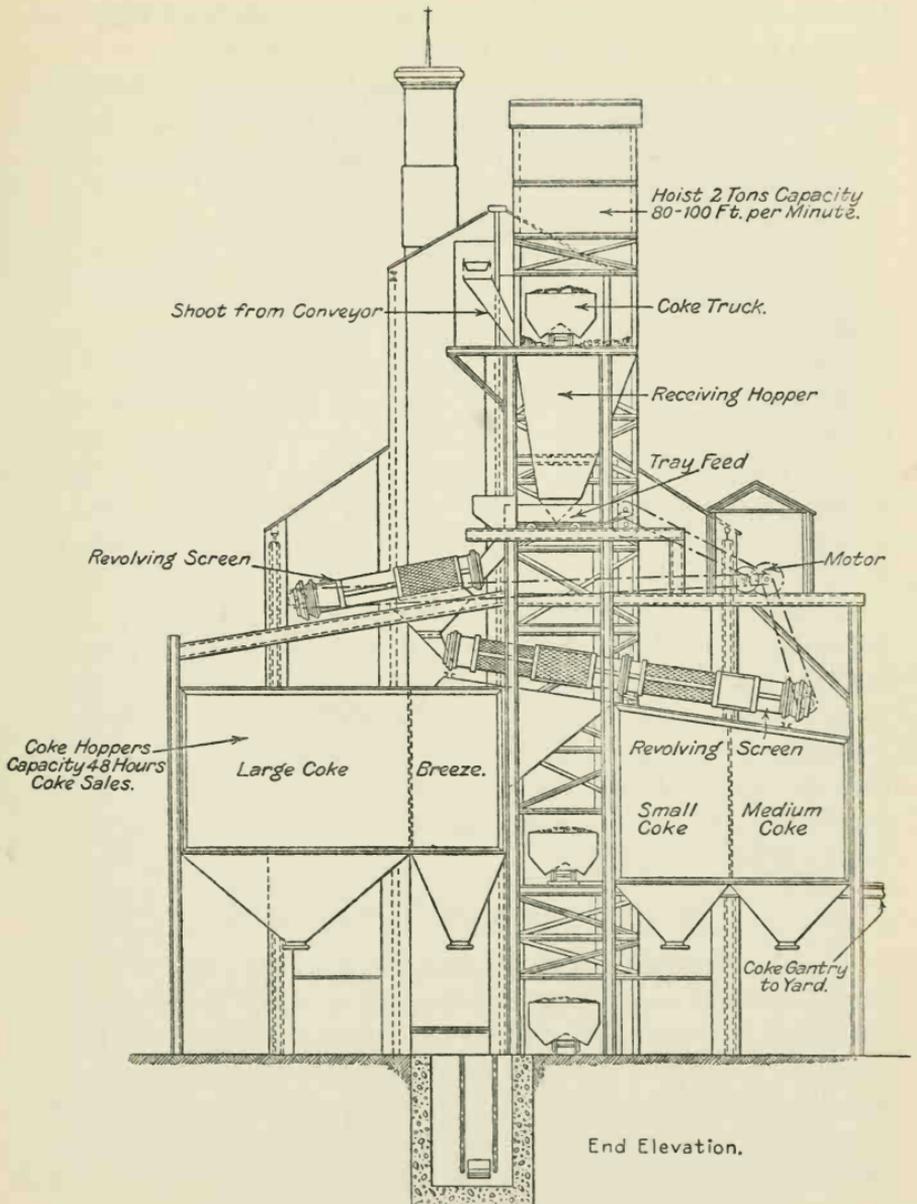


FIG. 2.—VERTICAL GAS RETORT. COKE SCREENING AND GRADING PLANT.
(Dempster & Sons Ltd.).

however, proved to be satisfactory, and the coke produced from such blends is scarcely distinguishable from horizontal retort coke.

Although the vertical gas retort has been adopted extensively, inclined and horizontal retorts, working at about the same temperature, still hold their own in the favour of both large and small gas-supply undertakings.

HORIZONTAL COKE

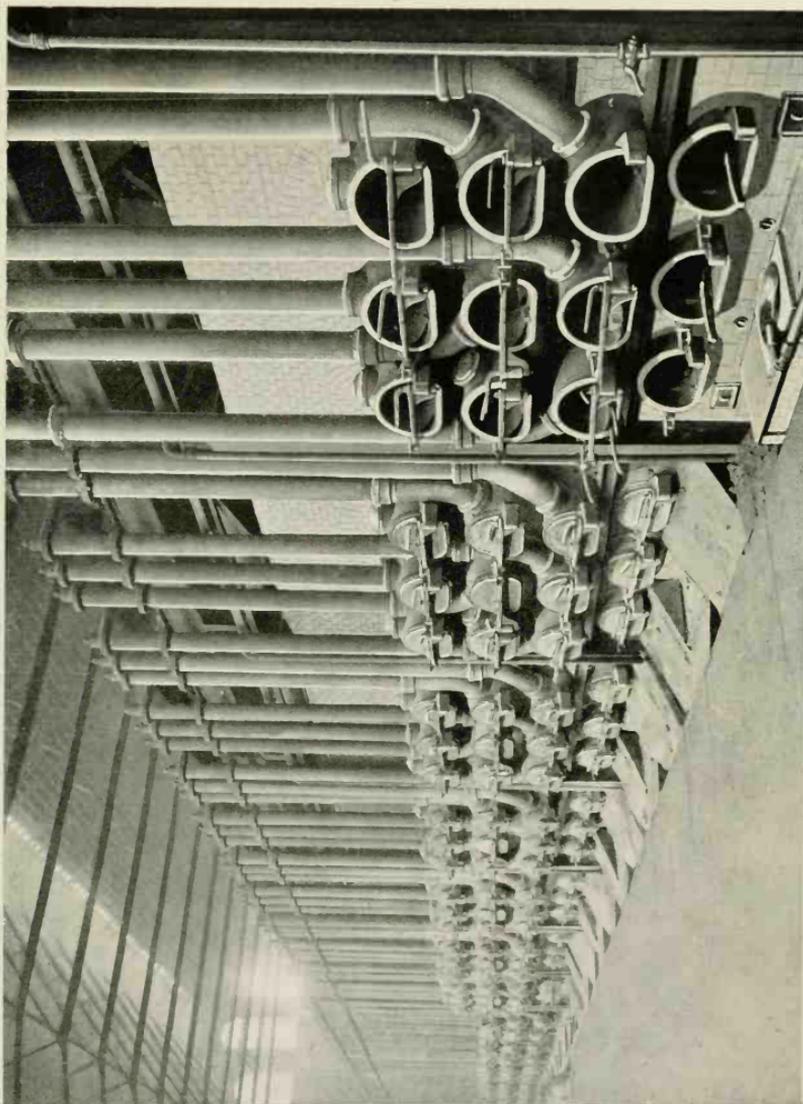
Originally charged by hand, up-to-date horizontal retorts are now automatically discharged and recharged in one operation by mechanical means, the average weight of coal per charge being about 12 to 15 cwt.

Although improved methods are constantly being tried and adopted, the system in use in many horizontal retort houses allows the incandescent coke to fall from the mouth of the retorts on to a moving conveyer, working in a shallow channel in the floor, passing under automatic sprayers. The coke is thus quenched and rendered safe to handle and store without risk of fire.

Compared with "vertical" coke made from certain descriptions of coal, horizontal coke is relatively hard and dense in physical structure. Its chemical composition is practically identical, and although vertical coke is sometimes preferred for use in certain types of open fire-grates, horizontal coke, of good average quality and suitably graded, leaves little to be desired for either domestic or ordinary industrial heating purposes, when used in modern heating appliances designed on rational lines.

COKE AS FUEL FOR OPEN GRATES

In this connection it may in passing be said that owing to the difficulty sometimes experienced in attempting to use it in ordinary open fire-grates, horizontal gas coke has been rejected as unsuitable for this purpose. Experience proves, however, that the fault lies not altogether with the coke, either in its chemical or physical characteristics, but to a very large extent with the fire-grate; and failure fully to consider or to appreciate this view has led to great expenditure of both capital



HORIZONTAL GAS RETORTS,
(Dempster & Sons Ltd., Elland.)

PLATE 2.

and energy in an effort to produce a semi-coke that will ignite and burn readily in existing fire-grates of more or less antiquated pattern, the great majority of which have not had common-sense principles applied either in their design or construction. The inefficiency and extravagance of the ordinary coal-burning fire-grate is proverbial, and has led to the production of grates primarily designed to retard the combustion of coal. This tendency in grate design has naturally militated against the use of coke as fuel. Although some of the modern open grates, by accident rather than design, happen to be more or less suitable for use with coke, there are, so far, only two or three types of grates which primarily have been designed for the exclusive use of ordinary gas coke.

A detailed description of one of these grates and the principles which are embodied in its design, are given in a later chapter.

QUALITY OF COKE

With the extended use of gas coke for both industrial and domestic purposes, the question of improving and maintaining its quality has attracted a great deal of attention. The importance of securing a low ash content in the coal used at gasworks is fully recognised as the obvious means to this end. Apart from the adverse effect of high ash content upon the quantity and quality of the gas produced per ton of coal carbonised, and gas output per retort, the effect of a high ash content in the resultant coke is often detrimental to the satisfactory operation of heating apparatus in which it is used as fuel.

Ash occupies space in furnaces, and, in closed stoves and boilers, where the draught is more concentrated, and the temperature of combustion higher than in open fires, the ash is unavoidably fused, thus forming clinker.

The formation of clinker generally increases fuel costs to a greater degree than is reflected by the percentage of ash, as considerable loss of heat and cinders, entrapped in the molten mass, is entailed in its removal from the furnace, and in raising the furnace to the working temperature again after cleaning.

The bad effect of excessive moisture in coke is now recognised ; and the matter of quenching, with a view to minimise the moisture content, has, at several important gasworks, been satisfactorily dealt with, the average moisture content being maintained at the lowest possible point consistent with safety.

By reason of its high ash content, coke made from impure coal has an abnormal affinity for moisture, which, of course, can only be evaporated at the expense of fuel.

These and other considerations, including the cost of freighting of impure raw material over long distances, have already brought about greater care in the selection of gas-making coal ; and with the recent advent of the thermal basis of sale for coke as well as for gas, it may be expected that eventually merely selective methods of coal purchase will give way to purchase on a calorific power or ash-content basis, which will tend further to improve and maintain the quality of gas coke, and raise its status from a mere by-product to that of a first-class anti-waste fuel.

Such methods of coal purchase at the pit-heads have already been organised by several of the leading gas-supply authorities, and the results are reflected not only in the production of gas per ton of coal carbonised but also in the commercial value of the coke produced.

It must, however, be borne in mind that in practice it may not always be economical or possible to use the most suitable coal, as commercial considerations may demand the use of a particular variety which can be cheaply obtained ; and it may be, and frequently is, more economical to use less efficient coal at a lower cost. Whether this is so will largely depend upon circumstances, but in the case of gas and coke manufacture it is always possible the cheaper coal may in fact prove to be the dearer.

Of the 18 to 20 million tons of coal carbonised annually at gasworks, one-half is resold as coke, containing double the potential thermal value of the gas produced in the process of carbonisation ; and apart from the adverse effect of excess inert matter upon the quantity and the quality of the gas and other products of carbonisation, its effect upon the thermal and commercial value of the resultant coke, in which it is

necessarily concentrated, is probably one of the most serious aspects of unclean gas coal.

In addition to diminished thermal value, relatively soft and friable coke produced from such coal has an inordinate affinity for moisture, absorbing and retaining, as it does, an undue amount of water used in quenching, thus further detracting from the fuel value of the coke to the user, and, consequently, its commercial value as compared with other solid fuels. Having regard to the great importance of its bearing upon the price charged for gas, no effort should be spared that will tend to improve and maintain the quality, and consequently the revenue, derived from coke. To a large extent, surplus moisture is within the control of the gasworks staff, but control of the mineral impurities in gas coal is largely a matter of selection and treatment at the pits.

With a view to economise in the use of coking coal, it is often found profitable to use a mixture of coking and non-coking coals for carbonising purposes; thus coal of a high coke yield, but inferior caking power, may advantageously be blended with a coal of low coke yield but good caking power. Such blends produce a satisfactory coke of good quality.

Various theories have been advanced to explain the difference between coking and non-coking coals, but it cannot be said that the matter is yet properly understood. No simple relation exists between coking power and chemical composition; but it has been shown that coals either very rich or very poor in hydrogen and oxygen, do not melt or cake.

The caking power of coal is in some cases nearly lost after exposure, owing to the rapid weathering of the coal. With an increase in ash content, the caking power diminishes, and good coke may not be produced if much inert matter is present in the coal. In such cases it is possible to obtain good coke by previous treatment of the coal whereby the ash content is reduced by 20 to 60 per cent. and the sulphur by 10 to 50 per cent.

Coal so treated, by means of modern washing plant, should not contain more than 6 to 7 per cent. of free moisture and not more than 6 per cent. of ash.

A typical proximate analysis of ordinary unwashed gas coal of average quality would be as follows :

Moisture	1.35 per cent.
Ash	8.21 „
Volatile hydrocarbons	27.19 „
Fixed carbon	61.59 „
Sulphur	1.66 „

It has recently been pointed out by certain colliery owners that, in the event of coal being purchased upon a strictly limited ash-content basis, they would be forced either to close down or to instal washing plant in order to enable them to comply with the requirements of users. The latter course has already been extensively adopted by discerning colliery owners, and experience shows that the improvement in value of the coal so treated justifies the cost of washing.

The average ash content of good quality gas coal should be of the order of 6 per cent., and this proportion, it has been suggested, should be the limit that should be accepted.

The ash content of coke resulting from the carbonisation of such coal at ordinary high temperatures would approximate to 8 or 9 per cent. The following are proximate and ultimate analyses of average good quality gas coke made from Durham coal :

PROXIMATE ANALYSIS.	ULTIMATE ANALYSIS.
Fixed carbon 85 per cent.	Carbon 88 per cent.
Volatile matter 1.5 „	Hydrogen 0.5 „
Moisture 5 „	Oxygen a trace.
Ash 8.5 „	Nitrogen 2.0 per cent.
	Sulphur 1.5 „
	Ash 8.0 „

Properly graded to suit the apparatus for which it is intended, gas coke of this description has proved eminently suitable for all domestic as well as most industrial heating purposes.

Produced as a secondary product by the ordinary gasworks process, it can be sold at a price considerably less than that of good quality coal,

which it in fact excels in efficiency and economy by reason of its greater radiant effect, freedom from hydrogen, and its absolutely smokeless characteristic.

Considerable experience with coke produced by modified processes, designed primarily with a view to facilitate its ignition in domestic grates, has forced the author to the conclusion that to modify in any particular the well-known physical characteristics of gas coke would not only impair its efficiency, but also seriously limit its all-round usefulness as fuel.

At the time of writing, the gas industry has only recently emerged from a period of several years during which gas supply authorities were forced to accept such coal as the colliery owners and the Coal Control Department of the Government thought fit to send them. There has also been the "fork *versus* shovel" controversy at the pits, the miners insisting on loading "tubs" by means of shovels instead of forks, thus incorporating with the coal much of the pit refuse, which inevitably reappeared in the coke. The combination of these baneful influences has led to much obloquy and many derogatory statements regarding the quality and utility of coke; but, these difficulties notwithstanding, coke has during the past decade made great headway in displacing coal as fuel for many industrial purposes.

The educational propaganda conducted by the London Coke Committee, and the consideration and energy directed by gas authorities towards improvement in the quality and grading of coke, have already endowed it with an immensely wider sphere of usefulness. Its record is already one of magnificent public service in the allied causes of smoke prevention and efficiency in fuel practice, as well as in the larger question of coal conservation. Comparatively recent public experience with coke as fuel in almost every industry, and for every domestic heating purpose, already affords a stable foundation for the immediate development of this important branch of the gas industry. Indeed, the gratifying, but only natural result of the London Coke Committee's propaganda, combined with the good service provided by individual gas companies, is that the local public demand for coke threatens to exceed the

corresponding output of gas, a position which, if allowed to exist, would tend to encourage the undesirable competition of imported fuels and other heating agents in the manufacture and use of which the tendency is to dissipate rather than to conserve the country's resources. Gas coke is the most important manufactured solid fuel which we possess. Having regard to its general utility and economy for both domestic and industrial purposes, its wide distribution and availability, the importance of gas coke as a fuel is second only to that of coal.

CHAPTER III

COKE LORE

THE scepticism and misapprehension shown by many contemporary engineers at the suggestion that coke should be used as fuel for large boilers tends to prove how little known its use for this purpose was less than ten years ago, and how thoroughly forgotten were its inherent advantages, which well-known engineers of the last century recognised and recorded.

To this day the author is frequently confronted with the statement that "coke will shorten the life of the boilers," and several stokers have been known seriously to object to handle coke owing to some supposed detrimental effect upon the respiratory organs.

Prejudice and scepticism displayed by potential domestic users of coke are no less emphatic and deep rooted. During the acute coal famine which prevailed in many districts as a result of the great coal dispute of 1921, the author has a clear recollection of a trolley-man vainly attempting to hawk coke to the fireless residents of a working-class suburb of a northern town. It was whispered, and evidently believed, that coke was a virulent cause of pneumonia!

Many, too, still believe that the combustion of coke is improved by the addition of water, a view that is certainly not endorsed by large steam users. Complaints, however, are still traceable to this practice; and a case in point will serve to illustrate one detrimental effect of added moisture. A greenhouse boiler with a metal chimney was giving trouble, and, according to the user, the coke supplied was practically incombustible. Investigation showed that moisture, deliberately added "to make it burn," was being evaporated in the fire-box. The vapour thus formed was condensed in the metal chimney and automatically returned to the fire-box, a sort of vicious circle well calculated to cause annoyance.

Another common statement, derogatory to coke, is that it is "full of sulphur," while those possessed of some technical knowledge will maintain that its calorific power is low as a result of "taking too much out of it." Indeed, a prominent coal-owner, whose name as a coal and coke merchant is well known at many railway depots, has circularised his customers advocating the use of coal, and, strangely enough, describing coke as "half-burnt coal."

During a long experience in advocating the use of coke as fuel, the author has frequently encountered these specious statements, and has dealt with them, singly and in pairs, as they have been made. The present opportunity to deal with these popular fallacies in a wholesale manner is not to be missed.

Taken in the above order, they may be disposed of as follows :

Coke is now used successfully and profitably by many of the most important steam users as fuel for both mechanically stoked and hand-fired boilers of the largest capacities. The advantages and relatively high efficiency of coke are referred to in some of the older text-books on Steam and the Steam Engine, and for many years coke exclusively was regarded as the staple fuel for railway locomotives. In this latter connection it is related how the fire-bars used to be chalked in order to mitigate the effects of overheating, due to insufficient draught, and how the cylinders used to be lubricated with axle-box grease, introduced through the exhaust pipe in the funnel, to counteract the effects of the dry steam generated. In one text-book, it is recorded that Mr. Dewrance, when Engineer to the Liverpool and Manchester Railway (about 1850), invented a locomotive boiler by means of which, it is said, "he was enabled to use coal instead of coke"—truly a retrograde step which, unfortunately, has almost universally been copied.

That coke, in common with most fuels—solid, liquid and gaseous—contains sulphur cannot be denied. Coal and fuel oil, for instance, contain as much as 2 to 3 per cent., or more, sulphur, which, almost invariably, is half volatile and half "fixed." Carbonised in gas-retorts at the usual temperature (2200° Fahr.), the volatile sulphur in coal is almost entirely driven off, leaving only the fixed sulphur in the coke.

Coke contains, therefore, certainly not more sulphur than coal; but being deprived of its tarry matter, there is in coke nothing to disguise the unpleasant odour of heated sulphur. Sulphur is therefore more in evidence than smoke when coke is burnt under improper conditions, which allow the escape of combustion products in directions other than the flues and chimney.

Volatile sulphur is, primarily, the destructive element in coal, so far as the corrosion of boiler plates is concerned. That coke is no more destructive than coal is proved by the comparatively long life of coke-fired steam boilers, of which a few illuminating instances may be given. Boilers of forty years' service, still working at their original, and even increased pressures, are common at gasworks. A Cornish boiler, after fifty years' service on coke exclusively has, at one gasworks, been reset for a further period of useful work. It is insured at its original working pressure, proving that its condition has satisfied the Boiler Insurance Company's inspector.

As regards water-tube boilers, which probably are in this respect the most sensitive and easily damaged, it was given in evidence before the Coal Smoke Abatement Committee that a Babcock and Wilcox boiler, hand-fired on coke fuel exclusively, had not had a single tube renewed in twenty years' service, whereas, using Yorkshire coal slack on similar boilers, it has frequently been the author's experience to renew several damaged tubes per week. If, in fact, coke had a harmful effect upon boilers it would have been found out long ago.

For similar reasons, coke is less destructive of the grates and fire-bars of steam boilers.

The supposed baneful effect of coke-firing upon the respiratory organs can best be disposed of by reminding readers that at gasworks and coke ovens, iron foundries and blast furnaces, which are certainly not regarded as unhealthy occupations, the workmen are constantly engaged in handling coke without any bad effects whatever.

One result of wetting coke before use is the removal, to some extent, of the fine coating of moist ash or breeze which sometimes adheres to it, and which causes the characteristic crackling sound when fired. This

may conceivably have given rise to the belief that by wetting coke it burned brighter ; but it must be borne in mind that, inevitably, added moisture must be evaporated, at the expense of fuel, before ignition and combustion can ensue.

The best reply to the allegation that " too much is taken out of it " is to indicate, as detailed in later chapters, the results obtained with coke in actual practice, compared with those obtained in similar circumstances with coal of equal or greater calorific power. In this regard, it cannot too often be repeated that coke successfully competes with and supersedes coal, entirely on its merits, as the more economical fuel. It is used in lieu of coal by discriminating steam users and others, not merely for sentimental reasons, but because it pays to do so.

More subtle and important are statements such as those emanating from a learned professor and published in a responsible journal dealing with matters pertaining to fuel economy and smoke abatement, which tend to convey an erroneous impression as to the noxious character and quantity of the combustion products of coke, as compared with those of coal :

" Coke contains in each 100 lb. 90 of carbon, $\frac{1}{2}$ of hydrogen, $1\frac{1}{2}$ of nitrogen, $1\frac{1}{2}$ of sulphur, and $5\frac{3}{4}$ of ash. . . . It should be remembered that the combustion of this fuel pours into the air considerably greater volumes of the negative poisons, sulphuric acid and carbonic oxide gases, than those given off by an equal weight of coal . . . hence between coal and coke it is a question of balancing the disadvantages of coal, which emits perhaps $\frac{1}{2}$ of 1 per cent. of its weight as visible smoke, against the disadvantages of coke, which emits, say, 25 per cent. more sulphurous acid gas than coal."

The immediate and most pressing aspect of the smoke problem is the elimination of the visible products of combustion. The emission of relatively minute quantities of other, and admittedly noxious, products is unavoidable, if industry is to be carried on by the combustion of fuel, whether solid, liquid or gaseous ; but in this connection it cannot too often be pointed out that the process of coke manufacture is carried on at a temperature of about 2000° Fahr., which has the effect of driving

off the volatile sulphur contained in coal. The sulphur contained in a ton of coke is, therefore, certainly not more, but probably less than that contained in a ton of coal. It is, moreover, of the fixed variety, difficult to volatilise, and, as a rule, is largely rejected in the ash and clinker, whereas the sulphur contained in raw coal is present, in about equal proportions, as fixed and volatile sulphur.

The professor points out, in the article referred to, that the flame from a coke fire is free from particles of carbon and tarry vapour. Deprived of these visible constituents, it is not surprising that in the combustion products of coke, sulphurous gases are more in evidence than in those of coal; but it certainly does not follow that they are in any way more noxious or deleterious. This is abundantly proved, as already shown, by the long useful life of coke-fired boiler tubes as compared with those of boilers fired with, say, South Yorkshire coal slack or other coal high in sulphur content.

For the year 1913 the total output of coal in the United Kingdom was approximately 287,000,000 tons, about 1,000,000 tons being exported. The following table accounts for the remainder:

	Tons.
1. Railways	15,000,000
2. Coasting steamers	2,500,000
3. Factories	60,000,000
4. Mines	20,500,000
5. Iron and steel industries	31,000,000
6. Other metals and minerals	1,250,000
7. Brickworks, potteries, glass works, chemical works	5,750,000
8. Gasworks	18,000,000
9. Domestic	35,000,000
	<hr/>
	189,000,000
	<hr/> <hr/>

The very large proportion of our total annual coal output used for the purpose of steam raising will be seen from the above estimate, made by the Coal Conservation Committee in 1918.

British railway locomotives alone devour raw coal at the rate of 15,000,000 tons per annum. This fact is deplored by the poet Dobell in the following delightful verses, which serve to remind us of the dwindling of our irreplaceable coal resources, and the urgent need for economising in its use :

“ Who comes, who comes o’er mountains laid,
 Vales lifted, straightened ways ?
 ’Tis he ! the mightier horse we made
 To serve our nobler days !

But now, unheard, I saw afar
 His cloud of windy mane
 Now, level as a blazing star,
 He thunders through the plain !

The life he needs, the food he loves,
 This cold earth bears no more ;
 He foddors on the eternal groves
 That heard the dragon’s roar.

Disdainful, from his fiery jaws
 He snorts his vital heat,
 And, easy as his shadow, draws,
 Long drawn, the living street.”

Although in terms of coal consumption per train mile the express railway locomotive is remarkably economical, it evidently does not require the trained eye of an engineer to discern its rapacious appetite for the “ food he loves,” in its raw state, or its want of economy in “ vital heat.”

Reversion to the old practice of carbonising coal for use in railway locomotives may possibly be foreshadowed by the recent installation by the Great Western Railway Company at Swindon, of a modern Dempster-Toogood vertical coal carbonising plant, to carbonise 240 tons of coal and yield 3,000,000 cubic feet of gas and 170 tons of coke per day, with provision for extension to double this quantity.

Of the 18,000,000 tons of coal used annually in the metropolis, only 4,000,000 tons are as yet treated at gasworks, producing about 2,000,000 tons of coke. As an example of what has been accomplished in organised

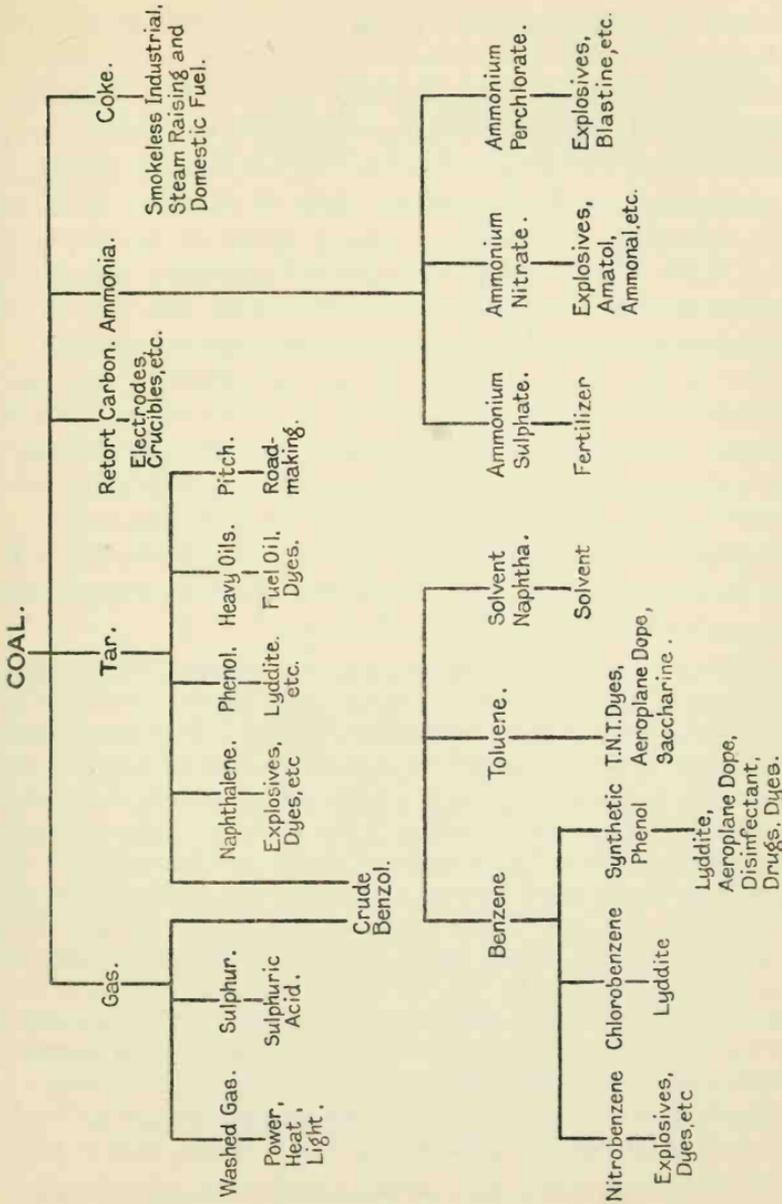


FIG. 3.—PRODUCTS OF THE GAS INDUSTRY AND THEIR INDUSTRIAL AND WAR TIME USES.

fuel manufacture and distribution in the metropolis, the following facts are interesting :

The largest gas undertaking, The Gas Light & Coke Company (in addition to 11 to 12 million gallons of gas oil used in the process of oil gas manufacture), carbonises about 2,000,000 tons of coal per annum, and finds employment for 15,000 workmen, most of whom are co-partners holding collectively half-a-million pounds worth of the Company's ordinary stock. The Company serves 900,000 consumers, who, through the operation of the "sliding scale," benefit equally with the workmen and proprietors in economies effected in working and management.

A few of the direct products of coal carbonisation, essential to the industrial development of the country as well as for the defence of the Empire, are indicated by the diagram on previous page, which serves also to indicate the scope and importance of the gas industry and its incidence upon the economic and industrial life of the community.

Referring to certain municipal gas authorities in *The Smokeless City*,¹ Mr. E. D. Simon, M.I.C.E., joint author, and late Lord Mayor of Manchester, makes the following important point :

"Progress in smokeless heating means, in practice, increasing the use of gas and coke, and decreasing correspondingly the use of raw coal. It is clearly the duty of the Government and municipalities to encourage this movement by all means in their power. And yet we may find many municipalities actively hindering it by deliberately putting a tax on the use of gas, while leaving the burning of raw coal free. This is not done openly in the form of an honest tax, so that the gas user may know what is happening, but is called a profit on the gas undertaking. But what does it mean ? The undertaking must of course pay interest and sinking fund on the capital invested, and should accumulate any reserve fund that may be necessary. Any profit beyond that goes in relief of rates, and is nothing but a direct tax on the use of gas. Now a tax on coal would be bad enough ; fuel is an absolute necessity, and everybody agrees that such a tax falls unduly on the poor, and is in every way a bad tax. But if fuel is to be taxed at all, why tax gas (often by as much as 10 per cent. of its value) and leave coal fires ? Think what it means :

¹ *The Smokeless City*, by E. D. Simon and Marion Fitzgerald. Longmans, London.

of two householders, living next door to one another, one has an all-coal house and pours forth smoke on his neighbour's garden all the year round ; the other takes the trouble to instal central heating, gas cooker and gas fires and makes no smoke at all. The latter is taxed heavily on his gas, the former pays not a penny. Truly a curious way of encouraging smokeless methods ! ”

CHAPTER IV

COKE AS FUEL FOR STEAM RAISING

SINCE the advent of the Ministry of Health, and the present high price of coal, more than usual interest has been bestowed upon the working of steam boilers and upon coal smoke abatement. Various remedies have been suggested with the view to obtaining better results; but expert investigation and research, the training of stokers and scientific methods of control have, so far, been apparently the only lines upon which either private or official action has been suggested. These measures are, of course, very desirable, and so far as they have been applied and maintained they have effected economies which will materially help the situation; but such expedients must, in the light of past experience, be regarded not as a panacea, but merely as palliatives which require not less, but more scientific knowledge and skill which are apparently not yet possessed by the average steam user or the great majority of stokers. On the other hand, it is of the essence of good management not to complicate, but to eliminate or render "fool-proof," so far as possible, operations or processes which must be entrusted to unskilled operatives. The efficient and smokeless combustion of bituminous coal under steam boilers is acknowledged to be a thermo-chemical process of great complexity, requiring great skill, experience and constant attention; but recent experience has proved that even this operation is amenable to treatment by a process of complete or partial elimination.

On many important steam plants the use of bituminous coal, with all its attendant inefficiency and waste, has now been eliminated entirely, or very materially reduced, by the substitution of coke, the furnaces being suitably adapted. The adaptation of certain types of existing mechanical stokers to the use of coke, or mixtures of coke and coal, has,

however, proved to be a more difficult problem ; but it may now be claimed that this has satisfactorily been accomplished so far as the popular and widely used chain-grate stoker is concerned. By means of a simple system of blending, introduced by the author, the use of bituminous coal as fuel for stoking by means of chain-grates is reduced to the minimum, while the relatively small proportion of coal so used is employed to greater advantage than has hitherto been found possible under ordinary everyday conditions. This system, known as the "Sandwich" system of blending and feeding fuel to steam boiler furnaces, which incidentally permits a material increase in national wealth through by-product recovery, enjoys the distinction of having been accorded official encouragement by the Coal Mines Department of the Board of Trade during the War. Readily applicable to existing mechanical stokers, it has already been adopted by several important steam users, primarily as a temporary expedient, in order to maintain essential public services during the period of acute coal shortage ; but extensive alterations to overhead storage bunkers which have since been carried out at electricity and other power stations, with the object of facilitating fuel-blending operations, appear to indicate that many of the more important users have adopted the system as a permanent institution, not merely from patriotic considerations but simply because it pays.

Certain definite factors have hitherto limited the range of fuels which could be utilised economically for steam raising at electricity supply, tramway and other power stations. The transport-economising "zone" system of satisfying local demands from the nearest sources of fuel supply, introduced during the War, has, in this country, as well as abroad, revealed faults in power station design which have unnecessarily limited the range of choice of fuels available. Almost invariably these stations have been laid out on the assumption that free-burning bituminous coal of uniform grade and quality would be the staple fuel used. Draught, mechanical coal-handling, storing and stoking appliances are more or less inflexible, and no provision has been made for the systematic grading and blending of different descriptions of fuel. In the light of present knowledge, and in view of the economies obtainable from the

Sandwich system of blending fuel, such methods must be regarded as primitive; except, perhaps, for their crude simplicity, they have nothing to warrant their embodiment in new, or their continuance in existing power stations.

So far as the author is aware, no attempt has hitherto been made systematically to blend solid fuels having different physical and chemical characteristics for the purpose of improving the efficiency and intensity of combustion. Mainly with the object of complying with specified conditions as to calorific power, viscosity, flash point, etc., fuel oils and spirits are frequently blended by distillers and dealers. The blending of coal gas with carburetted or blue water gas, so that the resultant mixture conforms to the declared standard of calorific power, etc., is also a practice which has been brought within the region of an exact science by gas engineers; and the possibility of blending, in order to improve the efficiency of combustion of gaseous fuel, is a subject which is now receiving close attention. Users of pulverised coal also recognise the advantages of blending high and low grade fuels, for specific purposes or for commercial considerations, a practice to which this system of combustion readily lends itself. For use in rotary cement kilns, for instance, a certain minimum of volatile combustible in the pulverised fuel is necessary in order to avoid risk of unburnt carbon finding its way into the cement material. With this knowledge, the large user, who is usually also a shrewd buyer, takes advantage of variations in prices, selecting those fuels which for the time being are the most advantageous; and, having ascertained their proximate analyses, he proceeds to compound a mixture of two or more different kinds that will conform to his requirements at minimum cost. This is one of the advantages of this system which has very considerable importance; but apart from the larger consideration of coal conservation, it may be of interest to examine to what extent the ordinary power user may avail himself of the practical and financial advantages that accrue from the judicious blending of different kinds or grades of coal—bituminous or anthracitic—with gas coke or coke breeze, with the object of improving the thermal and commercial efficiency of his boiler plant, and, at the same time, prevent-

ing the emission of visible smoke. As is well known, many of the rich hydrocarbons contained in bituminous coal begin to distil at temperatures much below those necessary to effect their ignition and complete combustion, and are therefore largely wasted; but, incidentally, it is this very characteristic of coal which enables it, by the process of carbonisation and by-product recovery, to contribute so largely towards the national wealth. To judge by the various systems of buying and selling coal and other fuels merely on the basis of their calorific power, and regardless of thermal efficiency, the bearing of this important factor upon the fuel cost of steam production and heating does not appear to have been fully appreciated.

So long ago as 1901 the late Mr. W. H. Booth advanced what was then a new theory of two-stage bituminous combustion in boiler furnaces. He showed that the furnace temperatures attainable in ordinary circumstances depend not so much upon the calorific power of coal as upon its composition. In a piece of coal, he argued, there exist solid carbon, solid hydrogen and solid oxygen. It is well known how great is the amount of heat required to be taken from the so-called permanent gases in order to reduce them to liquid form, and how it is still more difficult to render them solid; and the solid coal will dissolve into combustible vapour only at the expense of the heat in surrounding bodies, as ice dissolves to water, or water to vapour, at the expense of heat. In gas making, the heat required is obtained from the fuel used in the retort producer furnace, and this process of carbonisation and gasification absorbs anything from 15 to 25 per cent. of the heat available in the coal. In the steam boiler furnace the necessary heat is obtained from the incandescent fuel on the grate. If the volatile parts of ordinary bituminous coal could be caused to escape entirely unburnt, Mr. Booth further showed, the net fuel efficiency might be as low as 25 per cent., as the volatile hydrocarbons carry with them not merely their own calorific capacity but also the heat rendered latent in the process of distillation.

In dealing with non-bituminous fuel such as coke, which is a "single stage" fuel, experience has proved that efficient combustion and high

calorific effect are much easier to secure than in the case of bituminous coal; and the theory advanced by Mr. Booth affords one explanation. The main reason for the superior thermal efficiency of coke is that in its combustion no water is produced and therefore no heat is rendered latent by the formation of steam. The "gross" and "net" heating values are identical, while with coal, some of the heat of its combustion is expended in driving off the hydrocarbons. With coke, all the heat units evolved in the process of combustion are available for useful heating purposes.

CHAPTER V

COKE AS FUEL FOR ELECTRIC POWER STATIONS

THAT coke should be mentioned in a report now published annually by the Electricity Commissioners, as one of the three staple fuels used at electric power stations is certainly significant, as it tends to prove that not only have the difficulties attending its use been overcome satisfactorily, but also that coke has at last achieved the recognition which it merits as an economical and efficient fuel for steam raising.

Like daylight saving and other obvious aids to economy, the introduction of coke as fuel for steam raising had to await the strenuous conditions brought about by the War ; but it is gratifying to note that the economy effected by its use during a period of acute coal shortage has stood the test of competition with coal at prices which approach those quoted prior to the war period. Its continued use in preference to coal tends, in fact, to prove that its inherent advantages are now more fully appreciated by those who, by training and experience, are best able to appraise the relative values of different kinds of fuel.

The introduction of coke as fuel for steam raising at important power stations was not, however, merely a matter of opportunity, or simply one of offering it at an attractive price : coke has always been plentiful and relatively cheap. The chief difficulty was its utilisation on the existing natural draught mechanical chain-grate stokers installed at most power stations, which was said to be impossible ; and, indeed, many power station engineers had tried and failed to use it on chain-grates by ordinary methods.

Similar experiments made by the author led to the evolution of the Sandwich system of burning coke and coal slack in superimposed layers on chain-grate stokers, and as it is mainly by means of this system that coke is now used as fuel at power stations (which, incidentally,

include those recording very low fuel costs per unit generated), a description of the Sandwich system may be of interest.

Designed primarily as a means of utilising coke breeze as fuel for steam raising, experience has proved that this system of blending bituminous coal with non-volatile coke has certain inherent advantages which can be turned to good account in practice. In using moist coking-coal slack, containing as a rule about 30 per cent. of volatile matter, on a chain-grate stoker, a fire of only 4 inches, or less, in thickness, with consequent in-leakage of excess air, a low furnace temperature, the formation of smoke and the rejection of an unduly high proportion of unburnt fuel with the ash and clinker are among the difficulties

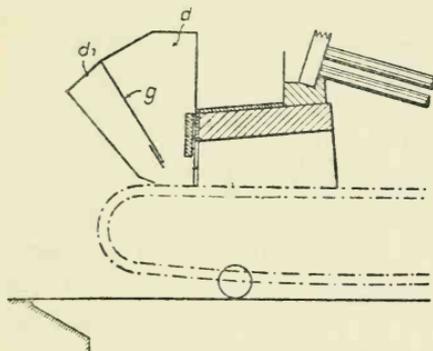


FIG. 4.—SANDWICH SYSTEM. CHAIN-GRATE STOKER.

commonly experienced. These difficulties may be attributed largely to the high proportion of volatile matter in the coal; but all effort at blending, simply by mixing intimately a considerable proportion of coke, failed as a result of such mixtures refusing to ignite. This, of course, was due to the ignition or coking arch not being maintained at an adequately high temperature.

By dividing the feed hopper, as shown in Fig. 4, it was found that coal and coke could be fed into the furnace in well-defined layers; and the coal being fed from d , the inner half of the hopper, the coal layer was uppermost and, consequently, in the position most effectively to maintain the temperature of the coking arch, so that continuous ignition of the coke was assured.

The thickness of the coke layer, fed from hopper d^1 , may be as much as 6 or 7 inches, according to the height of the coking arch above the grate level, and the draught available, representing 50 to 75 per cent. of the total fuel fired.

This layer of coke forms an ideal support upon which to burn the finely divided semi-volatile coal, which is fed in a thin layer, normally about 2 inches in thickness.

Obviously, however, the proportion of coal to coke is variable, according to circumstances, conditions of load, and according to the difference in price.

In other cases, where the primary object is to economise by using coal of an anthracitic character, which, used by itself, would tend to overheat the grate, the feed hopper has been divided into three compartments by fitting two adjustable diaphragms

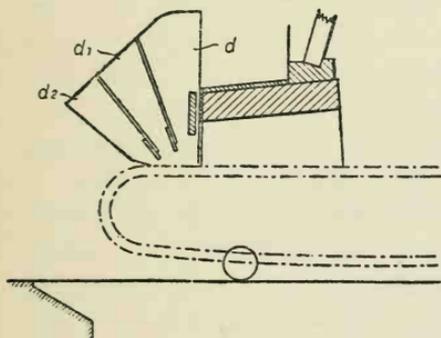


FIG. 5.—SANDWICH SYSTEM. CHAIN-GRATE STOKER.

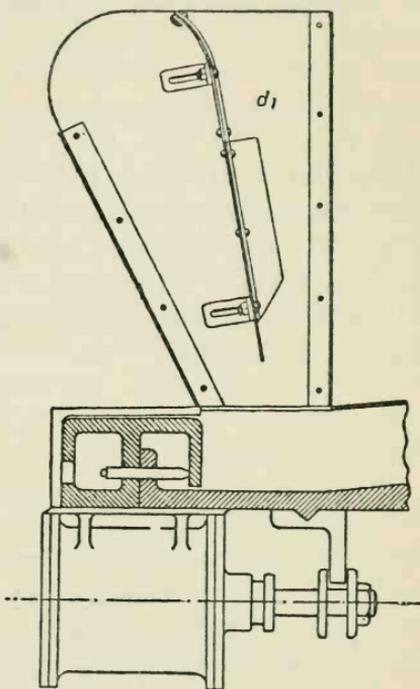


FIG. 6.—SANDWICH SYSTEM. CLASS E UNDERFEED STOKER.

(Fig. 5). Sandwiched in this way between two layers of bituminous coal slack, risk of damage to the grate is eliminated, while continuous ignition with a minimum proportion of bituminous coal is obtained.

The Sandwich system of fuel blending has also been satisfactorily adapted to the E type Underfeed stoker (see Fig. 6), but in this case the coke is fed into the inner half of the feed hopper, the proportion being varied by a lateral, instead of a vertical, movement of the diaphragm.

The utilisation, at electricity supply stations, of carbonised fuel in

conjunction with inferior coal slack useless for any other than direct fuel purposes, rendered possible and profitable by means of the Sandwich system, has an important bearing upon the larger question of a fuller utilisation of the country's coal resources and the problem of industrial coal-smoke prevention. It is probably one of the most remarkable facts of the present time that, out of a million tons of coal raised in this country every working day, less than 13 per cent. is subjected to treatment and by-product recovery at gasworks and coke ovens. Yet there is no practical limit to the extent to which the process of coal carbonisation could profitably be carried on. Given Parliamentary encouragement of the principles of coal economy that gave rise to the now historical Super Power Station scheme, the country's resources are more than adequate to provide the plant necessary to deal with and render innocuous the whole of the bituminous coal at present burnt in its raw state.

CHAPTER VI

FUEL BLENDING

THE PATENT SANDWICH SYSTEM

THE acute coal famine, which followed the great strike of coal miners in 1912, led the author to experiment with mixtures of inferior coal slack and coke breeze as fuel for firing water-tube boilers fitted with mechanical chain-grate stokers. Employed at that time as a power station engineer to an important electric power supply company, the imperative necessity for eking out the meagre stocks of coal provided the opportunity for experiments with coke breeze as a substitute. This material was obtainable from local gasworks and coke ovens in abundance at very cheap rates, but, hitherto, it was considered unsuitable for use with chain-grate stokers at power stations, working under natural draught conditions.

Preliminary experiments with intimate admixtures of coke demonstrated the impossibility of maintaining the necessarily high temperature of the coking arch when any considerable quantity of breeze was added. Mixed with coal in this way, the non-volatile breeze, which was more or less moist, had the effect of retarding the volatilisation of the coal, and misfiring occurred, due to the cooling-off of the ignition arch.

The introduction of the coke in a layer from a separate hopper, constructed in front of the existing coal-feed hopper (see Fig. 7), proved an immediate success. The layer of coke was increased, and the thickness of the upper coal layer was diminished, until a result was obtained that gave the normal maximum output of steam with the minimum consumption of raw coal.

After long and painful experience in firing Yorkshire coal slack by itself on chain-grate stokers, the results obtained with the coke and coal mixture, fed in Sandwich fashion, was a revelation. Excess air, usually

of necessity admitted to the furnaces to the extent of 150 to 200 per cent., was now diminished to the minimum. The boilers responded immediately to the increased furnace temperature thus obtained; and, instead of large quantities of partially consumed coal being rejected by the mechanical stokers as heretofore, only completely burnt out ash and clinker had to be removed.

The commercial potentialities of this discovery were fully realised

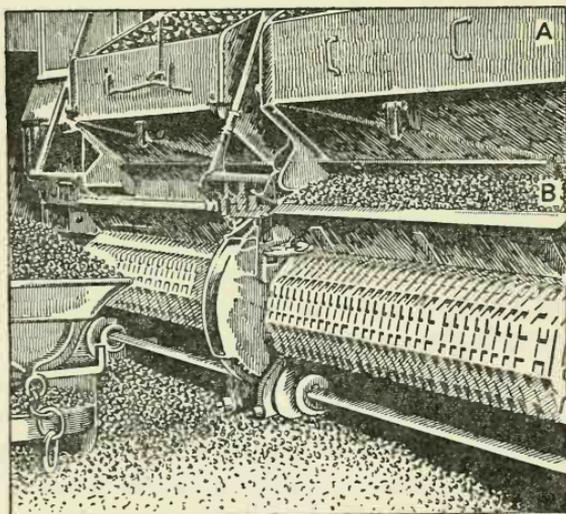


FIG. 7.—SANDWICH SYSTEM. CHAIN-GRATE STOKER.
A. Coal Hopper. B. Coke Hopper.

by the author, and there is considerable professional gratification in seeing the Sandwich system adopted as a permanent institution by electric power supply authorities, who, hitherto, had been considered as possessing "the last word" in economic fuel practice; but the new outlet thus opened up for a by-product of the gasworks, in a quarter that was naturally considered the least promising, is probably the most gratifying result of the author's present mission to promote the use of coke as fuel, one power station alone steadily absorbing 40,000 tons per annum, a quantity equal to about half its total fuel consumption.

Although used at electricity supply stations which claimed the lowest recorded fuel cost per unit generated, it required the imperative need for economy in fuel that was brought about by the War, as well as an invitation from the Coal Controller to view the Sandwich system in operation at the London County Council's power station at Greenwich, to impress steam users with its importance; and the comparative ease with which existing mechanical chain-grate stokers can be adapted to the use of coke on the Sandwich system led one unauthorised user to remark that "it would be impossible to obtain a valid patent for an invention so ridiculously simple," a remark that was backed up by the statement that "it would be as reasonable to apply for a patent for breathing the atmosphere."

Other users of the Sandwich system of fuel blending have acknowledged its advantages and pointed out the importance of its bearing upon the smoke question and upon the whole question of coal conservation by rendering available to the largest users of fuel inferior coal slack and a by-product of coal carbonisation which hitherto have been, and are still in many districts regarded as waste products.

At a conference of Municipal Tramway Authorities, the General Manager of the London County Council Tramways, in a paper on "Power Expenses," gave, *inter alia*, the following interesting data relating to coke and coal used as fuel at the Greenwich generating station during 1919-20, according to the *Electrical Review* :

"Tons of fuel used—176,400.

Average price per ton for coal—41s. 11·3d.

Average calorific value—10,780 B.Th.U.

Average per centage of ash—14·59.

Average percentage of ash in coke—10·0.

Average calorific value of coke—11,500 B.Th.U.

Average calorific value of coke breeze—9000 B.Th.U.

Tons of coke and breeze used—25,000.

"Early in 1918 experiments were carried out at the Greenwich power station with a view to burning coke on the 'Sandwich' system. These experiments proved successful, and, when the Coal Controller decided to curtail coal supplies by 15 per cent., it was found possible to make

up the deficiency by using coke in this manner. The results obtained were so satisfactory that the Coal Controller recognised them as being of public service, and arranged for engineers from other undertakings to inspect the lay-out with a view to adopting a similar system."

Incidentally, this arrangement, made by the Coal Controller then in office, is, so far as the author is concerned, the only known official recognition for this "public service," which was the means of maintaining, during a very critical period, the normal tramway service in London, while, in other less enlightened communities, the tramway services, and also the revenue derived from them, were curtailed by about 15 per cent. The following further data were also given :

"With Scotch nuts at 42s. per ton, and coke breeze at 22s. 6d. per ton, the cost per 1000 gallons of water evaporated is approximately 19s. 6d., using approximately equal quantities of each fuel, as against 23s. 2d. with coal alone. The coke was supplied from gasworks only a short distance from the power station."

From this statement it will be gathered that in addition to a saving in fuel transport and storage there is a net saving in fuel cost of about 16 per cent. on all steam generated from a 50 per cent. mixture of coal and coke breeze, by means of the Sandwich system. From these figures also it may readily be calculated that the *average* evaporation obtained per lb. of the mixed fuels (coal and breeze) is approximately 7.25 lb., or over 70 per cent. efficiency—a result that many steam users would be glad to obtain with high grade washed coal. At other power stations an evaporation of over 9 lb. has been recorded with coal and coke. At the Greenwich power station there are forty-eight water-tube boilers installed, and the extent of the saving effected will be gathered from the following official report of the London County Council Highways Committee :

"The results have been extremely satisfactory and have led to a large proportion of coke being burnt with the coal and a considerable saving in the cost of fuel. Owing to the increased use of coke and coke breeze, a saving of about £8000 a year can be effected.

“ Apart from the saving in money, low grade classes of fuel, which often have to be accepted during the present coal shortage, can be dealt with, on the Sandwich system, at a much higher efficiency than would be the case if burnt separately.”

From the national view-point, the latter paragraph, which confirms the experience of other important users of coke on this system, is probably the more significant. Low grade coal slack, practically useless for any other than direct fuel purposes, often considered unsaleable and buried in the pits, is now used, blended in this way with graded coke, efficiently and smokelessly, in place of the higher grades of coal, which are thus released for export or carbonising purposes.

Experience gained at other important power stations, where the Sandwich system of fuel blending has been in use for several years, also proves that important advantages, bearing upon fuel costs, boiler efficiency and capacity, have been introduced by the adoption of this system. Apart from the question of smoke prevention, these advantages, in view of the increasing cost of fuel, and the necessity for its utilisation on the most rational lines, command careful consideration. Briefly stated they are as follows :

BARGAINING ADVANTAGES

Certain concrete conditions which obtain at most power plants have hitherto limited the range of choice of fuels to certain grades of bituminous coal low in ash content. High freight charges and limited boiler capacity have necessitated freedom from smalls and dust, owing to difficulty in firing coal slack on mechanical chain-grate stokers without undue loss due to riddling, or sifting, of small coal through the grate. The use of anthracitic Welsh coal, however attractive in price, was precluded owing to the damage caused to the grates by its use. The use of relatively cheap gas coke, or coke breeze, as fuel, either exclusively or intimately mixed with low grade coal slack, has hitherto proved to be impossible owing to the inability of existing mechanical stokers to deal satisfactorily with this class of fuel, which, used in ordinary circumstances, often involves serious loss in steaming capacity or risk of

misfiring. Moreover, power station boiler equipment being largely of a similar character and type, the consequent universal demand for screened nut coal, of a uniform grade, has led to an inordinate increase in price, which has frequently been advanced far beyond its actual net evaporative value. On the other hand, relatively cheap coal slack, of about equal calorific power, is either allowed to accumulate on pit banks or is actually buried in the pits to the extent, it is said, of millions of tons per annum, owing to lack of adequate demand; and good quality coke breeze is in certain districts often discarded as unsaleable. The Sandwich system of fuel blending renders the use of these fuels not only practicable, but highly advantageous from every point of view; and the bargaining advantage of having alternative fuels, instead of only one more or less uniform kind of coal, will readily be appreciated by shrewd buyers, while the national advantage accruing from the possibility of carbonising the higher grades of coal, recovering the by-products and using directly as fuel only coal of low grade, will be appreciated by all.

PRACTICAL ADVANTAGES

The serious loss due to unburnt fuel and to riddling and sifting of small coal between the grate bars, particularly with the mechanical chain-grate stoker, the type of stoker by far the most extensively used, has always been an important factor bearing upon fuel costs. The magnitude of the waste due to this cause may be gauged from the following reference:

“The amount of unburnt fuel in the ash is a very knotty point indeed, and the most serious losses in this connection are undoubtedly taking place in many power stations. I know of one case in my own personal experience where an unusually efficient and wide-awake works manager was being paid to take away fine ash from a generating station, ostensibly for use as road material, and was then actually using it as fuel under his ‘Lancashire’ boilers and obtaining excellent results. One of the essential defects of the ordinary chain-grate stoker is the amount of unburnt material in the ash and riddlings that falls through the comparatively large air spaces rendered necessary by the size of the links.”¹

¹ Mr. David Brownlie, in the *Electrician*, 7th April 1923.

Various means have been tried to prevent this loss, but, ultimately, the use of relatively expensive screened and washed nut coal is resorted to as the most reliable preventative. Reference to the diagram (Fig. 4) will show how the Sandwich system effectively prevents loss due to this cause, and at the same time renders the use of relatively cheap fuels efficient and practicable. The layer of coke or coke breeze may be 3 to 7 inches in depth, according to the height of the coking arch and to the draught available, 0.25 inch w.g., measured over the fire, being sufficient for a 5 or 6 inch layer of coke. Now, it is well known that finely divided coal, when dry, flows through a moving chain-grate like so much graphite; but the coefficient of friction between the particles of coke is such that it does not flow freely like coal dust; and, moreover, the layer of coke forms an ideal "grate" upon which to burn semi-volatile coal slack, the innumerable interstices between the separate pieces of coke providing the fine streams of air essential to complete combustion, and at the same time providing an impenetrable baffle which prevents sifting of the fine coal particles. The semi-volatile bituminous coal, supported on top of the coke layer, begins to volatilise immediately it enters the furnace under the coking or ignition arch, the burning gases maintaining the under side of the arch at the high temperature essentially necessary to ensure continuous ignition of the fuel as it enters the furnace. It is in this essential feature that coke alone, or any considerable intimate admixture of coke and coal, fails in practice, as the temperature of the arch is gradually lost and misfiring occurs. By means of the Sandwich system, the use of smoke-producing bituminous coal is reduced to the minimum, and that so used is used to the best possible advantage. Being spread upon a thick layer of coke, it is in the best position for maintaining satisfactory ignition. The coke feed is adjusted, as in the case of the coal, by means of a sliding guillotine or shutter.

BOILER, FUEL AND GRATE EFFICIENCY

The term "boiler efficiency," of course, always includes the relative efficiency of the fuel used, as well as that of the grate or mechanical

stoker. Obviously, all fuels are not equally efficient, and all stokers vary in their capacity to convert the potential energy of fuel into useful heat. It is well known that in burning bituminous coal under a steam boiler a very considerable amount of heat has to be expended in volatilising or distilling the volatile matter in the coal, which amounts to about 30 per cent. by weight; and these gases, after having absorbed heat in the course of their formation, are, together with their latent heat, very liable to waste. They are not only difficult to ignite, requiring as they do a high temperature and a large excess of air, but are very liable to be extinguished owing to the proximity of the relatively cool boiler heating surfaces, with which they cannot possibly come into contact and remain ignited. The heat of the flame thus extinguished is not only lost, but smoke is formed and a fresh coating of insulating soot is deposited upon the boiler heating surfaces, thus preventing, to a large extent, intimate contact and transfer of heat from the escaping hot gases. It follows that it would be very desirable to eliminate the use of semi-volatile coal fuel altogether, or at least to restrict its use to the minimum. Less excess air would be required, smoke emission and sooting would be avoided and, consequently, a higher furnace temperature and a more efficient transfer of heat could be maintained. The use of non-volatile fuel alone on mechanical chain-grate stokers under ordinary natural draught conditions is, however, practically impossible. Adapted by means of the Sandwich system, the use of semi-volatile coal as fuel is not only reduced to the minimum, but that used is used efficiently, as will be gathered from the test results (page 46) obtained by an independent authority.

BOILER STEAMING CAPACITY

It automatically follows that if the above sources of loss are eliminated, the efficiency, as well as the capacity, of the boiler will be materially increased by means of the Sandwich system of fuel blending; that this is so, long experience and the test results quoted tend to prove. Instead of being in the proportion of 30 to 35 per cent. by weight, as it would be if bituminous coal alone were used as fuel, the proportion of volatile

combustible contained in the blended fuels is reduced to 10 or 12 per cent. In this respect the coal and coke mixture can be so regulated that the proportion of volatile matter in the blended fuels is identical with that of the best quality smokeless Welsh coal, which, probably, is Nature's most efficient solid fuel.

Coke, as already pointed out, being free from hydrogen, burns without the formation of water. This fact, and the reduction of the volatile matter in the combined fuel to the minimum, constitutes an important element in obtaining and maintaining smokeless combustion and a high thermal efficiency. The considered opinion of one important power station engineer, who, as a result of the substantial savings effected by means of the Sandwich system of fuel blending, has made extensive alterations to overhead storage bunkers, and installed coke cutters, in order to facilitate blending operations, is as follows :

“ After eighteen months' experience with the Sandwich system of fuel blending on a large scale at a power station using on the average 3000 tons of fuel per week, I have come to the conclusion that the use of this system has introduced quite a new line of thought in fuel use which has many important advantages from both the commercial and national points of view. Equipped with divided overhead storage bunkers, and other facilities for blending at the boiler furnaces, the combinations which can be secured are practically infinite. By means of a simple system of trial and error, the most advantageous mixture, having regard to price and all other factors, is readily determined ; and a high thermal and commercial efficiency can thus be maintained which, without the control and elasticity incidental to the Sandwich system, would be impossible.”

In recent power station design the stereotyped system of coal conveyers and undivided overhead bunkers, communicating by means of a single chute to each mechanical stoker, is still in evidence ; and having regard to recent experience in grading and blending fuels, and the financial advantages that accrue, it is to be hoped that in future due provision will be made to facilitate these operations at important new power stations.

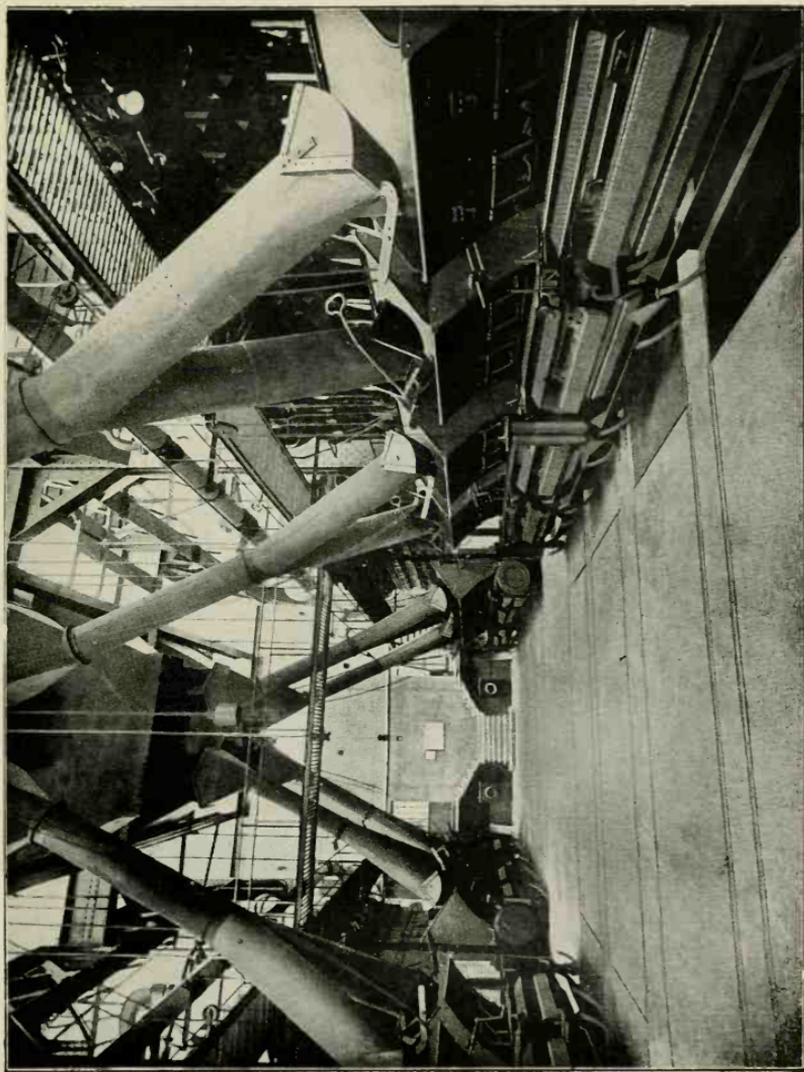
The following is an extract from an official report upon the results

of comparative tests with coal and coke, fired on the Sandwich system, and coal only, on a B. & W. Boiler at a London power station :

“ The normal guaranteed evaporative capacity of the boiler was 6000 lb. per hour. In Test No. 1 the coal and coke were each weighed separately and filled by hand into their respective feed hoppers on the chain-grate stoker. The patent double hopper Sandwich system of feeding adopted is substantially that indicated in Fig. 4¹; *d*¹, being the coke feed hopper and *d* that for the coal, while *g* is the separating diaphragm. Thus, the composite feed enters the furnace in well-defined superimposed layers, the coal being on top. The volatile gases given off from the latter maintain the firebrick ignition or ‘coking’ arch in an incandescent state, thus establishing positive and continuous ignition at the point of entry on the grate. With a simple and intimate admixture of coal with coke in any considerable proportion, it has been proved impossible to maintain these essential conditions, as the arch gradually cools and misfiring occurs.

“ The proportion of volatile matter was approximately 8 per cent. of that of coal only; this would appear to constitute an important element in determining the thermal efficiency, for the reason that the hydrocarbon loss is minimised, due to the reduction of volatile matter in the combined fuel. The thermal efficiency obtained in Test No. 1 was 80 per cent., and in Test No. 2, with coal only, 61 per cent., showing a difference of 19 per cent. in favour of the combined fuel.”

	TEST No. 1. Coal and Coke.	TEST No. 2. Coal only.
Calorific power as fired	11,138 B.Th.U.	12,150 B.Th.U.
Fuel consumed per grate-foot-hour	30.66 lb.	31.66 lb.
Ash and clinker, actual	16.22%	12.7%
Average steam pressure	178 lb.	179 lb.
Superheat temperature	486° Fahr.	490° Fahr.
Water evaporated per hour	10,505 lb.	8747 lb.
Water evaporated per square foot of heating surface	5.22 lb.	4.35 lb.
Water evaporated per lb. of fuel as fired from feed temperature	7.18 lb.	5.76 lb.
Water evaporated from and at 212° Fahr.	9.22 lb.	7.44 lb.
Efficiency : boiler and superheater	69.9%	53.12%
Efficiency : boiler with economiser	79.96%	60.98%
Draught over fire	0.25 inch	0.25 inch



UNDERFEED COKE-BURNING MECHANICAL STOKERS, ELECTRIC LIGHT AND POWER STATION.

PLATE 3.

Taking a 50 per cent. mixture of ordinary bituminous coal slack and coke, as commonly used on the Sandwich system, the following analyses show how nearly the chemical composition of such a mixture resembles that of smokeless Welsh coal, which, as already pointed out, is probably Nature's most efficient combination of volatile and fixed combustible :

	Bituminous Coal.	Coke.	50 per cent. Coal and Coke Mixture.	Smokeless Welsh Coal.
Volatile matter	28.0%	1.0%	14.5%	14.0%
Fixed Carbon	57.5%	89.0%	73.25%	76.0%
Ash	14.5%	10.0%	12.25%	10.0%

Other adaptations of the chain-grate stoker have been attempted by various makers with a view to using coke as fuel, but so far their use appears to be limited to coke breeze, which, containing as it does 4 to 5 per cent. of volatile matter, is for this purpose a relatively tractable fuel.

These adaptations consist mainly of impelled draught and elongated ignition arches projecting from both the front and rear of the furnaces, so that the fuel is consumed in a kind of tunnel with a narrow outlet near the centre. This system is no doubt effective in firing coke breeze, but its conception displays a lack of appreciation of the importance of the direct transmission of radiant heat.

The long arches practically cover the fire-grate, and effectively shade the most important heating surfaces of the boiler, *i.e.* the first rows of tubes, from the heat radiated by the incandescent coke. The rear arches, moreover, become incandescent, and reflect the heat downwards, not only upon the fuel that they are designed to burn, but also, with baneful effect, upon the unprotected portions of the grate, thus tending to destroy them.

The travelling grate mechanical stoker, designed and made by the Underfeed Stoker Company, has, over a period of many years, proved its capacity to deal efficiently with coke breeze.

The illustrations¹ show clearly the construction of this mechanical stoker; and the results, supplied by the makers, indicate both the capacity per grate-foot-hour and efficiency obtained.

¹ Pp. 51 and 53.

COKE AND ITS USES

RESULTS OF BOILER TRIALS MADE AT THE BRISTOL ELECTRICITY WORKS WITH COKE BREEZE FIRED BY MEANS OF THE UNDERFEED TRAVELLING GRATE STOKER

	Date of test	28th October 1921.
	Description of fuel	COKE BREEZE.
	Analysis of fuel	Ash . . . 25.03% Volatile . . 6.82% Moisture . . 13.68% Fixed carbon 54.47% B.T.U. as fired 8,927
	Duration of trial hrs.	6 full-load
PRESSURE .	Steam gauge lb.	200
	Draught gauge, damper . . . in. w.g.	0.3
	Absolute steam pressure . . . lb.	214.7
	Air pressure in windbox. . . in. w.g.	0.6
TEMPERATURE	Gases leaving boiler . . . degrees F.	553
	Feed water entering boiler . . degrees F.	240
	Steam degrees F.	538
	Superheat degrees	150
FUEL . . .	Total fuel consumed lb.	19,264
	Total refuse dry lb.	4,956
FUEL PER HOUR	Total refuse dry per cent.	25.72
	Fuel as fired per hour lb.	3,211
FLUE GAS .	Fuel as fired per sq. ft. of grate . lb.	28.16
	CO ₂ in gases leaving boiler . . . per cent.	13
TOTAL WATER	Total weight water used. lb.	116,000
	Factor evap. boiler including superheater	1.11
	Total from and at 212° including superheater lb.	128,760
WATER PER HOUR	Amount used lb.	19,333
	Evap. from and at 212° including superheater lb.	21,459
	Evaporation per lb. actual lb.	6.02
ECONOMIC EVAP.	Equiv. from and at 212° including superheater lb.	6.68
	Evap. from and at 212° per sq. ft. heating surface lb.	3.97
	Efficiency of boiler	72.36%

The following table gives the results on a percentage basis of a series of comparative tests on a hand-fired Cochran boiler, fitted with ordinary bars and burning coal, and a similar boiler, fitted with TURBINE FURNACE and using low-grade fuels as per analysis given, which tend to prove the advantages of blending coal and coke.

FUEL BLENDING

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It will be noted that for easy comparison, the rate of evaporation, and percentage fuel cost under ordinary conditions, are each given as 100.

SUMMARY OF COMPARATIVE TESTS

	Rate of Evapora- tion.	Relative Efficiency, lbs. Water per lb. Fuel.	Percentage Fuel Cost for Equal Steam Out- put.
ORDINARY BARS—			
Washed singles (coal)	100	10.0	100%
TURBINE FURNACE—			
Washed singles (coal)	113	10.2	98%
Coke breeze	95	7.3	61%
Cinders	118	8.9	50%
Hard coke breeze	93	7.8	51%
3 parts coke breeze	123	10.7	55%
1 „ washed singles			
3 „ coke breeze	120	10.7	63%
2 „ washed singles			
1 „ washery pond settlings	109	9.8	43%
1 „ coke breeze			
1 „ washery pond settlings	125	10.4	38.5%
1 „ hard coke breeze			
Equal parts, washery pond settlings, and cinders	133	10.3	41%
Washery pond settlings	140	12.2	33%

ANALYSES (PERCENTAGE VOLUME) OF ABOVE FUELS

	Volatile Matter.	Ash.	Fixed Carbon.	Free Moisture.	Hygro- scopic Moisture.	Thermal Value, B.Th.U.
Washed singles (coal)	33.95	4.93	51.54	0.99	8.56	11,739
Washery pond settlings (slurry)	23.41	27.99	40.83	4.94	2.83	9,249
Coke breeze	9.84	18.78	59.68	9.50	2.20	10,156
Coke breeze, hard	3.96	24.29	62.31	7.83	1.61	9,807
Cinders	2.56	33.92	50.05	12.05	1.42	7,727

CHAPTER VII

THE CHAIN-GRATE STOKER

FREQUENT reference has been made in previous pages to the mechanical chain-grate stoker as a means of utilising coke as fuel for steam raising. In various forms, which differ only in detail, this type of stoker is probably more in evidence at electricity supply and other power stations than any other type.

The long life of some of the earlier chain-grate stokers is remarkable. A number of the original Jukes stokers installed in the London and Manchester districts are still in use and apparently equal to a further long period of useful service, after being fifty years at work. Modern stokers of this type will no doubt give equally satisfactory results.

That the chain-grate stoker can readily be adapted to use a large proportion of coke in conjunction with bituminous coal slack, by means of the Sandwich system, has already been shown; and having regard to its long life, popularity, and, therefore, its importance as a potential user of coke, a brief reference to its history may not be out of place.

According to Mr. David Brownlie, writing in *Combustion*, "John Jukes, of Shropshire, took out his first British patent for the chain-grate stoker in 1841. His specification embodies the complete invention of the chain-grate stoker almost identical in every way with the modern stoker, including the endless chain of cast iron links or bars, and the movable framework or carriage as well as the vertical sliding door and the adjustable tension arrangement."

There is some doubt whether Jukes was the first to conceive the idea of the endless chain grate, but there can be no doubt that its first practical application to the steam boiler as a means of utilising small coal, and all that it entailed in financial and national economy, was due to him alone.

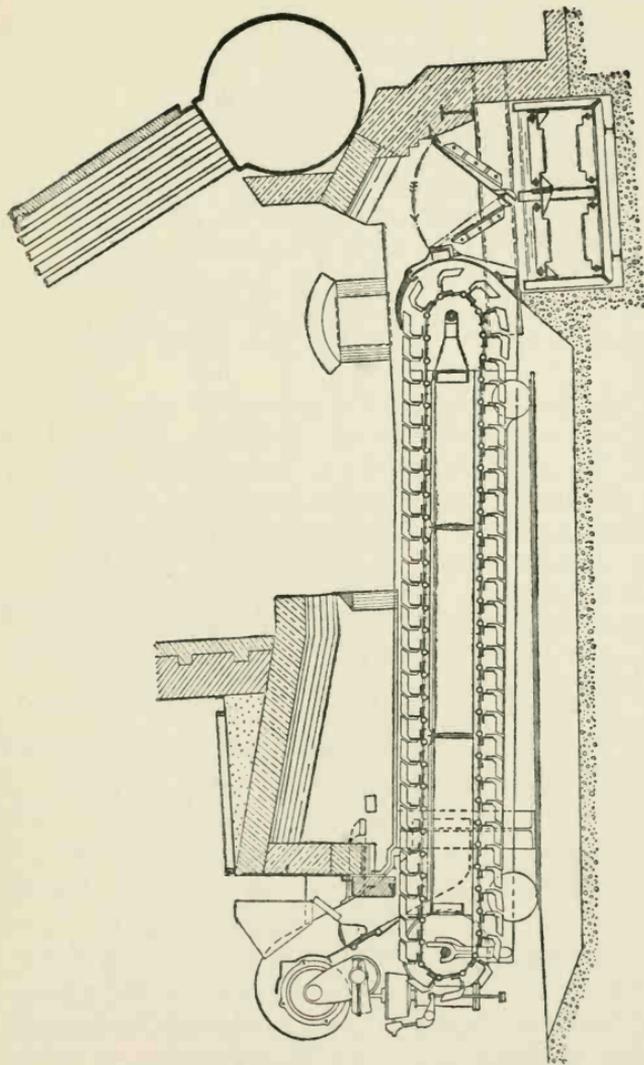


FIG. 8.—THE UNDERFEED SELF-CONTAINED FORCED-DRAUGHT TRAVELLING GRATE MECHANICAL STOKER.
(The Underfeed Stoker Co. Ltd.)

“Probably the first boiler plant fitted with the Jukes chain-grate stoker was that of the engineering works of Easten & Amos, in Southwark, London, in 1842. It showed a saving of 11 per cent. with good coal as ordinarily used, and 29 to 30 per cent. by utilising small coal which could be burned by the mechanical stoker, but not by hand.

“John Jukes gave evidence before the House of Commons Black Smoke Committee of 1843, and shortly afterwards his stoker had a very wide application for steam generation, in addition to which it was largely used for heating brewers’ coppers. In spite of the revolution effected by his discovery, the benefit to engineering in general, and the fact that many firms subsequently took up the manufacture of his stoker, presumably at a profit, Jukes himself reaped little pecuniary benefit. He died in London in abject poverty, being practically reduced to begging in the streets.

“In 1841 the type of boiler most in use was the externally fired boiler (to which the chain-grate was specially adapted). However, the much more efficient internally fired Cornish boiler was making headway, especially in the form of the two-flued Lancashire boiler. The chain-grate stoker is obviously not well adapted to the narrow furnaces characteristic of these boilers, and this in fact caused the eventual eclipse of the chain-grate. When, however, the water-tube boiler was developed, the original Jukes stoker was brought into use again, although many people, even to-day, believe that the chain-grate stoker is a comparatively new invention.”

Mechanical stokers specially designed for use in Lancashire-type boilers include the “Underfeed,” “Shovel” and “Sprinkler” types, and the “coking” or reciprocating fire-bar type. Several of these have proved satisfactory with coal and coke mixtures containing a considerable admixture of coke, suitably graded to conform to the class and size of the coal used.

Applied to the Lancashire-type boiler, the mechanical stoker has no doubt been effective in utilising small coal as fuel and, to some extent, in mitigating the smoke nuisance; but investigation has shown that the improvement in efficiency due to mechanical stoking of this kind, as compared with hand firing, is scarcely sufficient to warrant the extra cost of installation and maintenance.

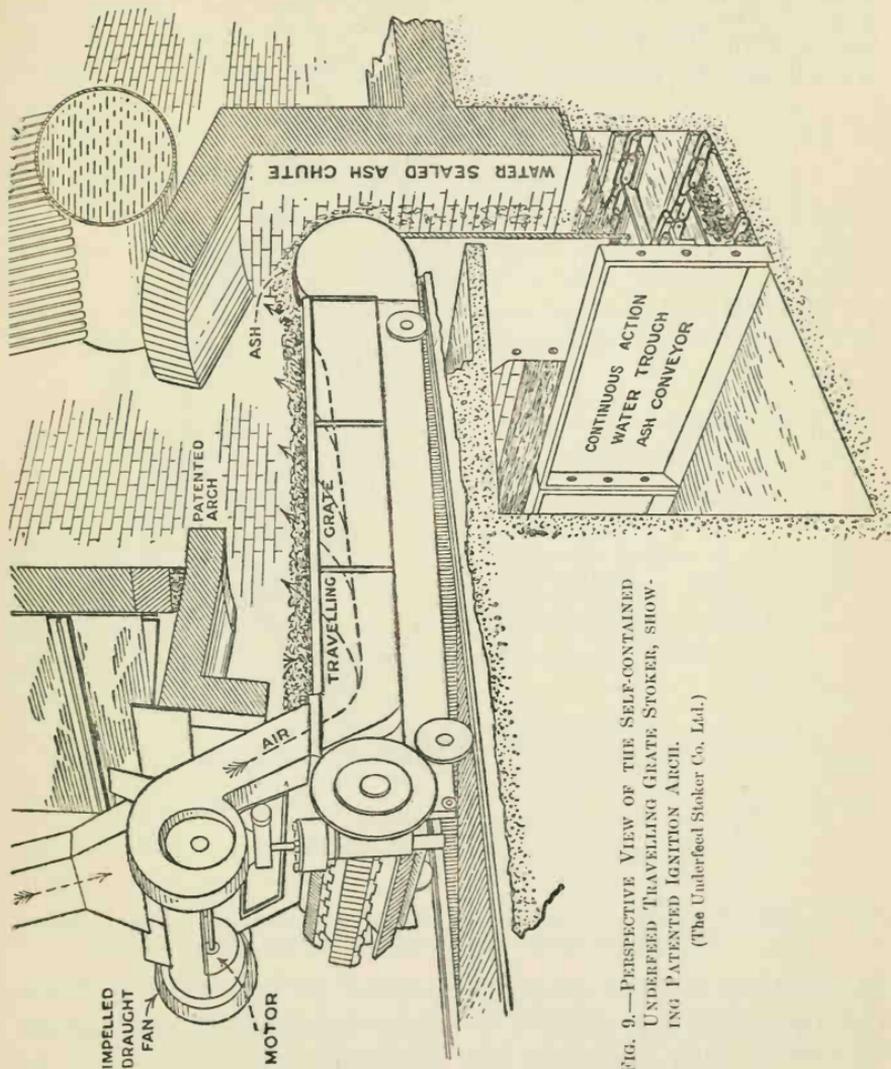


FIG. 9.—PERSPECTIVE VIEW OF THE SELF-CONTAINED UNDERFEED TRAVELLING GRATE STOKER, SHOWING PATENTED IGNITION ARCH.
(The Underfeed Stoker Co. Ltd.)

A well-known disadvantage of mechanical stoking is the restriction imposed in the range of choice of available fuels and, as a frequent consequence, their unduly high price. During the War, when specially graded coals for mechanical stoking were more than usually difficult

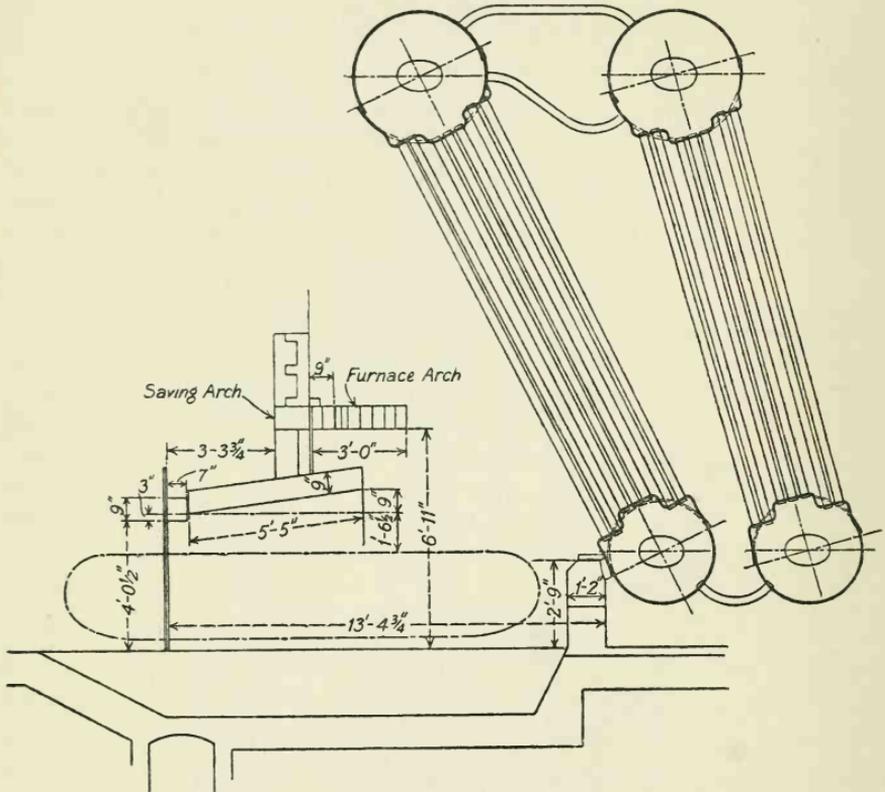


FIG. 10.—DETAIL OF IGNITION AND FURNACE ARCHES FOR FORCED-DRAUGHT COKE-BURNING MECHANICAL STOKER. THOMPSON WATER-TUBE BOILER.

to obtain, the author in several cases advised the removal of mechanical stokers, so that any available and cheap description of coal, or coke exclusively, could be used as fuel. The relief thus obtained, and the saving effected, were sufficient, in all cases where this course was adopted, to warrant the scrapping of the mechanical stokers.

The need for dealing in elementary fashion with the foregoing subjects, and, indeed, the *raison d'être* for the present work on coke and its utilisation, is emphasised by the following extract from correspondence, on the question of smoke abatement, which appeared recently in the *Manchester Guardian* :

Mr. C. E. Stromeier,¹ chief engineer to the Manchester Steam Users' Association, gave as his opinion :

“ If the gas and electric departments could play into each other's hands, the arrangement would be ideal, but their electric power-stations will not burn coke because it refuses to burn on chain grates unless intimately mixed with coal, and if burned in a Lancashire boiler the steam production is reduced one-half.”

That these latter statements are erroneous is shown, with ample evidence in support, in previous and subsequent pages.

¹ *Manchester Guardian* correspondence on Smoke Abatement, July-August 1923.

CHAPTER VIII

COKE AS FUEL FOR HAND-FIRED BOILERS

ALTHOUGH coke has been adopted by important users of mechanically fired boilers of large capacity, it is probably now used to a far greater extent exclusively as fuel for hand-fired boilers of all descriptions.

Tests innumerable have been conducted in order to determine the comparative net evaporative value of coal and coke in cases where these fuels are interchangeable; and in many cases where boilers have specially been adapted to use coke to the best advantage, results have been obtained that tend to prove that 1 lb. of coke of average good quality has a net effective evaporative value of 9 to 10 lb. of water, from and at 212° Fahr., while the rate of combustion maintained is sufficient to ensure not only the normal boiler output, but also a margin in capacity for emergencies.

In ordinary circumstances, an average rate of combustion of 12 to 16 lb. of suitably graded coke per square foot of grate area per hour can be maintained with natural draught only. With a suitable forced draught furnace, 25 lb. is a good average rate, while the best results probably are obtained with coke fired under conditions of balanced draught. The almost complete lack of volatile combustible in coke renders it specially suitable for use under this system of draught; and its intense radiant effect and freedom from hydrogen no doubt account to a large extent for its relatively high efficiency as compared with coal. In ordinary practice 14 to 16 per cent. CO_2 is maintained in the flue gases of coke-fired boilers, indicating an excess of air of only 30 to 50 per cent. (with a correspondingly high furnace temperature) as compared with 75 to 100 per cent. excess in good coal-fired boiler practice; and it is probably a fuller appreciation of this important factor, the restriction of excess air, that has led many engineers to adopt coke as fuel for steam raising.

The great diversity which exists in types of hand-fired steam boilers, and conditions of working, makes it impossible to lay down any hard and fast rules for firing coke. The variations and combinations of load and working conditions met with in ordinary industrial steam-boiler practice are indeed of almost infinite variety. In addition to fluctuations in demand for steam, according to seasonal and load conditions, in different trades and industries, there are wide variations in fire-bar spacing, proportion of grate area, and in draught conditions.

The demand for steam, or load on the boiler, governs the quantity of fuel which must be consumed. This figure varies from as low as 8 lb. per square foot of grate area per hour to 30 or 40 lb. In the case of express railway locomotive boilers, which, probably, are the most inefficient of all steam boilers, rates approaching 200 lb. are maintained for considerable periods. Although the locomotive boiler was primarily designed for use with specially prepared "locomotive" coke as fuel, when running schedules were less strenuous, the express locomotive fire-box of to-day is totally inadequate in capacity and grate area to permit of the necessary rate of fuel consumption with anything but free-burning coal of good quality, notwithstanding the fact that the draught pressure frequently exceeds 10 inches. There is, however, no adequate reason why local and shunting locomotives should not revert to the use of coke, as they did successfully during the War.

Where load conditions and plant capacity permit, as they frequently do at pumping stations, public institutions and certain factories, where the load is constant and uniform, the rate of fuel consumption is wisely restricted to the economic maximum.

In the case of one London public utility authority whose yearly fuel consumption runs into a quarter of a million tons, the maximum aimed at with a certain description of coal is about 10 lb. per grate-foot-hour; and the very admirable results obtained certainly fully justify the maximum adopted.

It is not, however, suggested that in ordinary industrial practice such a maximum rate would be economically possible. Such a course, if pursued, would indeed necessitate the provision of a large increase

in grate area, as the average rate for hand-fired boilers is probably from 14 to 18 lb. per grate-foot-hour.

These rates are frequently exceeded in cases where the output of factories has been allowed to outgrow the normal steam plant capacity, and, in passing, it may be stated that there is no more potent factor in aggravating the smoke nuisance than the overloading of coal-fired steam boilers in this manner; and it is precisely in this connection that restrictive legislation might be made to operate effectively.

In mechanically coal-fired boilers, where adequate provision is made for continuous and automatic removal of refuse from the furnace, rates of 20 to 30 lb. per grate-foot-hour under ordinary natural draught conditions are quite common. Under forced draught, or balanced draught, conditions these rates are sometimes exceeded.

In hand-fired boilers, the limiting factor, apart from draught, which determines the maximum rate of fuel consumption, is the length of time the fire can satisfactorily be maintained without cleaning, while using fuel of a given ash content. In the case of a hand-fired boiler, having 36 square feet of grate area, burning fuel containing 12 per cent. ash at the rate of 20 lb. per grate-foot-hour, the amount of refuse to be removed from the furnace after a four-hours' run would be about 3 cwt. In cleaning boiler furnaces, a necessary preliminary step is, ordinarily, the "burning down" of the fires, which, together with the actual cleaning operation, occupies a considerable period, and inevitably entails the risk of loss in steam pressure. Added to this is the time required to re-establish the fires and work them up to normal temperature.

A stoker attending to four boiler furnaces (2 Lancashire boilers), consuming fuel at the rate of 20 lb. per grate-foot-hour, has therefore little time to devote to duties other than those of actually firing the fuel, regulating the feed and cleaning the furnaces; and although in practice this rate is sometimes exceeded, it may be assumed that it represents about the limit physically possible. Sixteen pounds of fuel burnt per grate-foot-hour would be, and actually is, in many cases about the maximum average rate. In a Lancashire boiler having 36 square feet of grate area, this rate of coke consumption, with an average evapora-

tion of 9 lb. of water per lb. of coke, gives an output of 5000 lb. of steam per hour, a result that in all but exceptional cases would be regarded as satisfactory for a hand-fired boiler.

In the case of hand-fired boilers with a satisfactory natural draught, an average hourly rate of coke consumption of 16 lb. per square foot of grate area is frequently maintained; and where forced draught is available, this rate is often exceeded.

It is therefore clear that with coke exclusively as fuel the output of hand-fired steam boilers can be maintained at the normal rated capacity.

A factor which has an important bearing upon the rate of combustion of coke, and consequently upon the output of the boiler, is the grade or size of the coke as fired. Obviously, with coke broken to an average size of $1\frac{1}{2}$ -inch cube, a much greater area will be exposed to the process of combustion than with pieces of, say, 4-inch cube.

Experience tends to prove that, other conditions being the same, the maximum rate of combustion in steam boiler furnaces is attained with coke graded from 1-inch to about $1\frac{1}{2}$ -inch cube. It does not follow, however, that in all circumstances coke of this size is best. Due regard must be had to draught conditions and to the size of the furnace, and the combustion space available. For instance, in tests carried out with the larger-sized vertical boilers of the Cochran type, the best results, as regards both efficiency and output, were obtained with ordinary ungraded coke; and similar results probably would be obtained with the large capacity brick-lined furnaces common to most hand-fired water-tube boilers.

The thickness or depth of the fuel bed, relative to the size of the coke, is another important factor bearing upon efficiency and output. Generally speaking, the larger the coke the thicker should be the fire, and *vice versa*, excepting, of course, in the case of coke breeze, which is often most advantageously fired heavily on a special breeze-burning grate.¹

Unlike coal, which requires ample space to allow for the combustion of the volatile gases evolved during the preliminary process of heating

¹ The subject of steam-raising with coke breeze as fuel is dealt with exhaustively by Mr. W. F. Goodrich in his recent book on Low Grade Fuels.—AUTHOR.

and distillation, coke requires little or no such space; the aim in firing coke to the best advantage should therefore be to maintain the fire in close proximity, and, so far as possible, actually in contact with the heating surfaces of the boiler.

In this connection, internally fired boilers, which almost invariably have restricted fire-box capacity, are, when fired with bituminous coal, among the worst offenders in the matter of smoke formation and emission, while the low-set, externally fired water-tube boiler is probably the most prolific producer of coal smoke; and it is no doubt largely due to this common feature in steam-boiler design, which tends towards inefficiency in coal firing, that coke can compete so successfully with coal, both in the matter of output and cost.

The U.S.A. Bureau of Mines has investigated the effects of thickness of fuel-bed and air velocity on the products of combustion in hand- and mechanically-fired boiler furnaces. The results of a typical set of experiments with coke are given in the following table for a fuel-bed of 12 inches:

Distance from Grate at which Sample was taken.	Coke Fuel-Bed.			Temperature of Fuel-bed. ° Fahr.
	Per Cent. CO ₂ .	Per Cent. O ₂ .	Per Cent. CO.	
1.5 inch.	5.7	14.6	0.7	2165
3.0 "	7.2	13.3	0.3	2329
4.5 "	14.0	6.2	0.6	2437
6.0 "	15.5	0.0	8.5	2395
7.5 "	12.0	0.0	14.3	2212
9.0 "	9.7	0.0	18.2	2160
10.5 "	6.1	0.0	24.6	1722
12.0 "	6.8	0.0	21.4	—
13.5 "	10.6	1.3	14.2	—

From the above table it will be observed that the oxygen is almost completely consumed in the first four inches, at which point the waste products contain the maximum carbon dioxide and the minimum of carbon monoxide. This also is the point of maximum temperature.

Above this point (4 inches) reaction commences and CO_2 is rapidly converted to CO , while at the surface (12 inches) only 6.8 per cent. CO_2 is obtained and over 20 per cent. carbon monoxide gas which, together with its latent heat, is liable to be wasted unburnt or only partially burnt. The adverse effect of over charging a coke fire is indeed rendered obvious by the mass of pale blue flame produced, indicating reaction and the incomplete combustion of the carbon monoxide gas thus formed. This reaction is known as an "endothermic" or heat-absorbing reaction.

Due allowance should, of course, be made for the size of the coke as fired, but there would appear to be no advantage in exceeding a thickness of about 6 inches, except perhaps in special circumstances.

These investigators have also reached the conclusion that with ordinary rates of combustion it is unnecessary to exceed 6 inches in fuel-bed thickness in order to obtain a high CO_2 and a low oxygen content of the waste gases.

Thicker fuel-beds have also the disadvantage of imposing a greater resistance to the flow and distribution of air supply to the fuel, and moreover, they tend, not to increase, but to reduce the rate of combustion.

Draught regulation is probably the most important factor in obtaining, and maintaining, efficient combustion. Excess of air, it has been shown, entails loss of heat in the flue gases. Excess air may be admitted not only through the fuel-bed, but also by in-leakage through brickwork, smoke-box and flue-door joints, etc. A negative pressure, or suction, over the fire is therefore to be avoided so far as possible; but with natural draught above the fire a negative pressure is unavoidable; whereas with forced draught the chimney damper can be so far regulated that the "pull" over the fire is at zero, and in the flues reduced to the minimum, thus tending to prevent the in-leakage of cold air through brickwork and faults or holes in the fire-bed.

This system, known as the "balanced draught system," is, as already pointed out and detailed in a later chapter, particularly applicable to coke-firing, as the complete combustion of coke, fired on proper lines, eliminates the necessity for the admission of secondary air over the fire or at the furnace bridge. The balanced draught system was first introduced and

patented to work in conjunction with an air heater, by Messrs. Davy Brothers, of Sheffield.

Hand-fired boilers of the Lancashire type are in point of number by far the most extensively employed in this country, and statistics tend to prove that the average thermal efficiency obtained in ordinary everyday practice is about equal to that obtained with mechanically fed boilers, *i.e.* about 50 to 60 per cent.

TABLE I
SPECIMEN DAILY RECORDS OF COKE-FIRED LANCASHIRE BOILERS

Date.	Economiser.		Pounds of Water evaporated per Pound of Coke as fired.	
	Inlet.	Outlet.		
	Deg. Fahr.	Deg. Fahr.	Actual.	From and at 212° Fahr.
June 27 . . .	120	240	9-06	10-18
" 28 . . .	115	225	8-31	9-35
" 29 . . .	120	215	8-67	9-74
" 30 . . .	120	210	8-45	9-49
July 1 . . .	120	215	8-84	9-93
" 3 . . .	120	210	9-0	10-11
" 4 . . .	120	230	9-38	10-54
" 5 . . .	120	225	8-93	10-02
" 6 . . .	120	225	9-03	10-14
" 7 . . .	120	225	8-60	9-66
" 8 . . .	120	240	9-16	10-29
" 9 . . .	115	225	9-02	10-13
" 10 . . .	115	225	9-52	9-57
" 11 . . .	110	230	8-87	10-05
				Av. 9-9 lb.

NOTES

1. Inlet temperature maintained by means of live steam for which no allowance has been made.
2. Average pressure (24-hour day) 60 lb. Natural draught only.
3. Average fuel cost of evaporation per 1000 gallons, from and at 212° Fahr.—20s. 1d. Coke at 45s. per ton.

Table I. gives results summarised from the daily boiler reports of an important public institution where the annual coal consumption was 3000 tons. A brief analysis of the figures will show that while this

steam plant is working at a lower fuel cost than most similar plants fired with coal at prices now ruling, the overall thermal efficiency (approximately 78 per cent., assuming the average calorific value of coke at 12,000 B.Th.U.) is well above the average realised with coal-fired boilers and economisers. In addition to the saving in weight of fuel actually fired as compared with the bituminous coal formerly used, namely, 10 per cent., or 300 tons per annum—the yearly saving that would accrue to the nation, in residuals recovered in the process of gas making, by the substitution of coke for raw coal as fuel on this plant alone, includes 33 tons of sulphate of ammonia, 12 tons of raw material for dyes, motor spirit, etc., and the numerous fuel and other industry-promoting products of 30,000 gallons of coal tar.

Table II. gives comparative results obtained with coal and coke, of equal calorific power, and coke breeze, on hand-fired Lancashire and Cornish boilers, and mechanically fired B. & W. boilers, under natural, balanced and forced-draught conditions.

TABLE II
COMPARATIVE FUEL COSTS OF BOILERS FIRED WITH COAL,
COKE AND BREEZE

	Coal.	Coke.		Breeze.	
		Balanced.		Impelled.	
	Natural.	Hand.		Mechanical.	
	Mechl.	Lanc.	Cornish.	B.&W.	B.&W.
	W. Tube				
System of draught	Natural.				
System of stoking	Mechl.				
Type of boiler	W. Tube				
Grate surface, sq. feet	87-88	36-0	29-0	81-0	50-0
Fuel per grate-ft.-hr., lb.	26-9	15-0	16-1	25-2	28-28
CO ₂ , per cent.	8-0	14-0	16-0	14-5	11-7
Excess air, per cent.	130-0	48-0	28-0	43-0	75-0
Fuel loss, per cent.	23-0	13-0	11-0	12-5	16-5
Calorific power, as fired, B.Th.U.	12,000	12,000	12,000	10,083	9018
Evaporation from and at 212° Fahr. per lb. of fuel as fired, lb.	7-5	9-8	9-8	7-84	6-59
Plant efficiency, per cent.	60-3	78-8	78-8	75-1 ¹	71-01 ¹
Fuel cost, per ton.	45s.	45s.	45s.	22s. 6d.	22s. 6d.
Fuel cost, per 1000 gals. evaporated from and at 212° Fahr.	26s. 9d.	20s. 6d.	20s. 6d.	12s. 10d.	15s. 3d.
Financial saving effected	—	23%	23%	52%	42%

¹ No economiser or superheater.

The highest authorities are agreed that when using free-burning coal of good quality the best results are as a rule obtained at an average consumption of about 18 lb. per grate-foot-hour on hand-fired furnaces, and 20 to 22 lb. per grate-foot-hour on mechanical stokers. These rates, as already mentioned, are maintained with coal under natural draught only; but whereas coal does not necessarily require a high air velocity through the fuel-bed, it is an advantage to apply forced draught in burning low volatile fuel such as coke. With the latter system, the draught can, as a rule, be balanced in the furnace and the consumption can be increased considerably without adversely affecting the efficiency of combustion.

Certain types of mechanical stokers can maintain efficiently a rate of 30 to 40 lb. of coal per grate-foot-hour, as already stated, but this rate is regarded by some authorities as too high for general practice, as it leaves no margin for increase in case of emergency, except at the cost of reducing very seriously the furnace efficiency. In considering existing natural draught furnaces, both hand and mechanically fired, it cannot be too strongly emphasised that each, according to draught and other conditions, has its economic maximum capacity, for fuels of different descriptions and different grades, which cannot be exceeded without reducing efficiency.

In this connection there is scope for systematic investigation, and the results of research, instituted by the Fuel Research Board, are expected to be of great interest and importance. Meanwhile, figures, taken from the daily records kept at a London hospital, may be given as indicative of the very excellent results obtainable with graded gas coke of ordinary quality, burnt under suitable conditions. (Table III.)

It has been the author's privilege to visit many of the London hospitals and other public institutions with a view to investigate fuel practice, and to estimate the saving, if any, that could be effected by substituting coke for coal as fuel for steam raising. While conditions of load are as a rule of similar character, the fuel cost of steam raising at these institutions was found to vary considerably. That remarkable financial economies have in some cases been effected is shown by the case quoted on page 63. The results there obtained are confirmed by the following figures (Table III.) from another similar institution :

TABLE III
BOILER EVAPORATION TESTS

Date of Test.	December 6 and 7, 1920.	June 6 and 7, 1921.	March 6 and 7, 1922.	July 31 and August 1, 1922.	September 29 and 30, 1922.	March 5 and 6, 1923.
Boilers at work	Nos. 1, 2 and 3	Nos. 2 and 3.	Nos. 2, 3 and 4	Nos. 1 and 4	Nos. 2 and 3	Nos. 2, 3 and 4.
Duration of test	24 hours	24 hours	24 hours	24 hours	12 hours	24 hours
Description of fuel	Coke, broken	Coke, broken	Coke, broken	Coke, broken	Coke, broken	Coke, broken
Quantity of fuel used	22,400 lb.	13,440 lb.	16,668 lb.	9,632 lb.	6,946 lb.	16,912 lb.
Quantity of ashes and clinker	2996 lb. ; 13.3%	1596 lb. ; 12.7%	2046 lb. ; 12.2%	1540 lb. ; 16%	680 lb. ; 10.45%	2402 lb. ; 14.2%
Moisture in fuel	8.3%	2.1%	5%	3.3%	4.8%	1%
Quantity of water used	19,140 gals.	11,790 gals.	15,630 gals.	10,220 gals.	6,339 gals.	17,250 gals.
Lbs. water per lb. of fuel, actual	8.5 lb.	9.4 lb.	9.36 lb.	10.61 lb.	9.74 lb.	10.2 lb.
Average temperature feed water at economiser outlet	227° Fahr.	213° Fahr.	208° Fahr.	183° Fahr.	182° Fahr.	219° Fahr.
Average steam pressure	87.5 lb. per <input type="checkbox"/> in.	85 lb. per <input type="checkbox"/> in.	70 lb. per <input type="checkbox"/> in.	73.6 lb. per <input type="checkbox"/> in.	71.2 lb. per <input type="checkbox"/> in.	76.4 lb. per <input type="checkbox"/> in.
Evaporation from and at 212°	9.01 lb.	9.85 lb.	10.25 lb.	10.8 lb.	10.7 lb.	11.05 lb.
Average fuel per square foot grate per hour	9.4 lb.	8 lb.	7 lb.	6 lb.	8.2 lb.	7.1 lb.
Average outside temperature	—	—	—	49° Min. 69° Max.	53.5° Fahr. —	32° Min. 49° Max.
Efficiency of boiler and economiser	83%	84%	89%	87.5%	86.2%	88.4%
Calorific value of fuel	10,530 B.Th.U.	11,400 B.Th.U.	11,130 B.Th.U.	11,983 B.Th.U.	11,633 B.Th.U.	12,133 B.Th.U.
Grate area—33 square feet per boiler (Lancashire).						

The following table, which shows the approximate fuel cost of evaporation per 1000 gallons from and at 212° Fahr. with coke and various descriptions of coal in common use, is compiled from figures obtained in ordinary everyday practice :

TABLE IV
APPROXIMATE FUEL COST OF EVAPORATION FROM AND AT
212° FAHR.

COAL SLACK.		HARD STEAM COAL.		SMOKELESS WELSH COAL.		GAS COKE.	
Mechanically Stoked.		Hand Fired: Natural Draught.		Hand Fired: Natural Draught.		Hand Fired: Forced Draught.	
At per ton.	Evaporative Value 7.5 lb.	At per ton.	Evaporative Value 9.5 lb.	At per ton.	Evaporative Value 10.5 lb.	At per ton.	Evaporative Value 9 lb. net.
	Per 1000 gallons evaporated.		Per 1000 gallons evaporated.		Per 1000 gallons evaporated.		Per 1000 gallons evaporated.
s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
19 0	11 4	26 0	12 2	28 0	11 10	25 0	12 4
20 0	11 11	27 0	12 8	29 0	12 4	26 0	12 10
21 0	12 6	28 0	13 1	30 0	12 9	27 0	13 5
22 0	13 1	29 0	13 7	31 0	13 2	28 0	13 11
23 0	13 8	30 0	14 0	32 0	13 7	29 0	14 5
24 0	14 4	31 0	14 6	33 0	14 0	30 0	14 10
25 0	14 11	32 0	15 0	34 0	14 5	31 0	15 4
26 0	15 6	33 0	15 6	35 0	14 10	32 0	15 10
27 0	16 1	34 0	16 0	36 0	15 4	33 0	16 4
28 0	16 8	35 0	16 5	37 0	15 9	34 0	16 10
29 0	17 4	36 0	16 11	38 0	16 1	35 0	17 4
30 0	17 11	37 0	17 5	39 0	16 6	36 0	17 10
31 0	18 6	38 0	17 10	40 0	16 11	37 0	18 4
32 0	19 1	39 0	18 4	41 0	17 4	38 0	18 10
33 0	19 8	40 0	18 9	42 0	17 9	39 0	19 5
34 0	20 4	41 0	19 2	43 0	18 2	40 0	19 11
35 0	20 11	42 0	19 8	44 0	18 7	41 0	20 5
36 0	21 6	43 0	20 2	45 0	19 0	42 0	20 10
37 0	22 1	44 0	20 8	46 0	19 5	43 0	21 4
38 0	22 8	45 0	21 1	47 0	19 10	44 0	21 10
39 0	23 4	46 0	21 7	48 0	20 4	45 0	22 4
40 0	23 11	47 0	22 0	49 0	20 9	46 0	22 10
41 0	24 6	48 0	22 6	50 0	21 2	47 0	23 4
42 0	25 1	49 0	23 0	51 0	21 7	48 0	23 10

CHAPTER IX

EVAPORATIVE CAPACITY OF COKE-FIRED BOILERS

THE comparative evaporative capacity of coal-fired and coke-fired boilers is an important factor; and in view of a widespread misconception in this regard, the following extracts from the report of the well-known firm of consulting engineers and fuel specialists, Messrs. Brownlie & Green, bearing upon this and other points in connection with coke-fired boilers at a London dye-works, will be of interest:

“ Dimensions of boilers, 28 ft. × 7 ft. 6 in. Duration of trial, 9 hours; check trial, 1 week. Coke burned per square foot of grate per hour, 22.59 lb. Water evaporated per boiler per hour, 5093 lb. Average CO₂, one week's run, 14 per cent. Percentage CO, nil. Temperature of exit gases, average, 377° Fahr.

“ REMARKS.—When the increase of efficiency due to the superheaters is allowed for, and also the loss in efficiency due to using 3 per cent. of the steam under the fire-bars, the real net efficiency of the plant works out at 86 per cent.

The plant is burning a medium amount of fuel (about 50 tons per week); 5093 lb. of water per hour on boilers 28 ft. × 7 ft. 6 in. is about the correct evaporation for maximum efficiency. It would be possible to force the plant to evaporate more than this, but the efficiency would suffer.

“ The net efficiency of the plant, including economisers, is remarkably high, and we may say is the very best result we have ever obtained in testing boiler plant. The average working efficiency of the boiler plants of this country is between 55 per cent. and 70 per cent., and it is very rare that efficiencies of anything like 80 per cent., are being obtained.

“ The economisers are working fairly effectively, 5.7 per cent.

of the fuel bill being saved. It must, of course, be remembered that, with your system of coke-firing, the amount of heat which gets past the boiler is comparatively small, and although it is possible to save 20 per cent. of the fuel bill with coal fires by installing economisers, this is not the case with coke fires.

“ The range of draught obtainable with your system of steam-jet injectors is ample, and the amount of steam used is only 3 per cent. which is an extremely efficient arrangement. An induced draught fan would take $2\frac{1}{2}$ per cent. to 3 per cent. of the steam, even if well looked after.

“ For many hours your plant is running at 15 per cent. CO_2 , which is practically the theoretical percentage representing the maximum efficiency.

“ This test has been carried out under the normal everyday working conditions of the plant. The actual average heating value of several samples of the damp coke was determined by the Mahler-Donkin Oxygen-Bomb calorimeter.

“ The plant is the most efficient we have ever tested, and it will be quite impossible for us or for any one else to devise any improvement whatever in the working. In our opinion the plant is extremely well looked after, and the firing could not be improved, which accounts for the extreme high efficiency.

(Signed) “ BROWNLIE & GREEN,

“ Consulting Engineers, Manchester.”

From the foregoing remarks on the use of gas coke for steam raising in hand-fired boilers, which might be applied to many of the large number of steam plants now using coke fuel exclusively, it will be observed that :

1. The correct output of steam for maximum efficiency is obtained.
2. It is possible to force the plant to produce more steam in case of emergency.
3. The net thermal efficiency is about the highest attainable.
4. The net efficiency obtained under ordinary working conditions is about 20 per cent. above the average obtained with coal fuel.
5. The saving effected by using economisers with coke as fuel is only

5.7 per cent. ; with coal a saving of 20 per cent. is usually possible, indicating the higher efficiency of coke as a boiler fuel.

6. The rational way to obtain maximum efficiency in boiler plant, as well as smokeless combustion, is to use gas coke as fuel, no costly or elaborate plant being necessary to ensure the best results being obtained and maintained.



CHAPTER X

THE INFLUENCE OF EXCESS AIR

THAT gas coke requires in ordinary industrial practice only the minimum excess of air (30 to 50 per cent.) to effect its complete combustion is, as already pointed out, without doubt the most advantageous feature of this fuel from the view-point of efficiency.

The fortuitous combination of density, or porosity, low volatile and hydrogen content, which characterises gas coke of average good quality, is not possessed by coke of any other description, or by so-called smokeless coal or anthracite. Moreover, gas coke can be cut and graded, without undue loss, to suit the exacting requirements of modern heating apparatus. In specially prepared "smokeless fuel" or semi-coke, these desirable, and, indeed, essential features of a manufactured fuel are non-existent; and it is maintained that the well-known characteristics of gas coke could be varied materially only at the expense of limiting its efficiency as an all round fuel of general utility.

In promoting efficiency in fuel practice, the activities of the Fuel Economy Committee of the British Association are well known. With a view to direct attention to the enormous waste of coal that goes on incessantly as a result of the use in boiler furnaces of excess air in undue quantities, the Committee in a recent Report says: "The most frequent and serious cause of avoidable heat wastage in current boiler practice arises from the fact that large excesses of air are usually drawn through the system."

Coming as it does from a committee of experts, this simple statement of plain fact is a striking commentary on engineering progress in the use of coal as fuel for steam raising. Having regard to all the facts—the pursuit of economy on the one hand, and recurring campaigns against smoke emission on the other—it is, indeed, a lamentable con-

fession of failure. There is also a suggestion of neglect; but the Committee offers no solution to the well-known difficulty of using, with a smoke-producing fuel, only the minimum excess of air, and, at the same time, preventing the formation and emission of smoke.

How many realise that this very problem of burning raw bituminous coal with the minimum excess of air, and at the same time smokelessly, has deeply engaged the energy and skill of hundreds of clever engineers for over a century? A survey of Patent Office records adequately refutes the charge of neglect. Thousands of patents have been granted for inventions relating, directly or indirectly, to improvements in boiler and furnace construction which aim chiefly at the efficient and smokeless combustion of coal.

Latter-day proposals made with a view to improve efficiency and facilitate the combustion of coal with the minimum excess of air include processes which involve elaborate and costly mechanical preparation of the coal before use—washing, drying, pulverising—and also the preparation of colloidal mixtures of powdered coal and oil. But notwithstanding all these expedients and the sustained efforts of many engineers and men of science, the average thermal efficiency of coal-fired boilers has conclusively been shown to be of the order of 50 to 60 per cent., indicating the regular use of 150 to 200 per cent. excess air, possibly in a conscientious desire to comply with regulations as to smoke emission, whereas, with suitably graded coke, boiler efficiencies of over 75 per cent. are obtained, and approximately maintained, in everyday circumstances. It is proposed, therefore, to consider the chief chemical and physical properties of various kinds of solid fuel as a factor bearing upon the efficiencies obtained.

Considered as the ratio of heat delivered to heat received, the expression "boiler efficiency" is really very misleading. As already pointed out, several important factors are usually entirely ignored by engineers in reporting upon evaporation tests and so-called "heat balances." There is, for instance, the degree of skill possessed by the stoker or attendant. In addition to this extremely variable factor, the expression "boiler efficiency" includes at least three others equally important:

(1) The efficiency of the boiler itself, or its capacity for conveying or transmitting heat to the water and steam inside ; (2) "furnace efficiency," or its capacity for converting fuel into useful heat ; (3) "fuel efficiency," which may be described as its "availability" or capacity for being converted from potential energy into useful heat energy.

Obviously, as heating surfaces are clean or fouled with carbon scale or soot, the efficiency of heat transmission through boiler plates and tubes will vary. The boiler furnace and grate area may be too large or too small for the class or quantity of fuel used, there may be air leakages, or more or less fuel may be lost by "riddling" through the grate ; and the furnace efficiency will vary accordingly. The fuel used may be highly volatile, smoky or smokeless ; its use may necessitate a large excess of air, or, if devoid of volatile matter and not too dense in physical structure, it may require the minimum excess of air ; the draught conditions may be good, or indifferent, or totally inadequate to burn the fuel at a high temperature, with a corresponding effect on the results obtained.

Beyond the maintenance of the plant in good condition, the first two factors—*i.e.* the boiler and furnace efficiency—should be incapable of great improvement, except, perhaps, in the matter of draught ; but the third factor, "fuel efficiency," has been proved capable of considerable variation and improvement ; and it is the possibility of effecting improvement and economy in fuel practice by this means that it is now proposed briefly to discuss.

All fuels, whether solid, liquid, or gaseous, are not of course equally efficient ; some require more and some less excess air to effect their complete combustion. By judicious blending or mixing, either before or at the point of ignition, variable and advantageous results are obtainable. Ordinary non-coking bituminous coal containing from 25 to 30 per cent. volatile matter is by far the most extensively used in this country as boiler fuel ; but the large extent to which good coking coal is used directly as fuel is probably the most lamentable feature of the prodigal wastage of our coal resources. The metallurgical coke produced by carbonising this class of coal is absolutely essential in the iron and

steel industries, and the direct use of raw coking coal as fuel for steam raising is strongly to be condemned.

The disadvantages of bituminous coal as fuel have long been recognised ; and that particular characteristic, its low volatilising temperature, is the root-cause of the low average efficiencies realised in its direct use as boiler fuel. Decomposition and combustion are in ordinary circumstances effected in two stages. During the first stage of combustion, as is well known, many of the rich hydrocarbons contained in bituminous coal begin to distil off at temperatures much below those necessary to effect their ignition and complete combustion. They are therefore largely wasted during the first stage of combustion in the form of smoke and deposited soot ; but, as already pointed out, it is this very characteristic of coal which enables it, by the process of carbonisation and by-product recovery, to contribute so largely towards the national wealth.

During the second stage, the fixed carbon or solid residue is consumed as coke. In the steam-boiler furnace, the heat necessary to effect the distillation of the volatile matter is, of course, derived from the partially burnt fuel on the grate. The volatile hydrocarbons burn, or endeavour to burn, with a luminous flame, which, usually, is extinguished almost immediately through lack of sufficient oxygen and by the close proximity of the relatively cool water-tubes and other heating surfaces of the boiler, causing soot to be deposited and smoke emitted from the chimney.

Smoke means waste, but not in the way generally supposed. It has been argued in justification of smoke emission that the carbon contained in black smoke represents only a half of one per cent. of the total carbon in the coal ; but the fact is that the unburnt hydrocarbons carry away with them, not merely their own calorific capacity, but also the heat rendered latent by them in the process of distillation. In ordinary circumstances the volatile matter in a ton of bituminous coal, in the first stage of combustion, evolves 12,000 cubic feet or more of rich combustible gas, and no doubt the escape of large volumes of this gas unburnt, or only partially burnt, together with its latent heat, accounts largely for the waste and inefficiency which appear to be unavoidable in the direct use of such coal as fuel. It may therefore

be accepted that the proportion of volatile matter in coal is in effect a measure of the difficulty experienced in burning it efficiently. Efficient combustion, and, in turn, the efficiency of heat transmission, imply a high "temperature head" and a minimum excess of air; and it may be laid down that that fuel is the most efficient which is capable of being burnt at a high temperature with the least amount of air in excess of that theoretically necessary.

Theoretically, to burn a ton of coal the minimum volume of air required is about 320,000 cubic feet, or about 12 lb. of air per lb. of coal. The regular use of 50 per cent. excess, or 480,000 cubic feet, is considered very good practice; but quite frequently an average of 160 per cent. excess, or over 30 tons of air, is used to burn a ton of coal in many steam boilers, giving only about 7 per cent. CO_2 in the flue gases (which, as reference to the diagram, page 77, will show, is equivalent to a heat loss of about 25 per cent.) and a correspondingly low temperature head. These facts prove not only a deplorable state of inefficiency and waste on a colossal scale, but also tend to prove that the adaptation of both boiler and furnace to suit the complex composition and characteristics of our native coal fuels in their raw state is in ordinary circumstances largely impracticable; but in any case there is admission of failure generally to apply, if they do exist, the skill and apparatus necessary to maintain efficiency.

Various remedies of a more or less drastic character have been suggested with a view to obtaining better results with the skill and appliances available, and, at the same time, to recover some of the valuable chemical constituents of coal. These include predistillation at relatively low temperatures; but examination and experiment has so far failed to prove their commercial efficiency. The only process designed to improve availability and efficiency in the use of coal which has stood the test of time and has, during the past century, made steady progress (restrictive legislation notwithstanding) is, as already pointed out, the high-temperature process of carbonisation carried on at gasworks. These now number in this country some 1600, with an annual through-put of 18 to 20 million tons of coal; and with the freedom conferred through

the Gas Regulation Act of 1920, there would appear to be no limit to the possible development of the industry, except, perhaps, an adequate outlet for the gaseous as well as the solid products of the process. For instance, of the 18 million tons of coal used annually in the metropolis, only 4 million tons are carbonised.

The ready disposal of the coke produced is indeed a factor of prime importance in the economic conduct of a gas undertaking, and with this end in view a number of the London gas companies in 1913 combined to promote and extend its use for steam raising. One result of their educational propaganda, conducted by the London Coke Committee, has been to render permanently smokeless a large number of smoky boiler chimneys, and, incidentally, to improve very materially the efficiency of many boiler plants, simply by enabling them to operate consistently with the minimum practicable excess of air. No claim to superior knowledge or skill in firing is made by stokers who fire coke successfully ; indeed, less than the ordinary skill is required to fire coke efficiently, as it contains none of the smoke-producing and elusive volatiles of coal.

IMPROVING AVAILABILITY

The extent to which the availability of coal is improved by high-temperature treatment at gasworks is probably not sufficiently understood or appreciated. Separated by this process, the solid, liquid and gaseous combustible products are not only rendered capable of being consumed without the emission of visible smoke, but, as already explained, the net evaporative value of the solid and liquid fuels (coke and tar) so obtained from a ton of coal is nearly equal to that of a ton of raw coal, as ordinarily used under steam boilers ; the value of the gas, amounting to some 13,000 cubic feet, and also the recoverable benzol and ammonia, being thus rendered almost a clear gain to the nation. The explanation of this improved availability or efficiency is simple. In liquid form, the tar, amounting to some 10 gallons, is readily atomised in an oil-burner by means of an air or steam jet. Burnt completely at a high temperature

with the minimum excess of air, it will evaporate 14 lb. of water per lb. of tar. After allowing for that used in the carbonising process, about 11 cwt. of coke remains available. Fired in suitable circumstances under steam boilers, 14 to 16 per cent. CO_2 can be maintained in the flue gases, with coke as fuel, indicating the use of only 30 to 50 per cent. excess air. The resulting high furnace temperature gives a corresponding high duty, the average evaporation obtained being from 9 lb. to 10 lb. per lb. of coke of good average quality, whereas, at 50 per cent. efficiency, only 6 to 7 lb. is obtained with coal.

Another important factor in maintaining efficiency in fuel use is the outlet temperature of the waste flue gases, which, of course, should be as low as possible. To this end, "economisers" are frequently interposed between the boiler-flue outlet and the chimney, in coal-fired boiler plants. The economiser is, in fact, an apparatus, the conception of which is due to the very inefficiency of coal as fuel. It is an appliance rarely installed in gasworks boiler plants, the reason being that the outlet temperatures of the coke-fired boilers, which, compared with those fired with coal, are relatively low, do not, except in special circumstances, warrant the extra cost of installation and maintenance of economisers.

The combustion of coke is a "single stage" process. Being largely localised and completed at a high temperature within the furnace area, the transmission of heat to the water and steam inside the boiler is effected mainly by direct radiation, and is therefore more complete than that obtained with long flaming coal. The relatively low outlet temperature, or, where economisers are installed, the lower feed temperature, obtained in practice when coke exclusively is used as fuel tends to prove this theory.

In this particular connection, the following extract from the report on a coke-fired boiler plant by Messrs. Brownlie & Green, given in full in a previous chapter, is worth repeating :

"The net efficiency of the plant (86 per cent.) is remarkably high, and we may say is the very best result we have ever obtained in testing

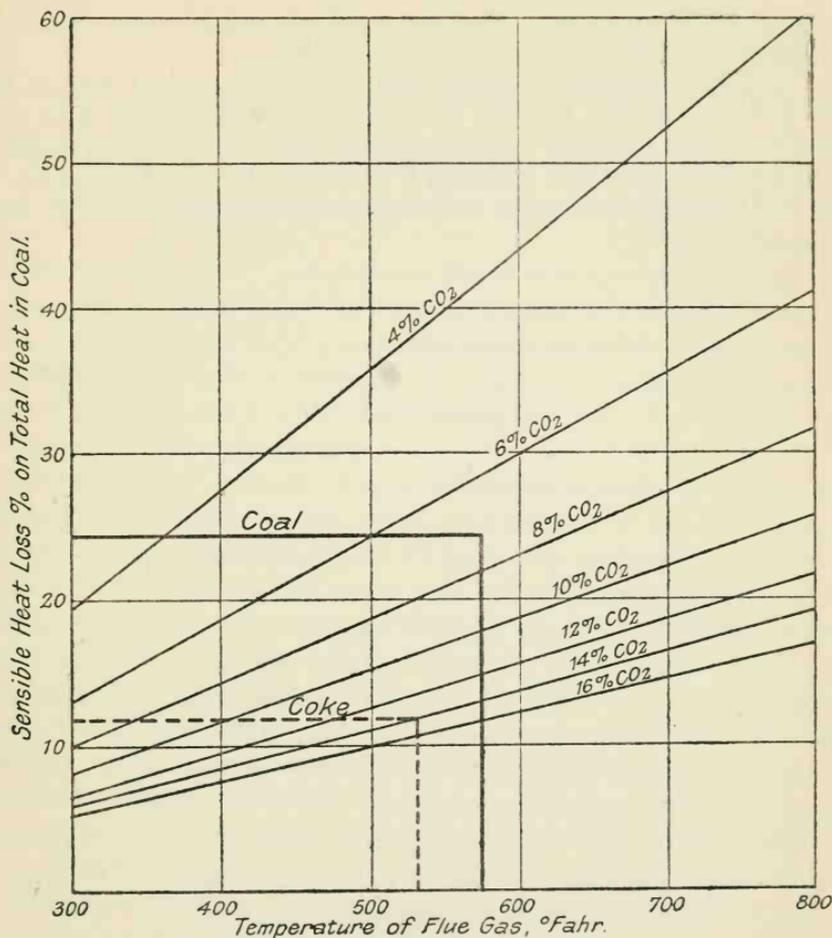


FIG. 11.—PERCENTAGE HEAT LOSS IN CHIMNEY GASES BASED ON TOTAL HEAT VALUE OF AVERAGE COAL WITH DIFFERENT PERCENTAGES OF CO₂ IN GASES.

Note.—The importance of using a fuel which gives, with the least amount of skill, a high percentage of CO₂ in the flue gases and a low outlet temperature, can be seen from the above Heat Loss Diagram. Typical results obtained in ordinary boiler practice with bituminous coal and coke are indicated by the full and dotted lines.

boiler plant. The average working efficiency of the boiler plants of this country is between 55 and 70 per cent., and it is very rare that efficiencies of anything like 80 per cent. are being obtained.

“The economisers are working fairly effectively, 5·7 per cent. of the fuel bill being saved. It must, of course, be remembered that with your system of coke firing the amount of heat which gets past the boiler is comparatively small, and although it is possible to save 20 per cent. of the fuel bill with coal fires by installing economisers, this is not the case with coke fires.”

CHAPTER XI

FORCED DRAUGHT IN FUEL PRACTICE

HAVING regard to its importance as a factor bearing upon economy in fuel practice, the whole subject of draught, as applied to steam generating plant, does not appear to have been adequately discussed by engineering societies, or to be fully appreciated by many steam users, if one may judge by the frequency with which inadequate natural draught conditions are met with in practice.

The use of boiler chimneys of a certain minimum height is often compulsory. But natural draught only, produced by a relatively high temperature and a tall chimney, is still by far the most commonly used. Apart from its relatively high initial cost, and limited capacity, as compared with other systems, natural draught, unassisted by mechanical means, although in many instances perfectly serviceable, cannot be regarded as altogether rational. Natural draught is unavoidably, and often adversely, affected by changes in atmospheric conditions. Beyond a definite and frequently inadequate maximum, attainable only under the most favourable conditions, it cannot go, while it may be necessary temporarily to urge the boiler fires beyond the ability of the chimney to supply the necessary air and to carry off the products of combustion. In other words, while the rate of firing is a variable quantity, the draught available is constant within a fixed maximum limit.

Primarily introduced with a view to increase the rate of combustion and steaming capacity of boilers, forced or mechanical draught was used to augment chimney draught, but mechanical draught has now rightly come to be regarded not merely as a means to accelerated combustion, but as a necessity in producing and maintaining conditions essential to efficient combustion.

The extent of its successful adoption as a substitute for the tall and costly brick chimney, or as an auxiliary thereto, must be accepted as evidence of its convenience and efficiency.

There are, however, many steam users who are unaccountably prejudiced against any system of impelled draught, and who regard it with distrust; and having regard to the fact that impelled and readily controllable draught is specially desirable in coke firing, it may be well, in order to eliminate the element of personal prejudice in favour (which is freely admitted by the author), to give the views of eminent and independent authorities.

The whole subject has been exhaustively and admirably dealt with by the Sturtevant Company, in a volume entitled *Mechanical Draught* (Bartlett Square Press), from which the following extracts are taken:

Mr. W. H. Bryan, in discussing the advantages of mechanical draught in 1896, said: "As a general rule it may safely be stated that the building of tall chimneys to secure draught simply advertises the owner's lack of familiarity with modern improvements or his want of confidence in results easily demonstrated."

Mr. William O. Webber: "Mechanical draught has the following advantages: Less first cost; and the larger the plant the greater the proportion of this saving in first cost. Secondly, the elasticity of this system; and third, the fact that impelled draught is absolutely controllable and is regulated to the pressure of steam in the boilers and the demand upon the boilers for steam; and, finally, it is not influenced by atmospheric conditions. In this latter connection few people realise, unless they have spent much time in a boiler room, how the barometric and wind pressures affect the draught of ordinary brick chimneys. The chief advantage in favour of mechanical draught is, that no matter what the weather conditions are, as good a draught can be obtained at one time as another. This system has been in use long enough now to have demonstrated its practicability and economy."

Mr. Alfred Blechyden, in the *Proceedings of the Institute of Mechanical Engineers*, 1891, pointed out that "it seems fairly well established that if boilers are provided with ample room to ensure circulation, their

steaming power may without injury be increased to about 30 to 40 per cent. over that obtained on natural draught for continuous working, and may be about doubled for short runs. Forced draught enables an inferior fuel to be used, and under certain weather conditions, when it would be impossible to maintain steam with natural draught, the normal power may with forced draught be ensured. In particular cases, any or all of these advantages may be a source of economy; and the first of them may render possible that which would otherwise be impracticable."

Artificial draught, states Mr. W. S. Hutton, in *Steam-boiler Construction*, London, 1891, "can readily be adjusted to effect the combustion of different kinds of fuel at different rates. It permits efficient combustion of fuel of inferior quality, and enables a steady supply of steam to be maintained, independent of climate or weather. It enables the supply of air to be properly distributed to the fuel in the furnace to effect economical combustion."

There is, in fact, no valuable feature of the chimney that is not possessed to a greater degree by any system of forced draught. In 1890 Mr. D. K. Clark, in his book on *The Steam Engine*, testified to the advantage of a rapid, or rather an intense draught in perfecting combustion, and pointed out that a system of forced draught opens the way for increase of efficiency in facilitating the adoption of grates of diminished area in combination with accelerated combustion.

The various systems of impelled or forced draught are divided, broadly, into two methods, "forced" and "induced," namely (1) that in which the artificial air pressure is applied under the fire-grate, the suction due to the chimney carrying off the waste products, and (2) that in which the pull or suction is augmented and applied over the fire by means of a rotary fan, the waste products being discharged, possibly under pressure, to the chimney, near the base of which the induced draught fan is usually placed. Either system can be used separately, or both in combination. Used alone, the latter system, in common with chimney or natural draught, has the disadvantage that it augments the partial vacuum maintained in the boiler flues and thus tends to increase the in-leakage of cold air through cracks, brickwork, etc.

Forced draught applied under the fire-grate is undoubtedly the more popular system. Readily applied to the enclosed ashpit of a boiler furnace by means of a rotary fan, or one or more steam-jet injectors, this system has been applied successfully to many steam boilers with a view to improve the efficiency of combustion and to facilitate the use of coke as fuel.

FLUE GAS TESTS TAKEN ON RANGE OF LANCASHIRE BOILERS, AT WORKS OF GAS LIGHT & COKE CO., LONDON, FITTED WITH WILTON'S PATENT FORCED DRAUGHT FURNACES

Boiler Number.	Fuel.	Steam on Blowers.	CO ₂ .	O.	CO.
12	Coke breeze.	Full.	17.4	2.6	nil.
13	"	"	16.8	3.0	nil.
14	"	"	16.8	2.6	nil.
15	"	"	16.8	3.2	0.6
16	"	"	16.4	2.4	0.6
17	"	"	17.2	2.2	nil.
18	"	"	16.8	2.2	0.8
19	"	"	16.4	2.8	0.4
20	"	"	16.6	3.4	nil.
21	"	"	16.4	3.6	nil.
22	"	"	17.8	2.4	nil.
23	"	"	17.0	3.0	nil.
24	"	half-turn	15.4	3.8	0.4
		Average	16.7	2.8	0.2

The inexpensive and portable steam-jet forced draught apparatus designed and supplied by the London Coke Committee has been fitted to a large number of coke-fired boilers of all kinds, including vertical and water-tube boilers. Attached to the boiler so that the steam-jet injectors maintain a pressure of about $\frac{1}{2}$ or $\frac{3}{4}$ inch water gauge under the fire, the normal output of the boiler is maintained with a moderate consumption of steam at the jets. The steam supply to the jets may with advantage be superheated by passing it through a coil in the boiler flue or furnace front.

Properly adjusted, this apparatus is flexible and simple to control. The steam consumption of the jets, in actual practice, has accurately been ascertained by means of a surface condenser and shown to be about

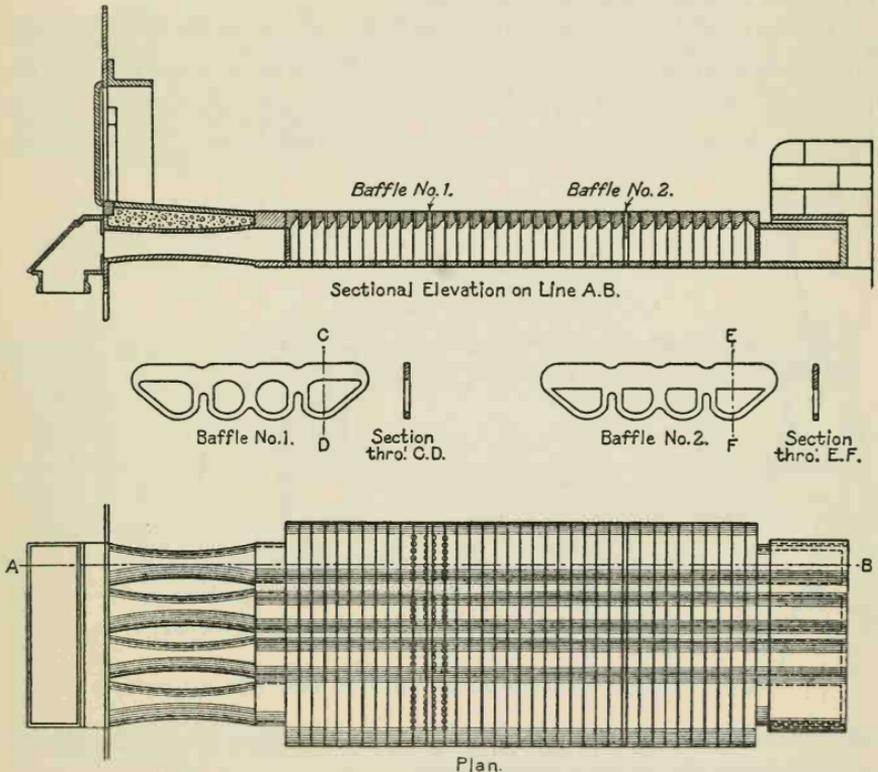


FIG. 12.—THE WILTON FURNACE. GENERAL ARRANGEMENT AND DETAIL OF BAFFLES.
(The Wilton Chemical & Engineering Co. Ltd.).

equal to 3 per cent. of the steam generated. Extracts from an official report detailing the results obtained with coke-fired boilers fitted with this apparatus are given on page 67, from which it will be seen that the normal output of the boilers was maintained, and a margin in capacity held in reserve to meet emergency demands for steam.

An important development of the closed ashpit system of forced

draught was that designed and patented by Crossthwaite, in which the fire-grate is so constructed that it is divided into three or more separate longitudinal sections, each of which is supplied with air under pressure by means of a separate steam-jet injector.

Several excellent examples of this type of forced draught furnace, which are applicable to all types of boiler furnaces, and are suitable for use with coke, are now deservedly popular amongst steam users. These include the well-known Turbine and the Wilton patent furnaces, both

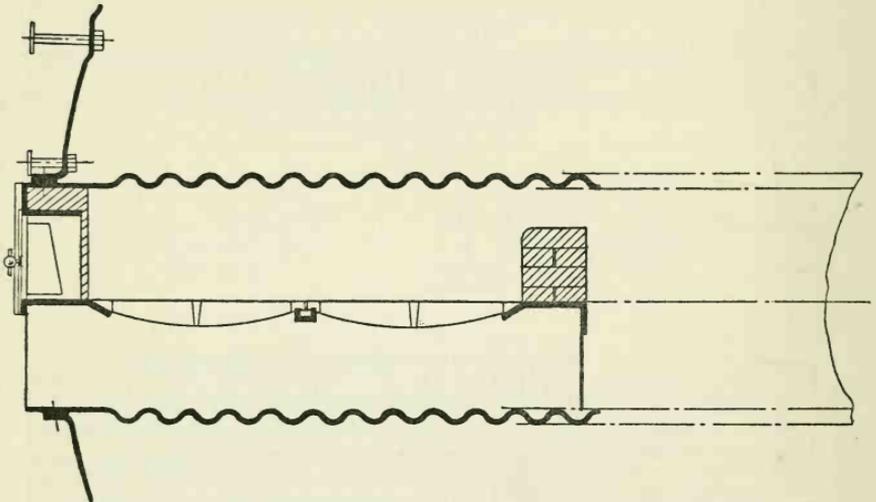


FIG. 13.—NATURAL DRAUGHT BOILER FURNACE WITH VERTICAL BRIDGE.

of which embody special features which tend further to equalise the air pressure over the whole fire-grate area.

A forced draught furnace of this type, installed in conjunction with a Gallagher and Crompton patent Baffle Bridge, and (in the case of Lancashire or Cornish type boilers) a "circulator," probably represents the latest and most efficient furnace equipment available at the present time, capable of consuming efficiently a very wide range of fuels.

Fig. 13 indicates the ordinary natural draught furnace, with fixed fire-bars and vertical bridge wall, which is typical of that in use in a very large number of boilers to-day, and identical with that in use nearly

a century ago. No means, other than the clumsy chimney or flue damper, is provided to control and regulate the draught according to the demand for steam; and no provision is made to facilitate the arduous labour of clinking (the removal of accumulations of refuse from the furnace), or to enable the stoker to maintain the steam-pressure at its maximum while this operation is being carried out. Unless otherwise ordered, this crude type of furnace is, as a matter of course, supplied with all new boilers of the Lancashire type.

Fig. 14 shows a similar furnace, adapted to operate with the simplest

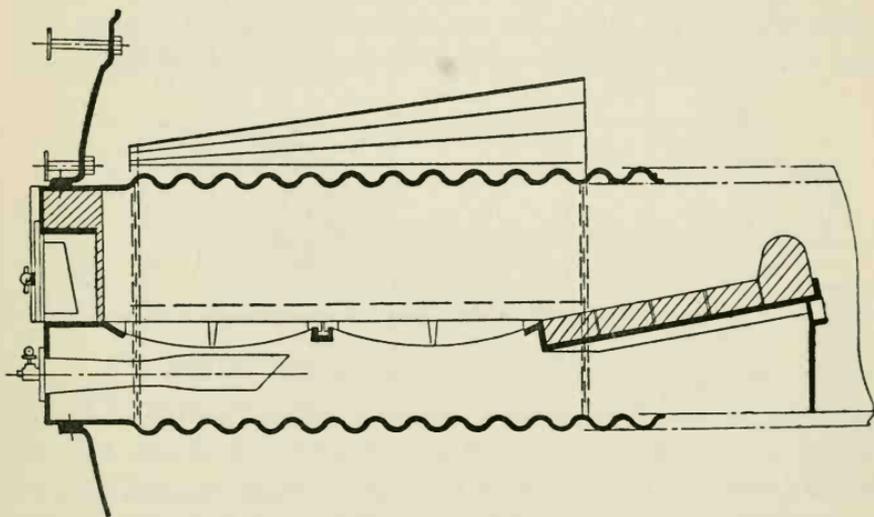


FIG. 14.—FORCED DRAUGHT BOILER FURNACE WITH GALLAGHER-CROMPTON BAFFLE BRIDGE.

form of portable forced draught apparatus, and fitted with the Gallagher patent Baffle Bridge, of which mention has already been made. This latter device has in practice proved efficient and popular among stokers who have used it. Designed primarily to facilitate the cleaning of the furnaces, it serves also to maintain a full head of steam during cleaning; the unburnt fuel being pushed back upon the sloping baffle as in Fig. 15, where it burns fiercely under the influence of the concentrated chimney draught and prevents the inrush of cold air, which otherwise is largely

unavoidable, thus maintaining also the normal chimney "pull" in the adjoining furnace or furnaces connected to the same flue and chimney.

Another desirable adjunct to the modern boiler furnace, which has an important bearing upon improved efficiency, is the "circulator," shown also in Fig. 14. Designed originally and patented by H. Schofield, it has been applied by him to a large number of land and marine boiler furnaces, including those of the ill-fated *Titanic*. This device promotes active circulation of the water in the boilers by directing the convection currents set up by the heat of the burning fuel, thus enabling steam to be raised from "all cold" to working pressure very quickly without undue strain on the boiler. Its use obviously is desirable, whatever the kind of fuel used. With coke as fuel, the combustion of which is largely

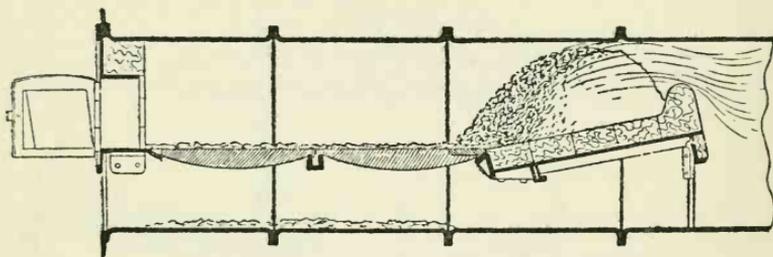


FIG. 15.—GALLAGHER-CROMPTON BAFFLE BRIDGE IN USE.

completed in, and confined to, the furnace area, the provision of some means of improving the sluggish and defective circulation, inherent in the Lancashire type boiler, is specially advantageous and desirable in the interest of efficiency and economy, although in no known case has neglect to do so led to trouble or damage.

The circulator has in practice an additional advantage in that it causes the accumulations of solid matter, or loose sediment, to be deposited in the bottom of the boiler towards the front end, where the "blowdown" valve usually is connected, thus facilitating its removal by the simple process of "blowing down."

In previous chapters, "balanced draught" has frequently been referred to as a system specially suitable for use with coke. As already stated, it is a combination of forced and natural draught, or forced and

induced draught, so adjusted that a neutral atmosphere is maintained over the fire; that is to say, neither vacuum nor pressure below or above that of the surrounding atmosphere.

In addition to preventing in-leakage of cold air through cracks and brickwork, this latter system has the great advantage of reducing to the

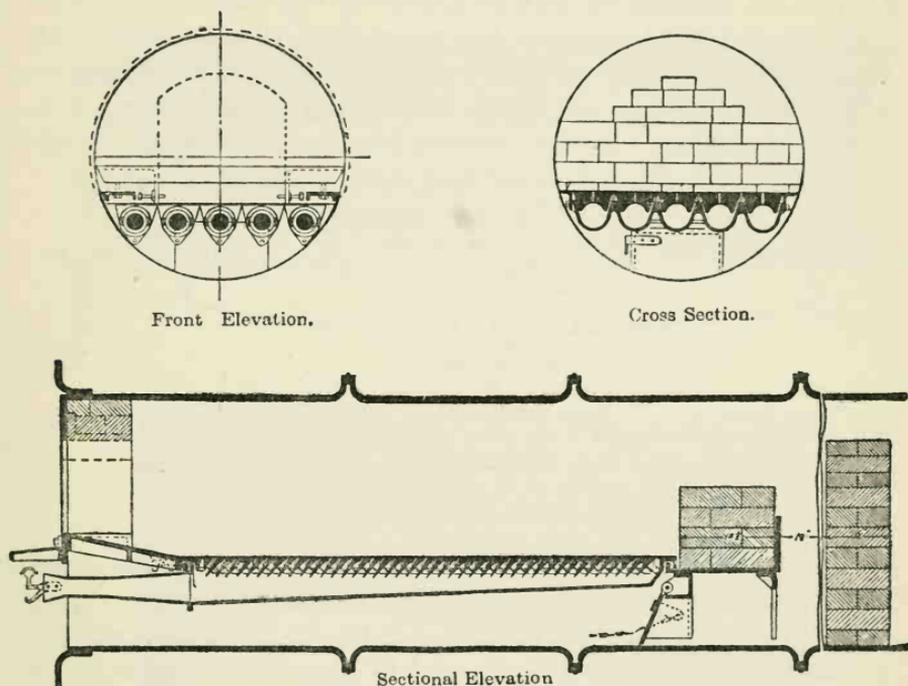


FIG. 16.—THE TURBINE FURNACE.

minimum the speed of the waste gases through the boiler tubes and flues, thus allowing more time for the transfer of heat to the water and steam inside and, at the same time, tending very materially to prevent dust and grit being carried over the bridge wall and discharged from the chimney, a difficulty common to all fuels burnt under forced draught.

Another advantage of forced draught, especially steam-jet forced draught, not, as a rule, mentioned by the makers of this apparatus, has

reference to the cooling effect, and consequently lengthened useful life of the fire-bars, whatever form of solid fuel is used.

It is well known that cast-iron, overheated in the presence of sulphurous compounds, is rapidly distorted and destroyed. For use with relatively weak natural draught, specially heavy and relatively expensive fire-bars are necessary in order to counteract this tendency, fairly frequent renewal being necessary and unavoidable, whereas it is within the knowledge of many users that, after twenty years' continuous use with coke as fuel, steam-jet furnaces of the Crossthwaite type are practically in new condition; and later improved types of furnaces will no doubt prove in this and other respects at least equally satisfactory.

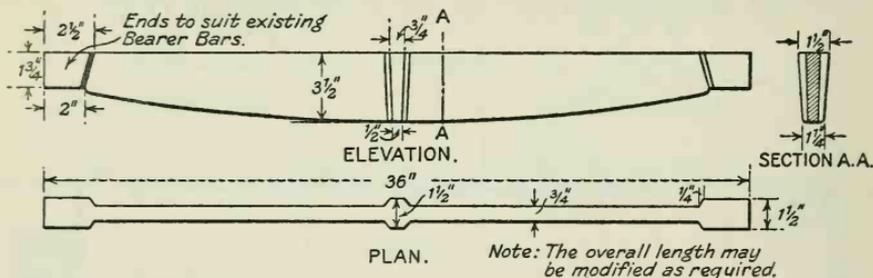
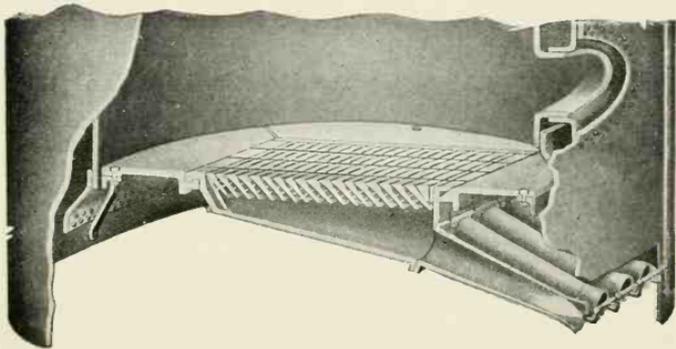
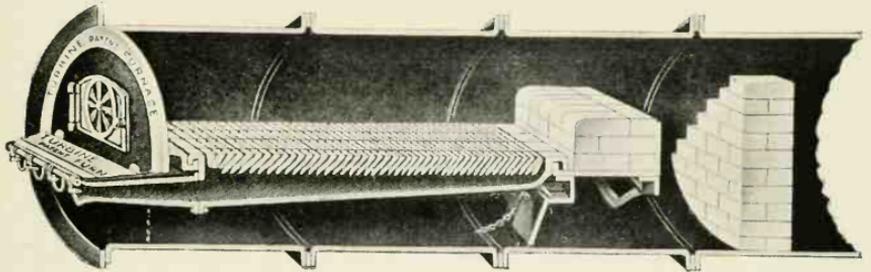


FIG. 17.—COKE-BURNING FIRE-BAR.

The importance of the ratio of air spacing to total grate area, especially in natural draught furnaces, requires emphasising, and as a guide in this connection dimensions are given in Fig. 17 of a fire-bar which in practice has proved over a long period to be specially suitable for use with coke, fired under natural draught conditions; but whatever the air spacing, type of fire-bar, or kind of fuel used, inadequate draught leads to overheating of the fire-grate and the inevitable and unpleasant consequences, not the least of which is the "running" of the fused mineral matter contained in the fuel, and its intimate adherence to the distorted fire-bars. These difficulties may, however, to some extent be mitigated by introducing steam or water vapour into the ashpit.

The adaptation of the Turbine furnace to the Cochran boiler was largely due to the suggestion of Mr. J. Ferguson Bell, the eminent Gas



THE TURBINE FURNACE
AS APPLIED TO LANCASHIRE AND COCHRAN BOILERS.
(The Turbine Furnace Co. Ltd.)

PLATE 4.

[To face page 88.]

Engineer, of Derby, who had installed Turbine furnaces to Lancashire boilers. The Cochran boiler in question was burning 4 tons of large coke per twenty-four hours.

It will be noted that the ordinary grate is removed (Plate 4) and solid segments and Turbine furnace troughs and bars substituted. The existing bearer rings and brackets are used, therefore no structural alterations are necessary. The effective grate area is somewhat reduced and all combustion takes place in the centre square of the grate, where maximum combustion space is available. The furnace is divided into a number of separate units, each consisting of fire-bars with narrow spaces, air trough, injector and steam blower, each unit forming an independent complete furnace in itself.

The air for combustion is forced evenly and automatically between the air spaces of the bars, resulting in an even rate of combustion and an even temperature of the furnace gases.

CHAPTER XII

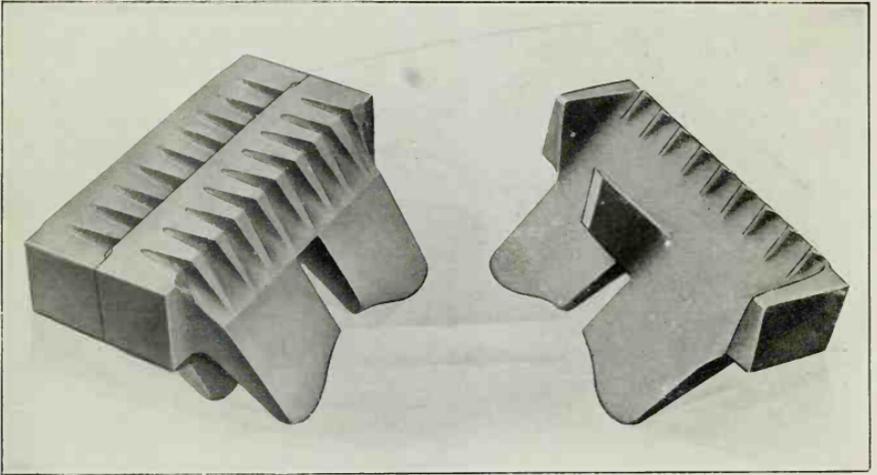
COAL SMOKE

THE popular, but erroneous, conception of visible smoke, issuing from a boiler chimney shaft, is that it is a combustible gas. To this day expert witnesses in police court proceedings against the emission of black smoke can be heard solemnly to testify that "the boiler furnace, in compliance with the Act of Parliament, is constructed to consume its own smoke."

When such palpable errors in description are committed by practical men, and by our legislators, it is not surprising that an unobservant public, not to mention magistrates and county councillors, should become familiarised with such absurdities as "smoke-consuming furnaces" "smokeless coal-grates," and "smoke consumers."

A brief consideration of the nature of the products into which the combustible constituents of coal are converted in passing through a boiler furnace, tubes and flues, should be sufficient to show the error of the popular conception of coal smoke and the waste incurred directly and indirectly by its formation and emission.

Ordinary coal contains from 3 to 6 per cent. of hydrogen, which, on combustion, combines with eight times its weight of oxygen, forming water vapour. Thus, a ton of coal containing 5.25 per cent. hydrogen will, on combustion, form about 900 lb. of water. The waste of heat entailed by the formation of this vapour, and its emission, together with its latent heat, at a high temperature, is of course very considerable; but it is probably not generally realised that this vapour, coloured with a relatively minute quantity of deposited carbon, largely constitutes the black smoke that issues from factory chimneys. There are, of course, other bulky, but invisible constituents that go to make up the cloud—*i.e.* nitrogen and carbonic acid, which, too, are incombustible; and, possibly, a small percentage of carbonic oxide, which will ignite only in favourable conditions at a high temperature.



TURBINE FURNACE. DETAIL OF FIRE-BARS.

PLATE 5.

[To face page 90.

The only visible ingredient of smoke as it issues from a steam boiler chimney is deposited carbon, or soot, which, if collected, can be burnt only with the greatest difficulty. The value of the carbon which produces the darkened colour of black smoke is relatively insignificant, representing as it does probably less than 1 per cent. of the carbon contained in the coal ; but a single grain of soot is sufficient to colour a cubic foot of gas, and its extraordinary light-absorbing property may be gathered from the fact that one grain will render opaque one gallon of water.

This precisely is the argument that in certain quarters has been advanced in an effort to justify the emission of coal smoke. Smoke, and waste, in the broadest sense, are, however, quite rightly regarded as synonymous terms.

The baneful influence of its light-obscuring effect upon health and vegetation are too well known to require repetition here. The destructive effect of sulphurous and carbonic acid, although serious enough, is relatively insignificant, and moreover, it is unavoidable, if industry is to be carried on. The process of coal carbonisation at a high temperature tends to mitigate the destructiveness of combustion products, not only by preventing the formation of visible smoke, but also by eliminating the volatile sulphur, which is recovered as a valuable by-product.

The temperature at which the carbonising process is carried on at gasworks is, as a rule, in excess of that attained in open fires, and indeed, in many boiler furnaces. Thus the sulphur contained in coke is necessarily less than that contained in coal, and, moreover, it is of the fixed variety and consequently less easily volatilised, whereas the volatile sulphur contained in coal forms, on combustion, sulphurous oxide and, ultimately, in combination with the moisture, sulphurous acid, the destructive effect of which is so evident upon clothing and exposed metal work. In American cities that have been rendered smokeless by the compulsory substitution of "hard" for "soft" coal, there is, however, no complaint regarding the effects of these invisible products ; the immediate and most pressing need is the elimination of the sun-obscuring visible matter suspended in coal smoke.

The following note, by an eminent bacteriologist, taken from the

London Evening News of 22nd June 1923, carries, in this connection, fresh conviction and should tend to promote the cultivation of a "sanitary" as well as a "coal" conscience among those who, by seeking to justify the emission of coal smoke, would subjugate the well-being of the community as a whole to the selfish interest of a relatively small minority who evidently attach no importance to such matters :

- " In the course of a judgment which he gave this week, Mr. Justice M'Cardie expressed the view that the germs of tuberculosis may 'hang about the house' for six months after a patient suffering from the disease has left it.
- " Some recent experiments strongly, indeed emphatically, support that opinion.
- " Cultures of germs which had been preserved in sealed glass tubes or dried on silk threads for from fourteen to twenty years were submitted to examination. The astonishing discovery was then made that many of them were still alive.
- " This was the case with the bacilli of typhoid and of paratyphoid fevers, and also with a germ known as the *bacillus coli*.
- " In a few cases typhoid bacilli were actually virulent—that is, they were capable of producing typhoid fever—after eighteen and a half years of enclosure in sealed glass tubes.
- " Other very hardy organisms were those of lockjaw and anthrax, which were living after nineteen years. Indeed, one culture of the latter disease which had been in a paper capsule for thirty-one years, actually infected and killed a mouse in a few hours.
- " Consequently, there can be no doubt that disinfection after an illness should be very carefully and thoroughly carried out.
- " One of the best of all disinfectants, as the learned judge pointed out, is strong sunlight."

Sir Arthur Holbrook, K.B.E., M.P., writing in the *Pall Mall Gazette* of 8th December 1922, on the subject of atmospheric pollution and the losses due to smoke-fog, says :

- " Our borough councils take almost meticulous care about the scavenging of the streets, but their lack of concern as to the

condition of the 'fenceless fields of air' nullifies to some extent the beneficial effects of sublunary sanitation.

- " The explanation is that a dirty sky—a sky fouled by a smoke screen similar to the one which has of late converted day into night over the metropolis—absorbs the golden health-giving rays of the world's greatest antiseptic—the sun.
- " The true test of this is the Registrar-General's returns of the death-rate in any winter. As the shadow of the sun rises—that is, as the sunshine strength shrinks—the death-rate mounts up. During the past few years medical men have been testing the effects of direct sunlight on healthy and sick people.
- " So impressive have the results of these experiments proved that still wider therapeutic uses of sunlight are now in contemplation.
- " The sunlight is, in fact, our 'sure shield' against most of the germs of disease, if allowed to pass, unfiltered by smoke or fog, to the earth's surface. Here, then, is a new argument in favour of smoke abatement.
- " On grounds other than those of precious health there are reasons for the abatement of the fog evil. London's fog bill is enormous. Surely this comes into the category of 'waste,' and anything that can be done to save the appalling annual loss inflicted on the community should have the support of all economists.
- " It is computed that 'a London particular' or anything approaching that density, costs £100,000. On an average London experiences at least thirty foggy days per annum, representing a total loss of £3,000,000 a year, but the vast majority of its eight million inhabitants give little or no thought to the matter. Yet their health and their happiness are jeopardised by the standing menace which undermines both, just as it corrodes and destroys the very buildings which house them.
- " They would turn with disgust from the mere thought of eating foul food or drinking or even washing in dirty water. With apparent unconcern they inhale polluted air, and thereby pay a tax in health and life. Atmospheric pollution also acts detrimentally on the lungs.

“ An adult consumes 40 lb. of air daily, as compared with from 2 to 3 lb. of food and from 4 to 5 lb. of water. Forty pounds of sooty air is a pretty poisonous dose to inhale on a foggy day.

“ To-day the evil of belching black smoke grows apace, almost unchecked by law. The fact is, of course, that the general public do not understand that they are being victimised by the wanton neglect of corporations, councils, and Commons.”

The baneful influence of coal smoke upon vegetation, and all that it implies, is probably not fully appreciated. Before Lord Newton's Departmental Committee on Coal Smoke Abatement, it was given in evidence that the scouring effect of deposited soot and tarry acids on cattle and sheep feeding upon grass growing in the vicinity of manufacturing towns, was frequently of a serious character, and, in addition to affecting milk supply adversely, it was in many cases sufficient to cause the premature birth and death of calves and lambs. The reading of this and other evidence which, as a witness before the Committee, he was privileged to see, made a profound impression upon the mind of the author. In quoting it from memory he trusts that no breach of confidence has been committed, and indeed, he would suggest that its publication *in extenso* would probably prove to be a most effective means of awakening public interest. Although the author has no complaint to make, the summarised matter contained in both the Interim and Final Reports of the Departmental Committee appears to do less than justice to the evidence submitted.

CHAPTER XIII

SMOKE PREVENTION

COAL smoke reformers, as well as those who seek "in the interest of British industry" to condone smoke emission, and to postpone smoke abatement legislation, by suggesting the necessity for further "research," are apt to overlook that which has already been accomplished in preventing the formation of smoke and, at the same time, benefiting industry by effecting substantial economies.

From a report ¹ dated Newcastle-on-Tyne, 16th January 1858, and bearing the influential signatures of W. G. Armstrong, Jas. A. Longridge, and Thomas Richardson, the following illuminating extracts are taken. The report is addressed to the Steam Coal Collieries' Association, and deals with the award of a prize of £500 offered by the Association for a practical method of firing Northumberland coal smokelessly. One hundred and thirty competitors entered, and a period of about three years was required in order to test and report upon the various appliances and methods submitted. Finally, the report says :

"We are unanimously of the opinion that Mr. C. Wye Williams, of Liverpool, must be declared the successful competitor, and we therefore award to him the premium of £500 which you offered by your advertisement of 10th May 1855.

"The prevention of smoke was, we may say, practically perfect.

"The results which we ourselves attained exceed, in economic value of fuel, all the results of other competitors' plans. This was chiefly due in a great degree, if not altogether, to the smaller amount of fuel burned per square foot of grate per hour.

"The consequence of this was a more complete absorption of the heat generated, so that the products of combustion escaped from the

¹ *The Combustion of Coal and the Prevention of Smoke*, C. Wye Williams, London, 1858.

chimney at a temperature lower by about 200° when we obtained our best economic results. The great increase in the economic value is also accompanied by a decided increase in work done when perfect combustion is attained and smoke prevented."

The findings of these eminent engineers, as true to-day as they were in 1858, indicate not only the most prolific cause of coal smoke but also reveal unmistakably the surest foundation for the construction of sound smoke abatement legislation and the attainment of a sanitary atmosphere in industrial cities and towns.

The smoke nuisance is no doubt at the present time infinitely worse than it was in the middle of the nineteenth century, the laudable efforts of smoke reformers notwithstanding. This is probably largely due to the consumption of coal having been enormously increased; but steam users and boiler attendants evidently do not yet possess either the skill or the means to fire bituminous coal smokelessly and economically.

In the interim, education in the sciences of sanitation and fuel technology has been acquired by countless thousands, all apparently to no purpose so far as smoke pollution is concerned; and while it is not suggested that in this country there exists a remedy generally and immediately applicable, there is no lack of evidence that in other countries the desired end actually has been accomplished, mainly by substituting smokeless for smoky fuel.

The prohibition in this country of the use of "soft" coal is at present impracticable. The country's resources in smokeless coal are relatively insignificant, and, indeed, after allowing for export, totally inadequate. There is, however, no apparent limitation to the extent to which the supply of smokeless fuels could profitably be augmented by the carbonisation of soft coal; but a necessary preliminary step would be the establishment of some degree of control in order to regulate and direct the hitherto haphazard furnace and fire-grate design and construction, so that, as coke became generally available, conditions suitable to its economic use would be the rule instead of the exception, as it is in many steam-using industries.

CHAPTER XIV

CALORIFIC POWER AS A BASIS OF FUEL PURCHASE

THE recent advent of the therm, as a basis of sale and purchase for gas, will no doubt tend to familiarise the public with the advantages of this system, not only in regard to the purchase of gas, but also solid and liquid fuels.

Being a highly purified manufactured article, the calorific power of gas can be regulated within close limits in order to comply with the requirements of any declared standard, and systematic testing and checking by Government or municipal officials in the interest of the consumer is a relatively simple matter.

The sale of coal, a natural product liable to wide variation in quality, cannot, however, be so regulated. It is sold as a rule upon an arbitrary basis, the price being fixed for the time being mainly by economic or seasonal conditions, and, to some extent, by well-known characteristics, such as smokelessness or low ash content, etc., or according to reputation.

Many large users now purchase solid fuels upon a guaranteed calorific power basis, but as the onus of testing is necessarily placed upon the buyer, it is only those whose fuel consumption is of such magnitude as to warrant the cost and maintenance of a fuel-testing laboratory who can afford this system.

To those in a position to purchase coal and coke upon a guaranteed thermal value basis, coal contractors and the principal gas-supply companies are generally willing to supply on that basis; but there are, as already pointed out, certain colliery owners who, not unnaturally, deprecate the thermal or ash-content basis of sale as being inimical to their interests.

Formerly, the calorific power of any solid fuel, as determined by a calorimetric test, was accepted as sufficient guarantee of quality. It

is now, however, becoming more fully appreciated that mere calorific power, although a useful basis for comparison, is no complete criterion of the economic value or "availability" of solid fuels, especially of such solid fuels as bituminous and semi-bituminous coals.

That due regard must be had to other factors which have a direct and important bearing upon the economic value of solid fuel is now fully recognised by certain large users. These factors include the volatile content and the hydrogen content, which, for steam raising, should be low, and the fusibility of the ash. Physical structure, or density, is also an important factor bearing upon efficiency and utility.

The system adopted by the Metropolitan Water Board, as outlined briefly below, may be regarded as adequate, and calculated to safeguard the seller as well as the buyer.

The system is based upon a basic price and a basic calorific power, with certain conditions as regards size which are suited to the Board's requirements. Payment is actually made upon a sliding scale in accordance with the calorific power of the fuel delivered.

Clause 7 of the Board's conditions of contract says :

"Samples of all steam coals, or coke in lieu thereof, supplied under the contract and delivered undried, will be taken at the time of delivery in the proportion of not less than one sample of every five hundred tons. The Board will ascertain the average calorific value of the fuel accepted during each month by taking the mean of the samples. The calorific value of each sample will be determined in a bomb calorimeter, and particulars of the results forwarded to the contractor. Payment will be made on the basis of the price quoted in the tender, corrected proportionately for variations exceeding 2 per cent. above or below the calorific value stated in the contractor's tender. Thus, for 2 per cent. variation, no alteration in price will be made; for 2.753 per cent. variation, .753 per cent. addition or deduction will be made, and so on. The sampling and tests will be made by the Board's officials, but the contractor is at liberty to send a representative to be present at both."

The tenders accepted by the Board are not always the lowest in price, due regard being had to analyses, and to relative efficiencies, as determined by actual boiler tests, so that, in effect, only those tenders are accepted that are the cheapest when the relative costs of evaporation are compared.

The point that in this connection the author desires to make is further emphasised in the following notes, taken from the admirable Engineering Page published in the *Daily Telegraph* of 23rd July 1923; and, having regard to their important bearing upon this subject, they are quoted at some length :

“ In recent years much has been written about the purchase of coal on its thermal value, and there is little doubt that where much fuel is used, as, for example, in large generating stations, this system must form the main basis of purchase. The suitability of coal for steam-raising purposes may, however, depend on more than its calorific value. The purpose for which it is used, and the method of its consumption, are large factors which must be considered if economical buying is to be attained. The results obtained with any fuel in modern boiler practice may depend upon the adaptability of the fuel, chemically and physically, to the type of stoking and grate devices employed as much as upon the calorific value of the fuel. As good results may accrue from the use of a coal low in calorific value, if properly suited to the grate, as may be obtained from a better grade fuel unsuited in size or chemical properties to the design of the grate.

“ Coals high in volatile matter are the most difficult to burn efficiently, since they yield at a comparatively early stage in their combustion large quantities of rich gas, the adequate aeration of which to ensure complete combustion is not easy in the ordinary boiler grate. An ample supply of secondary air is usually essential to bring about satisfactory combustion and non-smoky conditions. Again, the amount of ash in a coal is not of necessity a guide to its calorific value; still less in the field of boiler practice is it a guide to the amount of clinker discharged from the hearth.

“ The product known as clinker consists of the ash of the coal which may have assumed on the hearth a semi-molten condition together with a greater or smaller amount of the original fixed carbon of the coal. The

conditions which govern the amount of fixed carbon present in clinker are of much importance, and in some cases of more importance than is frequently realised. Consider, for example, the case—a by no means exaggerated one—of a boiler slack having the following analysis: Volatile matter, 28·90 per cent.; fixed carbon, 51·16 per cent.; ash, 16·34 per cent., and having a calorific value of 12,285 B.Th.U. per lb. This fuel was burned under modern conditions in a tubular land boiler, and the resulting clinker contained 17 per cent. of combustible matter. This corresponds to a loss of 3·40 per cent. of carbon calculated on the original coal. The 'available' calorific value thus becomes 11,800 B.Th.U. per lb., a loss of 4 per cent. of the heating value, from this cause alone. Much higher losses than these occur in many cases.

“There are two ways by which carbon may be transferred to the ash discharge: the first is largely a question of the composition of the coal ash, and the second is governed by mechanical effects produced on the grate. If the ash of the coal is of such a composition that it is easily fusible, it may assume a pasty condition on the grate and absorb particles of carbon, covering them over and preventing further access of air.

“The causes of the mechanical loss of carbon include, first, the speed of the grate. Since efficient combustion of any fuel has a time factor, loss of carbon must occur if the period during which the fuel is passing through the furnace is not long enough to effect combustion under the conditions of the hearth. A higher rate of steaming may be produced by speeding up the grate, but it may easily be obtained at the expense of producing a clinker with 25 per cent. combustible matter in it. Second, the actual condition of the grate is another vital factor in the loss of carbon in ashes. A badly burnt grate, owing to distortion, will have gaps in it through which particles of unburnt coal may easily be riddled, and further, will have solid areas through which the air supply cannot pass, and hence unburnt carbon on such areas will be carried through to the ash discharge. Adequate air supply through the incandescent fuel will be an important factor in preventing such loss, as even with a grate in perfect condition and a slow speed of working, loss of carbon must result from insufficient air supply. The third factor which produces these mechanical losses of carbon in ashes, and frequently the greatest of all, is found in the size of the fuels. In one case 12 per cent. combustible matter in the ashes discharging from a modern boiler was obtained

with a chain-grate stoker when the fuel was 1-inch nuts, whilst under the same conditions of working 35 per cent. of combustible matter in the ashes resulted from the use of a fine slack. It is obvious that which of these two fuels is the most economical cannot be decided by merely comparing calorific value and price.

“In view of the fact that modern boiler practice is almost inseparable from the use of mechanical stoking appliances, more attention might be given to the question of the loss of carbon in the ash discharge. It is necessary to determine carefully to what degree of efficiency any particular type and size of coal can be burned on the grates under the conditions with which the plant must operate, before the purchase of such fuels can be regarded as an economical proposition. Calorific value alone is not sufficient. It is the proportion of the heating value which is available on the hearth by the combustion of the fuel that is important.”

In the light of the foregoing statement, the practical value of the Sandwich system as a means of utilising efficiently cheap, semi-volatile coal slack, by facilitating complete aeration and preventing loss due to “riddling,” will be made apparent.

In the tables overleaf, the cost per therm (100,000 B.Th.U.) of good quality Welsh coal and coke are given over a wide range of prices per ton.

Writing in *Combustion*, an American publication, a New Jersey power plant superintendent points out that for industrial purposes nut coke and coke breeze will give results equal to those obtained with similar sizes of hard or anthracite coal. Quoting the results of eight months' experience, he says that during this period approximately 20,000 tons of coke have been consumed in his plant. So far as this particular plant is concerned, it has been shown that coke breeze as a boiler fuel is superior to the mixture of anthracite and bituminous coal that had been used for the preceding six years. In 1921 there was consumed as boiler fuel a mixture of this character which included 33 per cent. run-of-mine bituminous, and the average boiler and furnace efficiency was slightly over 70 per cent. During the year 1922, burning coke breeze, the average efficiency was slightly over 72 per cent.

As its chief combustible constituent is fixed carbon, the calorific power of which is 14,600 B.Th.U. per lb., the calorific power of gas coke

COKE AND ITS USES

APPROXIMATE CALORIFIC VALUES OF COAL AND COKE

WELSH STEAM COAL. Guaranteed Calorific Power, 14,800 B.Th.U.			
Cost per Ton, Shillings.	Lb. per Penny.	B.Th.U. per Penny.	Cost per Therm.
37	5-04	74,592	1-34
38	4-91	72,668	1-37
39	4-78	70,744	1-41
40	4-66	68,968	1-44
41	4-55	67,340	1-49
42	4-44	65,712	1-53
43	4-34	64,232	1-55
44	4-24	62,652	1-59
45	4-14	61,272	1-63
46	4-95	59,940	1-66
47	3-97	58,756	1-70
48	3-88	57,424	1-74
49	3-79	56,092	1-78
50	3-73	55,204	1-81
COKE, SCREENED, UNGRADED. Guaranteed Calorific Power, 12,000 B.Th.U.			
27	6-90	82,800	1-20
28	6-66	79,920	1-25
29	6-43	76,160	1-31
30	6-22	74,640	1-33
31	6-02	72,240	1-38
32	5-83	69,960	1-42
33	5-65	67,800	1-47
34	5-49	65,880	1-51
35	5-33	63,960	1-56
36	5-18	62,160	1-60
37	5-94	60,480	1-65
38	4-91	58,920	1-69
39	4-78	57,360	1-74
40	4-86	55,920	1-78
41	4-55	54,600	1-85
42	4-44	53,280	1-87

CALORIFIC POWER AS A BASIS OF FUEL PURCHASE 103

may readily be estimated from its proximate analysis. Thus if a sample is shown to contain, say, 12 per cent. ash and 4 per cent. moisture, the calorific power may be calculated approximately as 14,600—16 per cent. =12,264 B.Th.U. per lb.

For the heaviest description of gas coke—the product of heavy twelve-hour charges of Durham coal—the minimum space usually allowed is 60 cubic feet per ton, whereas 80 to 85 cubic feet is necessary for the lightest description of vertical coke, *i.e.* nearly double that allowed for steam coal.

The angles of slide and repose for coke, of different grades, on various surfaces are approximately as follows :

Coke on Coke.			Coke on Smooth Concrete.		Coke on Steel Plate.	
	Repose.	Slide.	Repose.	Slide.	Repose.	Slide.
No. 1, graded over 2 ins. . .	43°·7	46°·2	19°·7	20°·7	13°·7	14°·2
Ordinary ungraded . .	44°·5	46°·9	20°·5	21°·6	14°·4	14°·9
No. 2, graded $\frac{3}{4}$ -2-ins. . .	39°·7	42°·1	20°·0	20°·9	17°·2	18°·5
No. 3, graded $\frac{3}{8}$ - $\frac{3}{4}$ -in. . .	39°·0	41°·1	30°·8	31°·8	20°·2	21°·1

CHAPTER XV

COKE AS FUEL FOR MOTOR ROAD TRANSPORT

“THE motor fuel problem is one of ever-increasing difficulty. Petrol at its present price contributes appreciably to make motor road transport of less commercial value than it would otherwise be. Petrol will not be procurable indefinitely, and the end of each year witnesses more anxiety as to the supply obtainable in the future.”—*R.A.C. Journal*.

One result of inadequate railway service has been to divert to our highways an ever-increasing volume of long-distance goods traffic; and apart from the relatively high price of fuel for petrol motors, the steam wagon, and especially the coke-fired steam wagon, fully maintains its superiority for heavy haulage. In organising motor road transport, an adequate, reliable, widely distributed and cheap supply of fuel is a factor of paramount importance.

For steam wagons operating in towns and cities, smokeless combustion is a *sine qua non*; this consideration confines the range of suitable fuels to Welsh coal and coke.

Various boiler makers have demonstrated during official tests that suitably graded gas coke will generate 9 to 10 lb. of steam per lb. of coke, as fired. Under favourable conditions, good quality Welsh coal may exceed this figure by 8 or 10 per cent, but the difference in cost varies considerably and is usually greatly in favour of coke. Taking advantage of this fact, many of the leading steam wagon makers now invariably send out vehicles equipped to use coke fuel only, instead of Welsh coal; others do so only by request. With suitable fire-bars, coke is equally efficient for most types of steam wagons and tractors.

The production of smokeless coal is practically limited to South Wales, whereas coke is produced in suitable form at some 1600 gasworks

located in every city and township. From these works, and from innumerable merchants and dealers, as well as from many roadside supply depots organised in the metropolitan district by the London Coke Committee, the bunkers of steam wagons can be replenished on any inter-city or country journey, usually without deviation from the route, or undue loss of time.

The great advantage of this wide distribution of coke supplies is now recognised by many users, and also by two or three makers of steam wagons who provide special facilities for the use of coke exclusively as fuel. These include the "Garrett," the "Atkinson," the "Sentinel," the "Leyland" and the "Clarkson." Most steam wagons are, however, readily adapted to use coke, but of those specially designed for its use the "Sentinel" is probably the most in evidence.

Thousands of coke-fired vehicles are running in this country on coke exclusively, and their number is increasing. The secret of success from a coke-burning point of view is the design of the boiler. The fire-grate area provided should be large with specially wide air spaces between the fire-bars.

For loads exceeding $2\frac{1}{2}$ tons the steam-driven motor wagon is probably the cheapest form of mechanical transport. As the load is increased from $2\frac{1}{2}$ tons to, say, $8\frac{1}{2}$ tons, steam wagons keep lower and lower in both first and running costs, especially for long journeys.

The low running cost of the steam wagon is mainly due to its relatively low fuel cost, and the lowest fuel costs probably are realised by using graded gas coke.

The actual financial economy of using coke in a steam wagon depends, necessarily, upon the relative price and quality of gas coke and Welsh coal in each district; but that a great deal of work can be done upon a very small quantity of gas coke is proved by the records of the work and fuel costs kept by numerous users of steam wagons in all parts of the country.

To mention but a few examples—supplied by representative users—a standard six-ton "Sentinel," in the ordinary course of its work averages 15 miles run per cwt. of gas coke used, carrying a useful

load of 6 tons, *i.e.* less than 2d. per vehicle mile, with coke at 45s. per ton.

Another "Sentinel" ran from the Midlands to beyond London and back, a total of 320 miles, on one ton of gas coke—thus using fuel at the rate of only 1 cwt. for each 16 miles run—and the average useful load carried all the way in this case was $5\frac{1}{2}$ tons.

Yet another "Sentinel," this time of 3 to 4 ton load capacity and 12 m.p.h. legal speed, shows a day's run of 60 miles, for which only $2\frac{1}{4}$ cwt. of gas coke was used, making an average of nearly 27 miles per cwt. of coke while carrying a useful load of $3\frac{1}{2}$ tons. At 45s. per ton—a high price—the average fuel cost is, therefore, 1d. per mile.

Tests conducted by the Royal Automobile Club Technical Committee on a Clarkson 3-ton steam wagon, having a gross running weight of 6 tons 11 cwt., showed the average coke consumption to be 3.84 lb. per mile, over 219 miles at 12 miles per hour. The calorific power of the gas coke used (an ordinary commercial sample) was stated by the Committee to be 12,486 B.Th.U. per lb. The fuel consumption was, therefore, equivalent to approximately 48,000 B.Th.U. per mile.

Fuel consumption tests conducted in the presence of responsible authorities on ordinary standard 5-ton "Foden" locomotive-type wagons with trailers, having a gross weight of 20 tons, have proved the coke consumption to be from $15\frac{1}{4}$ to $17\frac{1}{4}$ lb. per vehicle mile fully loaded. Various authorities allow averages of 15 to 20 lb. of Welsh coal per mile for a gross load of 17 tons.

With suitably spaced fire-bars the coal and coke consumption of the locomotive type of wagon should be about equal, under similar conditions of load. The financial saving to be effected by substituting coke for coal should, therefore, be approximately equivalent to the difference in cost.

There can be no doubt that coke always gives satisfaction on the score of cleanliness. The driver usually prefers its cleanliness in handling, the mechanic appreciates the absence of soot in the boiler tubes, and the "man in the street" likes best the coke-fired steam wagon because, as it passes him, it leaves no trailing clouds of smoke and soot. The

radius of action of the coke-fired wagon is practically unlimited. The wagon which is dependent on Welsh coal as fuel must of necessity carry large supplies on long journeys, and the loss due to breakage of this relatively friable coal is considerable.

Sir George Beilby, F.R.S., late Director of Fuel Research, has called attention to the fact that coal is now, and is likely to remain, the world's principal source of liquid fuel. Sir George states that "while the world's output of coal is of order of 1500 million tons per annum, the output of petroleum is about 75 million tons." He emphasises the necessity for dealing with the fuel question from the view-point that in this country, the natural source of heat and power is coal, and that unless and until it is

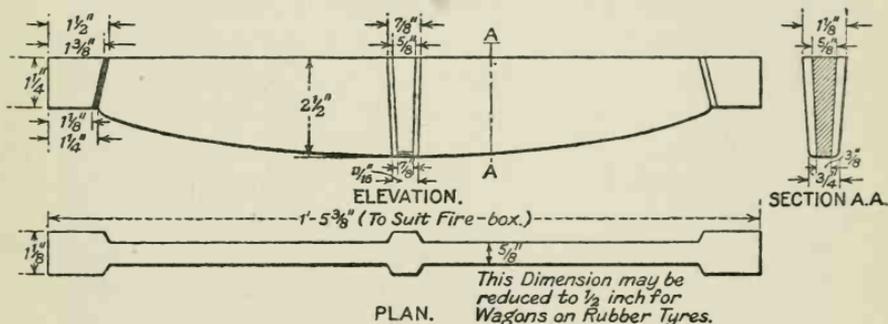


FIG. 18.—FIRE-BAR FOR 5-TON FODEN WAGON.

proved that oil exists here in very large quantities, we have no alternative but to concentrate our best energies on the adaptation of the products of coal to the purpose of transport by sea and land.

As the principal products of coal are gas and coke, these forms of fuel, in the interests of economy and efficiency, should be utilized to the fullest extent. The cost of 1,000,000 B.Th.U. in the form of petrol, at 1s. 6d. per gallon, is about 10s. 6d., or eight times that of coke at 38s. per ton.

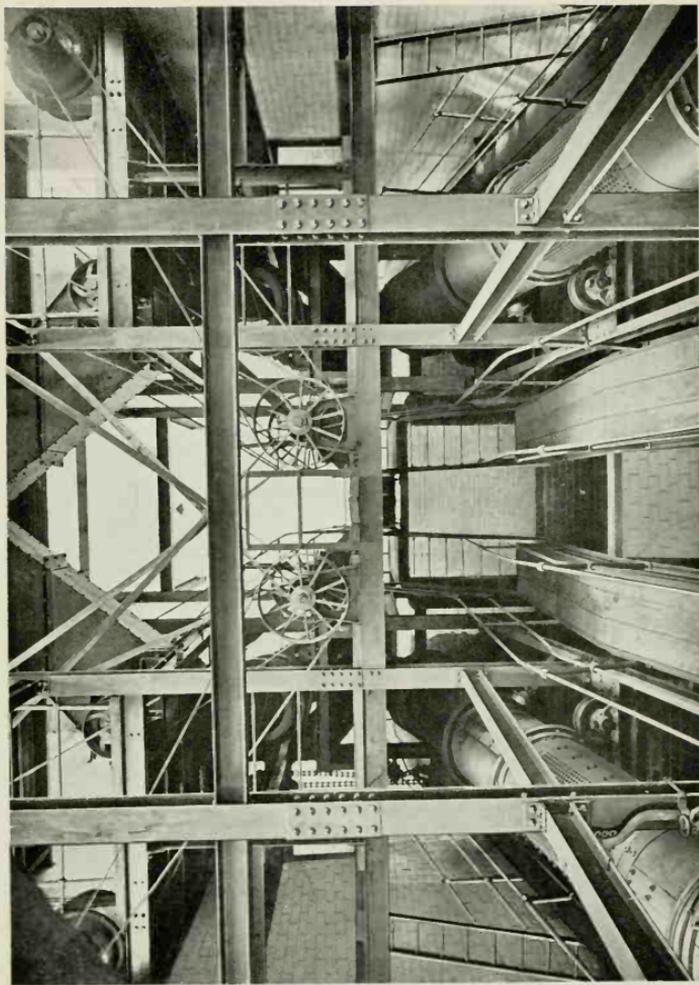
Sir George estimated that there would be 750,000 motor vehicles in use in this country at the end of the year 1921, while in America the number registered was 12,000,000, a figure still growing.

To the motor wagon user, and those contemplating the purchase of

motor vehicles for heavy long distance transport, the most significant feature of the motor fuel problem is the fact that America has already begun to import petroleum. Most steam wagons have in the past been provided by the makers with fire-grates having extremely limited air spaces. These are designed to burn friable Welsh coal without undue waste, and are usually unsuitable for use with gas coke, which is less friable and requires about $\frac{1}{2}$ to $\frac{5}{8}$ inch air spaces for wagons on steel tyres, and slightly more where rubber tyres are used.

Coke-burning fire-grates may be fitted to any type steam wagon at trifling cost, and should always be specified. These should enable coke exclusively to be used as fuel, and the waste due to accumulations of coal dust to be avoided.

Fig. 18 gives details of a fire-bar suitable for use with suitably graded coke.



COKE SCREENING AND GRADING PLANT.
(Dempster & Sons Ltd.)

PLATE 6.

CHAPTER XVI

COKE AS FUEL FOR MARINE BOILERS

THE emission of smoke from the funnels of steamships lying in harbour, and from river and canal steamers, is particularly objectionable, having regard to the low level at which such emission occurs, and to the class of residential property often situated in close proximity to river banks.

In districts where regulations as to coal smoke emission are strictly enforced, the use of relatively expensive smokeless coal is usually considered the only alternative as a means of smoke prevention ; but the utility and economy of coke as a suitable substitute fuel for steam-tugs and pleasure steamers has been proved by long experience.

Powerful tugs, constantly engaged in handling ordinary river transport, have for many years been fired successfully with ordinary gas coke exclusively under both natural and forced draught conditions. In common with all other coke-fired steam boilers, the boilers of these tugs are subjected to the usual annual inspection by boiler insurance inspectors, and investigation fails to reveal any undue deterioration that can be attributed to causes other than ordinary wear and tear.

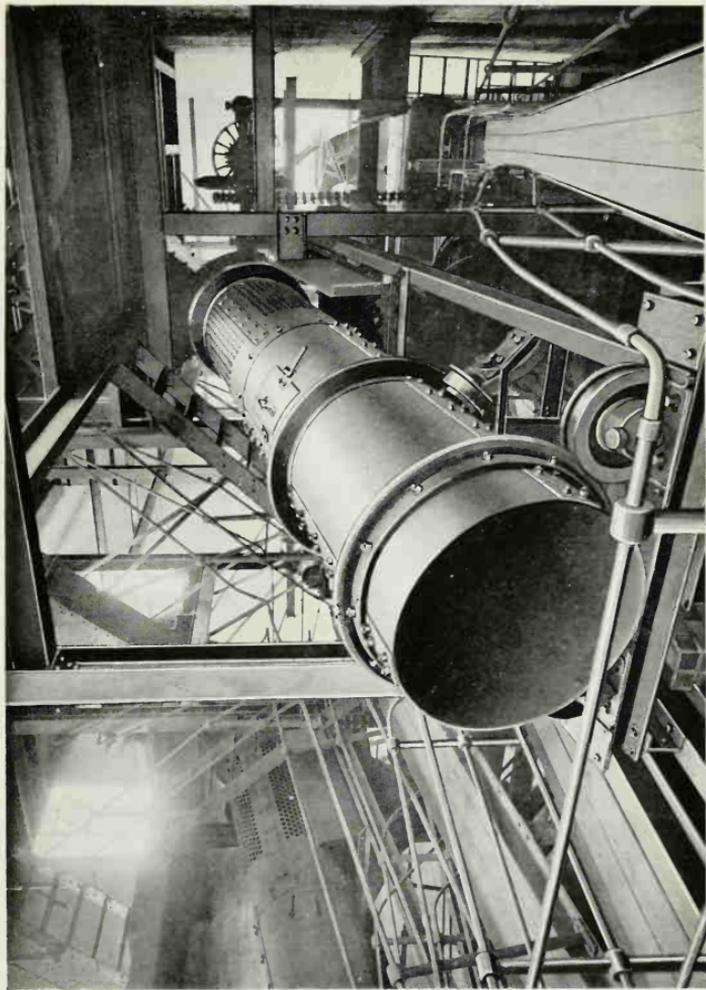
A case in point which will serve to illustrate the economy effected by substituting coke for Welsh steam coal is that of the City Steamship Company which, for several years, operated on the river Thames the passenger paddle steamers built originally to the specification of the London County Council. These boats were fitted with the well-known Howden system of forced draught, but hitherto large Welsh steam coal was considered to be the only smokeless fuel available.

A trial trip with coke exclusively as fuel, undertaken during the most strenuous conditions of tide and load, under the personal supervision of the author, proved that the coke consumption was very slightly, if any, in excess of that of coal. Bunkered regularly from a coke barge

moored in the river, the saving effected, due to the difference in price, was in the aggregate considerable, and was calculated by the manager to be the equivalent of an additional 6 per cent. dividend payable to the Company shareholders.

Although coastwise steamers, trading between London and the North-East Coast, have been bunkered at Thames-side gasworks and fired successfully with coke exclusively over long periods, it is not suggested that the bunker space generally available or the saving to be effected is sufficient to warrant the change from coal to coke in such steamers; but sufficient has been said to show that, in many cases, such craft as dredgers, hoppers, ferry-boats, steam-lighters, tugs, tenders, and river steamers, as well as the donkey boilers of large steamers lying in port, might advantageously be fired with coke.

If the demand for coke for these purposes was shown to be sufficient, adequate and convenient facilities for expeditious bunkering could no doubt be arranged.



REVOLVING COKE SCREENS.
(Dempster & Sons Ltd.)

PLATE 7.

CHAPTER XVII

GRADING OF COKE

IN previous chapters the importance of grading as a factor bearing upon the utility and efficiency of coke as fuel for specific purposes has frequently been indicated. For use with mechanical stokers, for instance, coke must be suitably graded, not only to facilitate automatic feeding by gravitation through schutes from overhead bunkers to stoker feed hoppers, but also in order to "time it," or approximate its rate of combustion to that of the coal with which it is, for this purpose, usually blended.

There are, of course, other important considerations in connection with the question of grading coke on a large scale, the financial and practical values of which must be taken into account. These include the losses incidental to the formation, in the process of cutting and screening, of smalls and breeze which, ordinarily, can be disposed of only at a loss. Reduced by means of efficient coke cutters to a uniform maximum size to pass a $\frac{3}{4}$ -inch screen, the size usually necessary for use with mechanical stokers, the proportion of breeze produced should be small, and moreover, for this purpose, it should be unnecessary to remove the breeze so made. The breeze in this case has been sold, without distinction, as coke, thus eliminating the loss which otherwise would accrue; but for most other purposes, and especially for domestic uses, the cut coke should be carefully screened free from breeze.

The extent to which grading should be carried in order to satisfy the public requirements is a matter which the Technical Sub-Committee of the London Coke Committee has given careful consideration. The importance attached to this question in marketing anthracite, which, ungraded, is regarded by certain producers as unsaleable, may be taken to some extent as indicative of the importance of grading.

In chemical composition, coke and anthracite are almost identical. Unlike coke, however, anthracite is extremely dense in physical structure, and, therefore, relatively difficult to burn. Grading has therefore a more important influence upon the rate of combustion of anthracite, which explains the meticulous care with which it is usually separated into different sizes for various purposes.

In preparing anthracite for the market, ten or eleven different kinds or sizes are made by cutting, and by means of dry and wet separation, which are designed to fulfil the requirements of special apparatus, and each size goes under its own name. These generally are known as under :

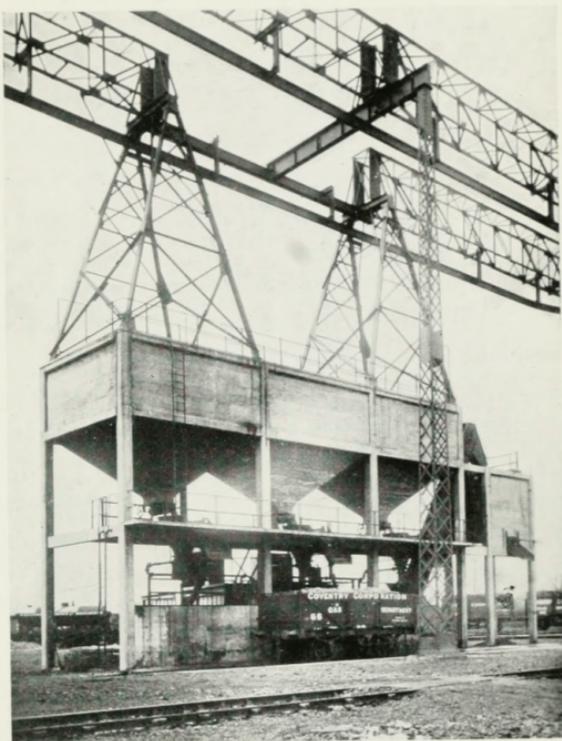
6-8 inches	. . .	Malting Large.	Specially selected.	
" "	. . .	Ordinary Large		} Dry Separation.
$2\frac{1}{2}$ -4	" . . .	Cobbles		
$1\frac{3}{4}$ - $2\frac{1}{2}$	" . . .	Large French Nuts		
$1\frac{3}{4}$ inch	. . .	Small French Nuts		
$1\frac{1}{4}$ - $1\frac{3}{4}$ inch	. . .	Stove Nuts		} Wet Separation.
$\frac{5}{8}$ - $1\frac{1}{4}$	" . . .	Pea Nuts		
$\frac{1}{2}$ - $\frac{5}{8}$	" . . .	Beans		
$\frac{1}{4}$ - $\frac{1}{2}$	" . . .	Peas		
$\frac{1}{8}$ - $\frac{1}{4}$	" . . .	Grains		} No Treatment.
$\frac{1}{8}$ inch-nil	. . .	Billy Duff		
" "	. . .	Breaker Duff		

With a view to satisfy the requirements of coke consumers in the matter of grade, and, so far as possible, to simplify gasworks screening plant and storage hoppers, several sizes have been considered, with the result that the following are the standards finally adopted by the London Coke Committee as necessary to fulfil present needs :

- No. 1. Large Grade Coke, rejected by a 2-inch screen.
 - No. 2. Broken or Domestic Coke, passing through a 2-inch and rejected by a $\frac{3}{4}$ -inch screen.
 - No. 3. Forge Coke, or Coke Nuts, passing through a $\frac{3}{4}$ -inch and rejected by a $\frac{2}{8}$ -inch screen.
- Coke Breeze, $\frac{2}{8}$ inch to nil.

The screens in all cases are square mesh screens.

No. 1 size is in special demand for glass-works annealing furnaces,



COKE STORAGE HOPPERS,
WASHING AND SCREENING PLANT.
(Dempster & Sons Ltd.)

PLATE 8.

[To face page 112.]

carbon dioxide plants, and for firing central heating and steam boilers having large furnace capacity.

No. 2 is specially suitable for use in open fire-grates, for steam raising, for smaller sized central heating boilers, and also for the large sized domestic hot-water supply boilers.

No. 3 is specially designed for use in closed and anthracite stoves, small hot-water supply boilers, kitchen ranges, and for mechanical stoking and smiths' forges.

For use as forge coke, as well as for other special purposes, No. 3 grade is now treated in large quantities by passing it through a process of washing with a view to remove adhering breeze and other extraneous matter. In this connection it should be noted that in cutting and grading, coke fractures, usually, at a point where impurities in the form of hard shale are present, the shale being thus released. It has, in fact, been observed that in the process of cutting and screening, a considerable proportion of the free mineral matter contained in coke is eliminated thus tending to enhance the calorific power of the graded product. This fact is further proved by reason of the invariably higher proportion of ash contained in breeze.

The cost, and loss, incidental to the cutting and grading of coke is usually covered by an extra charge of 1d. per cwt., a charge that is more than justified by the improvement in quality and convenience in use.

The extent of the potential demand for coke suitably graded for use in independent domestic hot-water supply boilers alone (apart from that already in active demand for stoves primarily designed for use with anthracite and for industrial purposes), may be gauged by the fact that the output of such boilers already runs into several hundreds per month. A conservative estimate of the average yearly coke consumption of each boiler is about 5 tons. There are, of course, alternative fuels, but these being necessarily limited to the smokeless anthracitic coals, they are relatively expensive and, as tests have proved, less economical. They are, moreover, not so generally available as coke, their production, as already pointed out, being limited almost entirely to the South Wales district.

CHAPTER XVIII

THE SMOKELESS FIRE

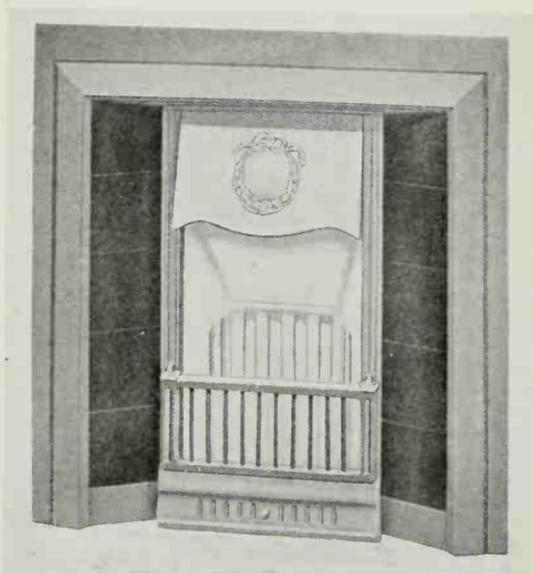
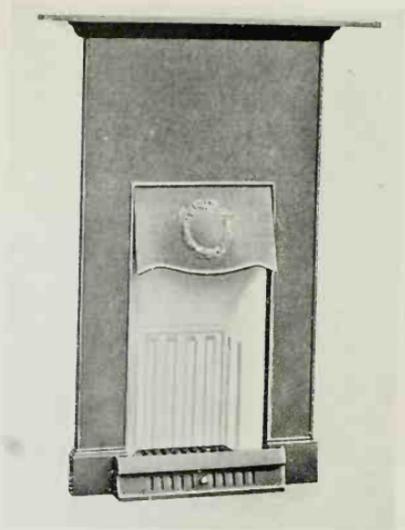
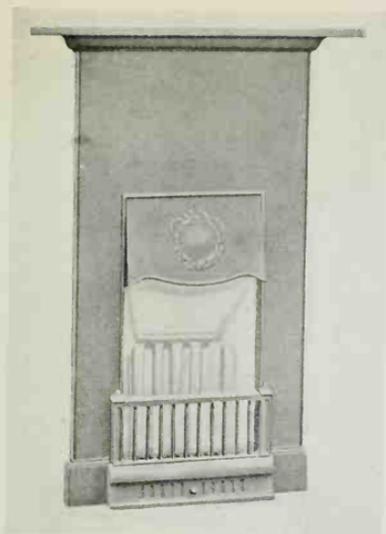
CONTINENTAL visitors with a sense of humour have been known to remark upon the bewildering variety and number of chimney-pots which may be seen from the high-level railways that traverse the metropolis and other large cities, and to question the utility and economy of that peculiarly British institution, the open fire.

Reared in contemplation of a closed stove and elongated stove-pipe, the continental mind is no doubt apt to regard our display of smoking chimney-pots as outward evidence of waste, and our blazing open fires as the last word in luxuriant extravagance.

This, no doubt, to some extent at least, is the rational view; but envy is displayed by the fact that in certain Scandinavian cities wealthy magnates often have an open coal fire installed in their palaces as a special mark of affluence.

In ancient Rome, before the chimney flue was invented, it is recorded that architects built houses without any outlet for the smoke arising from cooking operations. The smoke simply found its way into the upper rooms, which were let to poor tenants at low rents, graduated, probably, according to the smoke density of the atmosphere, or degree of average visibility. It is recorded also that the smoke nuisance was at its worst when culinary preparations for visitors were being made.

Examples of contemporary architecture, as seen in "Garden Cities," tend to prove that in the past the domestic chimney-stack as an ornamental feature has, in fact, been somewhat overdone. Instead of an array of chimney terminals surmounted by pots and "tall-boys" as heretofore, a single chimney-stack centrally situated, and containing two or three flues, is cleverly made to serve for both heating and cooking apparatus which use solid fuel. In bedrooms, gas fires, communicating



THE N.C. OPEN COKE-BURNING FIRE-GRATE.

Pat. No. 167031/20.

(R. & A. Main Ltd., Edmonton.)

PLATE 9.

[To face page 114.

with cavity flues and concealed terminals, have eliminated the need for ponderous chimney-breasts and separate chimneys.

That this arrangement of heating and ventilating is capable of artistic and dignified treatment has been proved by the examples mentioned. It remains only to secure and maintain that which has been described as the "smokeless aspect" in order to complete what should be an ideal home with a garden undefiled by soot.

The development of coke-fired heating, cooking and hot-water supply apparatus has brought this ideal within the possibility of attainment, without the necessity for dispensing with the open fire, with all its hygienic virtues and sentimental associations.

It has been the author's privilege, over a long period, to experiment with a view to produce an open fire-grate suitable for use with gas coke exclusively as fuel.

Inquiry among the leading stove manufacturers failed to secure a grate recommended for use with coke, except those which were provided with sliding shutters or hinged doors, designed to act as "blowers" by concentrating the chimney draught upon the fuel.

It was felt that such appliances could not safely be recommended, as experience had proved that the shutters frequently were closed, with a view to "draw" the fire, and inadvertently forgotten, with the result that the grate was destroyed through overheating.

Finally, a fire-grate, now known as the "N.C.," and manufactured by Messrs. R. & A. Main Ltd., of Edmonton, was designed, which promotes the active and satisfactory combustion of ordinary high-temperature gas coke, without the aid of shutters or hinged doors, which, as has been shown, are liable to abuse.

The ordinary open or barless grate, as designed for use with free-burning coal, is not as a rule suitable for use with coke, although there are occasional exceptions to this rule. Owing to some subtle difference, which is by no means apparent, there are certain isolated grates in which coke burns brilliantly; but, usually, coke does not burn actively in ordinary open grates. It does not, therefore, burn at a sufficiently high temperature to create and maintain in the chimney a draught sufficient

to carry off the combustion products, which, in these circumstances, often escape into the room; and it is this experience which no doubt accounts for the prejudice against coke as a domestic fuel. In this connection it is frequently remarked that a "good" draught is necessary in order to burn coke; but it should be remembered that the intensity of the draught is largely, if not entirely, dependent upon the temperature of the waste products entering the chimney, which temperature is invariably greatly reduced by the inrush of cool air as well. The chimney draught, in fact, has little or no influence upon the burning of coke in an open grate. This can be proved by observing the action taking place in the familiar coke-fired brazier, as used in the open air by watchmen and others, which burns brilliantly without the aid of a chimney. It will be seen that the air currents which promote active combustion are induced entirely, in a still atmosphere, by what is known as convection; and it is entirely upon this principle that the design of the N.C. grate is based.

As will be seen from the illustration, a series of deep vertical channels (not to be confused with merely ornamental fluting) have been formed in the one-piece fire-brick back and sides. These channels, which extend from the hearth level to a point above the normal level of the fuel in the grate, function as miniature chimneys, inducing currents of air inwards through the fuel-bed, from the front towards the back, and thence upward through the channels. These induced or convection currents have in practice proved to be sufficient to maintain ordinary gas coke (suitably graded to about 2-inch size) in brilliant and satisfactory combustion.

Some degree of control is effected by opening the ashpit cover or "fret," and so admitting cool air direct to the lower ends of the channels. The channels being thus chilled, the upward draught is diminished and is no longer concentrated upon the fuel in the grate. In ordinary slow-combustion coal grates, this operation has the reverse effect, the fret being opened to promote quicker combustion.

Front bars are provided in order to facilitate the maintenance of a large fire if required, but these may be removed and a smaller fire main-

tained simply by piling up the coke at a high angle towards the back of the grate.

Another feature of this grate, to which some authorities attach importance, is the adjustable damper, provided under the hinged canopy, by means of which the opening to the chimney, and consequently the circulation of air through the room, can be regulated; but it should be pointed out that the fundamental principle of the grate, from the coke-burning view-point, is embodied in the serrated fire-brick back. The finish of the metal frame or surround may be executed in any style desired.

Fed with suitably graded coke at intervals of about two hours, a large, radiant fire, of a generous, satisfying and brilliant character, is obtained in practice with this grate at an ascertained expenditure of 2 lb. of coke per hour (costing rather less than $\frac{1}{2}$ d. at 45s. per ton), without the emission, in the smallest degree, of soot or visible smoke. Kindling is effected in the usual manner, by using the previous day's cinders, without the aid of coal.

Equipped with this grate and other coke-burning domestic appliances described in the following chapters, the use of raw coal has, in fact, for many years been entirely dispensed with by the author.

In order that the N.C. invention may be clearly understood, reference will now be made to the accompanying drawings (see page 119) in which—

Fig. 19 is a transverse section of the improved grate or "interior."

Fig. 20 is a front view with the grate proper removed.

Fig. 21 is a horizontal section just above the grate.

Fig. 22 is a detail diagram showing the channels as in cross-section.

a and a^1 are respectively the back and cheeks of the grate and a^2 is the usual forwardly inclined upper block or head radiator.

bb are the deep and wide channels, ducts or draught inducers which extend from the bottom of the fireplace and are of rectangular cross-section.

A front grating or set of ordinary removable front fire-bars d of the upright or spindle type may be provided, and the ash-space e is closed by a close-fitting front cover plate or fret f in the manner usual with well grates, such fret having an air regulator or register device g .

In the present grate, however, this cover or fret prevents the lower open ends of the air channels from obtaining air, and thus the suction or draught induced up the vertical channels is concentrated upon or confined to the body of the fuel, and active combustion is promoted, which is particularly useful when ordinary gas coke is being employed. Moreover the radiation from the walls *a* and the surfaces of the channels *b* striking on the fuel, greatly promotes its combustion and enables ordinary hard coke to be efficiently and properly burnt without the inconvenience of a closed stove.

When it is desired to retard combustion, cold air is admitted to the lower open ends of the channels by opening the front cover *f*, thus diminishing the draught through the body of the fuel. When, however, the slide is closed, they tend to draw air horizontally through the fuel, towards the back of the fire.

As the channels *b* extend down to the hearth level or bottom of the interior any dust or ashes collecting in them falls freely down out of the way. At the lower ends the ducts may be opened out and made wider to facilitate this clearing action. For the rest of their length they may be about 1 inch each way.

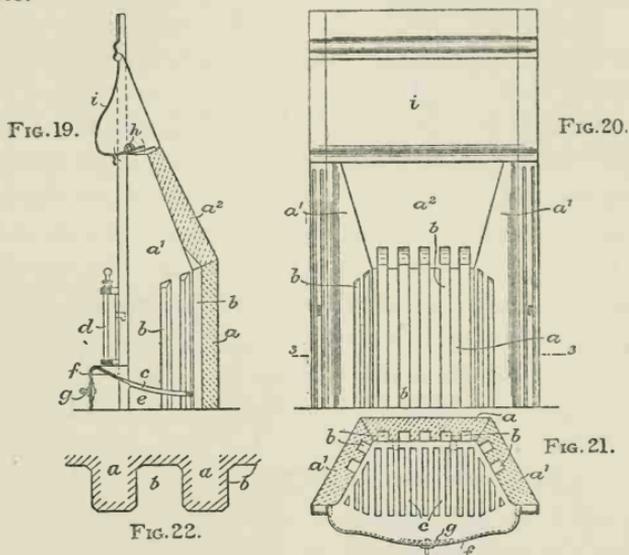
On the other hand, the main portions of the channels do not get choked on the grate, as the fuel (especially in the case of coke) usually contains a sufficient quantity of moderate-sized or large pieces, to extend across and cover the front opening of the channels or grooves without actually going into them. Moreover the walls of the latter become very highly heated and, by retaining and radiating heat on to the new or raw fuel, greatly assist in kindling and promoting combustion.

The grate may be converted into an ordinary, open well grate simply by removing the aforesaid front bars *d*.

To efficiently and closely regulate the suction of the chimney, the auxiliary regulator or damper *h* is adjustably mounted in the mouth of the ordinary adjustable sloping canopy or hood *i* of the grate. It may be carried on pins or pivots secured in the end-plates, cheeks or quadrants of the canopy so that it can turn or tilt on its longitudinal axis to adjust more closely (according to the height or draught of the chimney) the

usual opening which still remains when the hood is pushed in as far as possible towards the closed position.

If a hot-water supply boiler be fitted at the back of the grate, as is sometimes the case, the side of the said boiler exposed to the fire may be ribbed or corrugated to correspond to the channels or grooves in the fire-clay back of the grate.



DIAGRAMS, N.C. OPEN COKE-BURNING FIRE-GRATE.

In reference to the comparative radiant efficiencies of coal and coke when burnt in open fire-grates, Dr. Margaret Fishenden, for the Manchester Air Pollution Board, has carried out a series of tests the results of which are of general interest.

Working with a number of coal-fired open grates, which did not include the N.C., but included what were supposed to be the best and the worst types, the radiant efficiency of coal in all cases was found to be between 20 and 24 per cent. When dry coke was used as fuel, radiant efficiencies up to 28 per cent. were obtained, but the value was materially diminished when wet coke was used (*British Association Fuel Economy Committee Report, 1922*).

CHAPTER XIX

COKE-FIRED HOT-WATER SUPPLY BOILERS

THERE should be no need to emphasise the importance of coke from the financial view-point, or its bearing upon the price charged for gas, as, under the terms of the sliding scale, revenue derived from coke helps very materially to reduce the price of gas. A steady local market for coke is in fact fundamental to the economic conduct and development of the gas industry, avoiding, as it does, the expense and loss incidental to the storing of coke at the works. In their own interest, therefore, the gas-consuming public should, so far as possible, utilise also the solid product of the gasworks in preference to coal, which for most domestic purposes it excels in efficiency and economy. The large and growing extent to which coke is now used as a substitute for anthracite, the present price of which is more than double that of coke, is probably the most convincing evidence of its efficiency and utility as a domestic fuel.

Reviewing the whole subject of domestic hot-water supply, E. D. Simon, M.I.C.E., joint-author of *The Smokeless City*, and a member of the Coal Smoke Abatement Committee, has said, "A separate coke boiler is far more efficient and is smokeless."

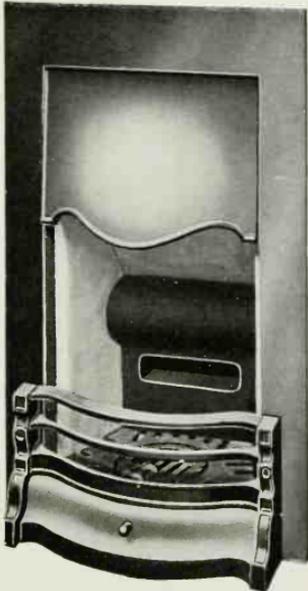
Used in combination with a gas cooker, the independent coke boiler provides an ideal kitchen equipment, and it is already regarded by many as indispensable, not only for the ordinary household equipped with a kitchen range, but also for the all-gas, as well as the all-electric house. The modern coke boiler provides not merely for the continuous and adequate supply of hot water, heated, if need be, to boiling point, but also for heating the kitchen, minor cooking operations and, to a limited extent, for heating adjoining rooms by means of radiators.

There are many types of coke boilers now available. All are good by reason of the fact that all are actual or potential users of coke, and

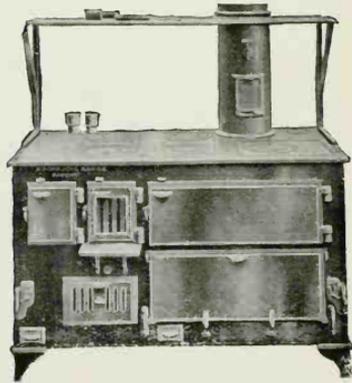
THE GLOW-WORM
BOILER.
(Bruster &
De Launoit.)



THE KOKE
BOILER.
(Balmforth & Co.
Ltd.)



THE FLORENCE COKE GRATE,
WITH BACK BOILER.
(London Warming Co. Ltd.)



COKE-BURNING COOKING RANGE.
(London Warming Co. Ltd.)

therefore eliminators of coal smoke. Several, in addition to being good, are attractive in appearance; and a few have the additional advantages of being highly efficient, relatively cheap and convenient to use.

It has always been, and still is, the policy of the London Coke Committee to promote and encourage the development of the domestic coke boiler. Selected types of boilers have been tested, and if found to be reasonably efficient and otherwise satisfactory, have been modified to comply with the Committee's standard specification (a copy of which is appended) as regards finish and cleaning facilities, etc., and finally have been adopted for recommendation to prospective users.

This method of encouraging development in design and construction has already led to the production of several really attractive and efficient boilers which, to judge from the rate at which they are being adopted by the public, have satisfied a want long felt by private householders, as well as builders and architects, for a simple hot-water supply apparatus easily installed and cheap to maintain.

The Committee's propaganda to promote the manufacture and sale of coke boilers was necessarily suspended during the War; but since the cost of manufacture has permitted the sale of these boilers to the public at an economic price, they have been so freely adopted and installed that a very substantial increase in demand for specially graded coke has already been recorded in the metropolitan district.

Taken over a period of forty-two days' continuous working, night and day, the average coke consumption of a No. 1, or smallest sized "Glow-worm" boiler, connected to a radiator also in continuous use, was 26 lb., or, say, $\frac{1}{4}$ cwt. per day. This figure may be regarded as a minimum for a small household having only one bath and one small radiator connected. The average yearly consumption spread fairly evenly over the twelve months may, therefore, be taken as approximately 5 tons of graded coke nuts, the fuel generally preferred.

Now, it is well known that the gas produced per ton of coal carbonised is about 70 therms, or 14,000 cubic feet of 500 B.Th.U. gas. This quantity of gas, produced from coal, leaves a net residue of 10 cwt. of coke for sale; so that in order to establish and maintain a balance as

between coke and gas sales, one coke boiler should be installed in a gas-supply district for every increment of 140,000 cubic feet in gas output per annum.

There are, however, in more than one district, many years of leeway in local coke sales to make good. Large quantities of coke, unfortunately, are in such districts as yet unsaleable locally for any purpose at a remunerative price.

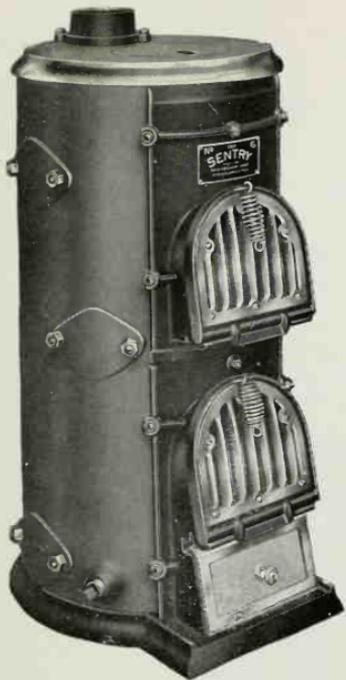
Recent developments in the design of coke boilers provide improved facilities for connecting flow and return pipes, for internal cleaning and for cooking. This latter feature does not necessarily clash with the interest of gas; indeed, any feature of any heating appliance which tends towards true economy promotes the best interest of all concerned.

Limited to plain boiling and simmering, the hot-plate provided with all modern domestic coke boilers is certainly most useful and economical; but the efforts of certain boiler makers to combine an oven with their coke boilers is to be discouraged, except, perhaps, for use in districts where gas is not available. The coke boiler is essentially and primarily a water-heater; and to attempt the dual operation of, say, roasting and water heating, must necessarily lead to inefficiency and to a repetition of the waste which has proved to be inseparable from the ordinary combination of kitchen range and back boiler.

The modern coke boiler, with open or close fire, eliminates the necessity for a gas fire in the kitchen; it provides for the destruction of all house refuse, thus obviating, in certain cases, the necessity for a gas-fired incinerator. It can be, and frequently is, provided with automatic temperature control; and, as already shown, the fuel cost of maintenance, namely, 6d. per day of 24 hours (coke at 40s. per ton), compares most favourably with that of any other system.

Banked over night with coke nuts, the fire need never go out; and the advantage of a storage tank full of hot water in the early morning, ready for baths, etc., is provided at an insignificant cost in fuel.

Cleaned once in twenty-four hours, the fire requires little special attention if fed with suitably graded coke. This, probably, is the most important item of information that could be passed on to all users, as



SENTRY DUPLEX BOILER.

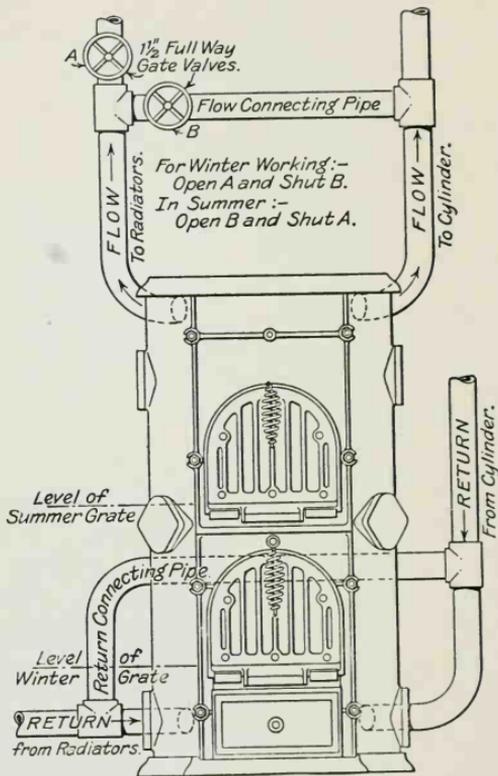


DIAGRAM OF PIPE CONNECTIONS.

(Wood, Russell & Co. Ltd.)

PLATE II.

[To face page 122.

in the grading of the coke lies to a very material extent the success or failure of the boiler. Fed with coke nuts, the fire can be left unattended for ten to twelve hours, and meanwhile the boiler will circulate and accumulate a tank full of hot water, whereas with large coke, the fire requires almost constant attention.

The use of bituminous coal in these boilers, even for kindling, is very detrimental, and, indeed, long experience has proved that it is quite unnecessary. The volatile gases evolved from such coal condense on the water-cooled heating surfaces of the boiler, forming a hard carbon scale which is extremely difficult to remove, and which forms an effective heat insulator, thus preventing the heat reaching the water inside.

Made usually in cast-iron or wrought welded steel, the smaller coke boilers are designed to operate satisfactorily when connected to existing storage tanks, which, generally, are from 25 to 30 gallon capacity; but when new tanks are fitted, 35 to 40 gallon capacity is preferable. If the tank is too small in capacity the tendency is of course to overheat the water, which then must be run to waste. The capacity of the storage tank is, in fact, a measure of the difficulty of using the boiler to any serious extent for cooking purposes.

There does not appear to be any recognised standard basis for rating the heating capacity of coke boilers. Regard must be had to the number and size of radiators it is proposed to connect. These should be strictly limited in number, as the water, due to corrosion inside the radiators, is apt to be discoloured by rust. For larger installations, separate boilers are to be recommended for heating and for hot-water supply; but for moderate-sized installations, where it is desirable, from the labour-saving view-point, to maintain only one fire for both purposes, the Sentry Duplex boiler provides a satisfactory solution. This boiler is divided to form two separate boilers with separate circuits for heating and for hot-water supply when required. In summer-time, the boilers, by means of pipes and valves, are coupled together, and the radiators being shut off, both supply hot water. The fire-grate may also be raised to bring the fire closer up to the hot-plate during the summer months.

It will be noticed in the case of the boilers illustrated that all hand-

hole covers are provided with external joints. This feature tends very materially to reduce the cost of production, and from that view-point is very desirable. Properly followed up, when first the boiler is heated, the external joints have proved in practice to be perfectly satisfactory.

In selecting and using a coke boiler due regard must be had for the characteristics of the water supply. Hot water is liable to deposit solid matter in the form of hard scale, in both the pipes and boiler, necessitating frequent internal cleaning. The frequency of cleaning may, however, be reduced to the minimum by preventing the overheating of the water. If kept below 180° Fahr. little scale should be formed, and with a view to avoid overheating, the installation of a thermometer in the flow-pipe is to be recommended. A safety valve should also be used to guard against any accidental increase in pressure due to stopped pipes.

Certain makes of coke boilers are now provided with revolving or shaking grates for removing the fine ash from the fire. This device does not, however, provide for the removal of clinker, the formation of which is largely unavoidable. Personal experience tends to prove that the fire is most conveniently and thoroughly cleaned by bringing it up to the maximum temperature and deliberately fusing the whole of the ash into a solid clinker, which may then be removed through the feed door by means of a sharp-hooked poker.

The standard specification for coke-heated boilers, drawn up by the London Coke Committee for the use of individual gas companies, with a view to ensure safety and general utility, is as follows :

1. *Conditions of Service.*—The boilers are required for ordinary domestic service, and when possible will be connected to existing flues, hot-water service-pipes and apparatus.
2. *Rating.*—The boilers shall be capable of operating continuously under the above conditions at their maximum rated capacity, which shall be expressed in gallons of water heated per hour to an average temperature of 130° Fahr. from an inlet temperature of 50° Fahr. Fuel used to be ordinary gas coke broken to sizes not more than 2 inches or less than 1 inch.
3. *Materials.*—Both cast-iron and welded steel boilers are required,

and tenders may be submitted for either type. The thickness of the plates must be uniform, and not less than $\frac{5}{16}$ inch. Test pieces of the material used shall be submitted for examination, and, when required by the Company, the plates shall be drilled in order to prove the thickness of same. The cost of drilling and plugging at least 5 per cent. of the boilers ordered to be borne by the contractor. The materials selected for the construction of the boilers to be of the best quality only, complying in all respects with the specifications of the Engineering Standards Committee.

4. *Castings*.—Cast-iron fittings and mountings to be of the best quality for the purpose intended, and external surfaces to be finished smooth for the application of heat-resisting paint or blacklead. Small parts liable to damage through overheating or rough-handling to be of wrought-iron or steel. Castings of a light or flimsy nature will not be accepted.
5. *Workmanship and Finish*.—The workmanship to be of the best quality and the general finish to be consistent with that of similar domestic kitchen apparatus. All welds and joints to be finished smooth and filled in when necessary. Two coats of heat-resisting paint (of approved manufacture) to be applied to each boiler.
6. *Pressure Test*.—A hydraulic pressure of 75 lb. per square inch shall be applied by the contractor to each boiler before being painted, in the presence of the representative of the Company, who shall hammer-test welds and castings and otherwise examine the boilers while under the test pressure.
7. *Open Fire*.—The boilers to be suitable for continuous working (but not necessarily at their maximum capacity) with the fire or clinker door open wide. A suitable detachable or hinged bracket to be provided for the purpose of heating flat-irons, etc., at the open fire.
8. *Cleaning Facilities*.—Space to be allowed for the accumulation of solid matter in the waterways below the fire level. A sufficient number of access doors to be provided to allow of all heating surfaces being reached for the purpose of hard scale or mud removal. The cleaning doors to be jointed with rubber joints of approved manufacture on machined

surface only. A screwed boss, tapped 1 inch standard Whitworth gas thread, to be provided near the bottom of each boiler for draining purposes, the boss to be plugged with a wrought- or cast-iron shouldered stopper and rubber washer (similar provision to be made near the top of each boiler for the application of a safety valve when required).

9. *Grate Bars*.—To be of special approved mixture of cast-iron and a sufficient area, and proportioned to ensure satisfactory continuous working with gas coke exclusively as fuel, and easily removable through ashpit or fire door. The boiler furnaces to be suitable for the destruction of domestic waste.
10. *Fuel Magazine*.—Although the addition of a fuel magazine is not expressly stipulated, it will be considered as enhancing the practical value of a boiler if it is so designed as to be capable of being worked continuously with a fuel magazine.
11. *Range of Sizes*.—A range of four sizes of boilers will be required, *i.e.* 40, 60, 80, and 100 gallons per hour as rated according to Clause 2.
12. *Standardisation*.—Similar components of each size of boiler, and, so far as possible, for all four sizes, to be of the same design and interchangeable.

CHAPTER XX

COKE AS FUEL FOR COOKING

VARIOUS and eminent authorities have stated that three-fourths of the damage caused by smoke to property and health is due to the house chimney. They might well have gone further, and indicated particularly the kitchen chimney, and exactly when, during the weekly cycle of domestic culinary operations, the output of smoke was at its worst.

That this event can be timed with some degree of accuracy may not be common knowledge ; but the fact is that the maximum demand for gas in the metropolitan area occurs during the hours when the Sunday midday meal is in course of preparation. This fact clearly indicates the culinary habits of the great bulk of the people ; and it may safely be inferred that during the same hours the use of smoky coal in kitchen ranges reaches a maximum.

Further proof of this contention may if necessary be had by simple observation from an elevated position. Many years' residence in a house from which is obtained a panoramic view of London and district has enabled the author to form, by actual observation, an estimate of the relative smoke output of factory and domestic chimneys in the metropolitan area. Such observation proves that it is unwise to generalise in this connection. On Sundays, although by no means the only smoke produced, that emitted from domestic chimneys is by far the most in evidence. On weekdays, but then only in industrial districts, the factory chimney, in point of volume and density of output, is the most conspicuous. During the early hours of darkness, when the lighting load is at its maximum, the electric power station chimney contributes very materially towards the general atmospheric pollution, although in this respect, but only when retorts are being recharged, the gasworks are not entirely above suspicion. Incidentally, knowledge of many London factories, their system of boiler-firing and the processes carried

on, leads one to inquire why it is that, whereas certain chimneys are practically smokeless, others at similar factories, having similar stoking equipment, almost invariably emit smoke; and why some oil-fired boiler plants are among the worst offenders?

That the domestic smoke nuisance has been very materially mitigated by the adoption of gas cooking appliances goes without saying; the extent to which coke could, and actually does supersede coal, where solid fuel is preferred, is less in evidence. This probably is due more to lack of knowledge than prejudice; but, in any case, independent testimony, emanating from reliable and disinterested sources, will be the more effective in promoting the use of smokeless coke in lieu of smoky coal, both on the score of atmospheric hygiene and economy in the fuel cost of cooking, for use in ordinary kitchen ranges and in ranges of the type primarily designed for use with anthracite.

In view of a general belief to the contrary, the recorded experience of one user of the former type of range, which is as follows, is of interest:

- “ For a range of the open and closed type such as I have, coke nuts is an excellent fuel; and except for the use of about 8 to 12 oz. of coal when lighting up in the morning to obtain quick ignition, no other has been used for the past seven years.
- “ Coke is much preferred, keeps a steadier heat, and is more economical than coal.
- “ The dimensions of my fire-box are $7\frac{1}{4}$ inches wide, 9 inches from front to face of saddle-back boiler, $5\frac{1}{2}$ to 8 inches in depth.
- “ The lifting grate is always kept on the top notch, so that whereas the depth of the fire to underside of sliding top is 8 inches at the back, it is only $5\frac{1}{2}$ inches at the front. It is possible to maintain good combustion for cooking with oven damper out about an inch when the range is thoroughly heated.
- “ There is no difficulty in maintaining a high temperature and continuous combustion to do all the cooking for a family of five with ample margin for double the number. It should be mentioned that with the damper in this position boiling is done on the hot-plate as well.

- “ The range is not an unusual type, in fact, it is a very common range, 36 inches×48 inches ; open and closed lifting fire, light weight, and may be seen in thousands of houses.
- “ It cannot be too strongly emphasised that a fuel such as is described is already available in large quantities and at a reasonable price—the ordinary gas coke produced as a by-product from every gasworks. All that is necessary is that the coke should be sized and graded for the purpose.”

The following extracts are taken from an official report issued by the Board of Fuel Research :

“ Direct comparison was made between the practical performance of experimental range No. 15 and range No. 9. The two ranges were tested side by side in exactly identical conditions, except that coal was used for No. 9 and coke for the experimental range. The work was done by an independent expert cook, in the presence of Dr. Lander (Director of Fuel Research), who witnessed the test on behalf of the Fuel Research Board. The result was as follows :

“ Special range used 17 lb. of coke. The ordinary one used 26 lb. of coal, for the same duty.”

“ In comparing those test results with others, it must be remembered that in all cases the home-designed ranges were used with coke, whereas all the others could only be used with coal. There seems no reason why a range of this design should be more expensive than the ordinary type if it is made in similar quantities. The result of this constructive experiment has been to reduce the fuel usually required for any given duty by about 70 per cent., *i.e.*, taking the consumption of a range of any ordinary design as 100, the experimental range used 30 for the same duty.”

American experience in this connection, which tends to corroborate that given above, is given by a writer in *Combustion* (U.S.A.) :

“ Hundreds of householders in this section of New Jersey adopted coke as fuel last autumn. They burned it according to instructions, with results that were gratifying, to say the least. In most cases coke

equalled anthracite coal ton for ton ; but as there was a \$3 difference in price in favour of coke, the saving for the average householder was worth while."

To the makers of a well-known cooking range, Sir Courtenay Bennett has written as follows :

" You will have noticed in the Press that a great deal of attention is being paid to the production of smokeless fuel for household fires, and that the experts of the Advisory Committee on Atmospheric Pollution are experimenting with coke produced by gas companies under high temperatures, being under the impression, apparently, that no kitchen range in existence will burn ordinary broken coke.

" During the War, and afterwards, anthracite was with difficulty to be obtained for use in the Kooksjoie which I purchased from you some three years ago, and I had to use ordinary gas coke to eke out the anthracite. The plan succeeded well—so well, in fact, that I gradually decreased the amount of anthracite used until at last I reduced the anthracite to zero, and still the results were good. For the last twelve months I have used nothing but broken coke purchased from the local gas company and am more than pleased with the results. The Kooksjoie does all that it should do, and with less trouble and expense than when I used anthracite."

Another user writes in reference to coke as follows :

" I may remark that I find the most satisfactory fuel is coke and not anthracite—and, as it is much cheaper, the matter is important. The fire can be made rather hotter with anthracite, but coke gives all the heat we ever require. On the other hand, it is easier to make the stove burn slowly with coke, after a meal has been cooked, and it is desired to slow down the fire quickly."

These experiences, although they have no direct bearing upon the question of smoke abatement, coke and anthracite being both smokeless fuels, tend to prove the adaptability of a popular type of cooking range to the use of coke exclusively as fuel.

Another advantage of coke, often remarked by users, is the improved efficiencies of the boilers usually attached to kitchen ranges. The regular

use of coke tends to remove from the boiler-heating surfaces the hard carbon scale deposited by the tarry products evolved from coal, thus permitting a quicker transfer of heat from the burning fuel to the water inside. The insulating effect of this carbon scale, which is said to be five times as great as asbestos, is entirely eliminated if coke only is used as fuel.

From the foregoing chapters on the use of coke as fuel for open fire-grates and for cooking ranges and hot-water supply boilers, it will be seen that for domestic purposes two grades of coke are necessary, *i.e.* No. 2 grade, for open fires, and No. 3 grade, or coke nuts, for closed stoves and small boilers. In designing a "smokeless" house equipped with these appliances, the need for making provision for storing separately these two grades of fuel will therefore be apparent.

CONCLUSION

IN preceding chapters, frequent reference has been made to the London Coke Committee, and for the benefit of those unfamiliar with the constitution and aims of the Committee, the following explanation is due.

The London Coke Committee was formed, in 1913, by the nine (now eight) London and Suburban Gas Companies, under the chairmanship of Mr. David Milne Watson, Governor of The Gas, Light and Coke Company, and President of the National Gas Council, to study the best methods of using gas coke as a fuel, and to give to both domestic and industrial users, and prospective users, in the London district, expert advice as to how they can obtain most effectively the advantages of what is admittedly the cheapest and most convenient smokeless solid fuel available in this country.

In pursuance of this end, the Committee, acting through its Fuel Expert, systematically examine and test the various solid-fuel consuming appliances produced from time to time by manufacturers, its function being neither to sell coke directly nor to engage in trade in appliances, but to promote the use of coke by assisting users with expert and unbiased advice on all matters relating to steam raising, heating and hot-water supply. In giving particulars relative to appliances which have been tested, it is not suggested that such appliances are the best or that no others could be recommended.

Although perhaps not altogether inspired by disinterested motives, it is claimed that the work of the Committee has been in a large measure successful in mitigating the smoke nuisance both directly, by demonstrating the advantages of substituting coke for coal, and, indirectly, by promoting the production of domestic and industrial appliances primarily designed for use with coke as fuel, and by educating the public by advertisement and other forms of publicity in the advantages of such appliances.



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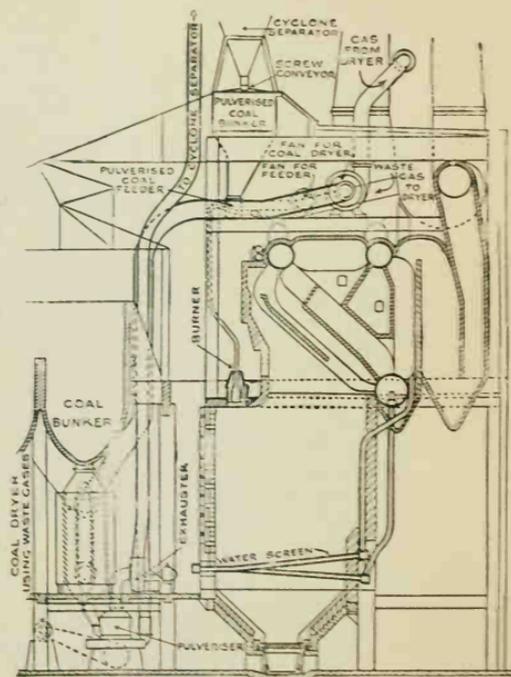
 Yorkshire coal, effect on boilers, 21.

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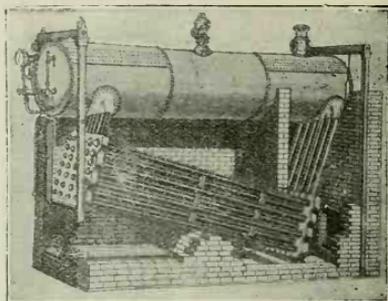
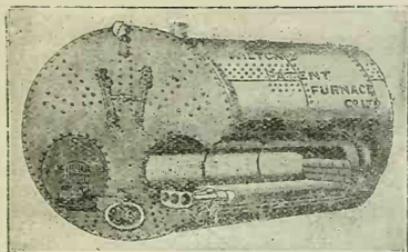
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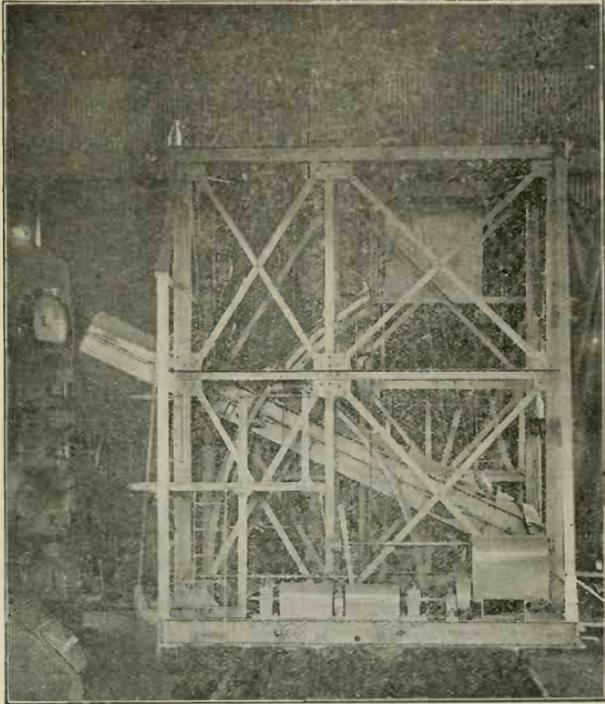
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