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Smoke Prevention and Fuel Economics,

BY MR. J. R. M. FITCH (MEMBER),

READ

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CHAIRMAN: MR. JOHN McLAREN (MEMBER OF COUNCIL).

THE most important problem at the present day affecting the steam user undoubtedly is that connected with the economical combustion of fuel. It is the chief engineer who has actually to grapple with the problem; it therefore behoves him to have sufficient knowledge of the chemistry of combustion to know where economy may be introduced. The author has written the following paper with the hope that it may prove of interest to engineers, and serve to raise discussion on this important question; at the same time he wishes to apologize to those members whose actual experience in and knowledge of this subject is so much more extensive than his own.

Whereas in the past, engineers have concentrated their efforts principally on the improvement of the engine-room plant, they have now awakened to the fact that a far greater economy is realized by the scientific control of the generation of steam power. Two factors in particular are here involved: the chemical examination of the fuel, which leads to the selection of that which gives the best results for cost, and the control of the actual combustion in the furnace of the boiler. The author does not propose to extend this paper beyond coal, although the methods apply with equal force to other classes of fuel, viz., petroleum, which has been used to some extent, especially in the neighbourhood of the sources of its production. Coal consists essentially of carbon, hydrogen, and oxygen, the hydrogen combined with some of the carbon in the form of hydrocarbons. In brief, the following kinds of coal are distinguished :—

1. Anthracite, or glance coal, is a flinty hard variety of carbon which gives only a low percentage of volatile matter, consisting principally of carbon; it therefore burns with very little flame and is smokeless.
2. Semi-anthracite, or steam coal, contains from 10 up to 20 per cent. of volatile matter; it therefore produces a certain amount of smoke, but when burnt in well-designed furnaces and with careful firing can be said to be almost smokeless.
3. Bituminous coal contains from 20 to 35 per cent. of volatile matter, and, if great care is not exercised and sufficient air allowed for combustion, produces much smoke.
4. Coke is the residue left after submitting bituminous coal to dry distillation. It burns without smoke and contains a high percentage of ash.

To obtain a correct and representative sample of coal requires great care, more in fact than is often devoted to it; it is obviously of little value to obtain accurate estimations of the proportions of the various constituents in a coal if the sample itself is not representative of the bulk. Small coal is relatively simple to sample, but a mixture of large and small coal must be dealt with strictly according to a definite scheme, and it is quite useless to pick out a few handfuls from a heap of coal.

Rules for Sampling Fuel taken from Liverpool Engineering Society Paper on Fuel Economy, Nov. 8, 1903.

"As each barrow load or fresh portion of fuel is taken from the pile or store heap, a count is kept of the number used, and the whole contents of each tenth or twentieth barrow, or portion, are placed on one side, in a cool place, under cover. Care must be taken that the barrow, or portion, selected for the sample does not contain an unfair proportion of lumps, or smalls. At the end of the day, or period for which the sampling is to be carried on, the heap of fuel obtained for sampling purposes, as described above, is transferred to a sampling plate, and the larger lumps are all crushed down to walnut size. Should no sampling plate be available, four of the iron plates used for covering manholes and boiler flues may be utilized to obtain a hard clean surface on the floor of the boiler house, and the crushing down of the sample may be carried out on these plates with any heavy and flat lump of iron at hand. The heap of fuel, after this first crushing, is thoroughly mixed by turning over and over with a spade. The heap is then flattened down, two lines are made across it at right angles with the edge of the spade, and two of the four opposite sections are selected to form the reduced sample. The lumps in this are again crushed, the sample is again mixed, and the quartering operation repeated until about 8 or 10 lb. of fuel only remain, with no lumps that will not pass through a $\frac{1}{4}$-inch sieve. Two 1 lb. tins with ordinary or patent lids are filled from this remaining heap of fuel after thoroughly mixing the same with the hands or with a small shovel. One of these tins is to be sent per parcels post to the fuel expert for analysis; the other is to be kept for reference in case of dispute."

In all fuel analysis it is advisable for the analyst to adhere to some definite course of procedure, so that every analysis of the same nature, even if made at very different dates, will be carried through in precisely the same manner. It is only by proceeding in this manner that uniformity can be ensured. It is, for example, inadvisable to grind up one sample of coal to powder immediately on receiving it, and yet leave another for a considerable period in the warm laboratory before undergoing analysis. Usually the following constituents in coal are determined: (1) Moisture, (2) ash, (3) volatile matter, (4) coke, (5) sulphur, (6) calorific value.

Moisture.—A large amount of moisture in a coal is undesirable and means that we are paying for water at an abnormal rate, unless, as often happens, the coal has become wetted during transit or storage. In comparing coals it is necessary to calculate their composition on the dry coal.

Ash.—The amount of ash contained in coal is of considerable importance and varies greatly, even in coal taken from the same colliery. The accumulation of large quantities of ash obstructs the air in its passage through the grate. Furthermore, the time taken in clinkering fires allows large quantities of cold air to rush in, cooling the gases, tubes, etc., and causing a great loss of heat. Another source of waste is the enclosing of unconsumed carbon in the fused ash or clinker and stoppage of further combustion.

Volatile matter.—The percentage of volatile matter in coal varies from about 10 per cent. in South Wales steam coal to 35 per cent. in north-country slack. Should it rise above 35 per cent. it is very difficult to burn the coal without smoke production. This is chiefly due to the liberation of the hydrocarbons and to the lack of oxygen or air essential for their complete combustion to carbon dioxide and water. At high temperatures these hydrocarbons decompose and the carbon is separated as soot or graphite, and should the air supply be insufficient or injudiciously applied, these particles remain unconsumed, and besides proving a loss of heat, will adhere to the tubes, etc., and considerably impair the heating efficiency of the boiler.

Sulphur, which is due to the presence of pyrites or brasses in the coal seams, is generally found in natural fuels. This constituent burns to oxides of sulphur, which ultimately condense as sulphuric acid. "Sulphur also forms a gaseous compound with hydrogen, known as sulphuretted hydrogen, when the combustion of a fuel containing much sulphur and hydrogen occurs without a sufficiency of oxygen (or air) being admitted to the grate. This gas has a distinctive odour, and its presence in the waste gases is always a sign of imperfect combustion." (Booth & Kershaw, *Smoke Prevention and Fuel Economy*). It is the sulphur which is responsible for the damage done to vegetation, metal, brick and stone, and it has also a very detrimental effect on parts of the boilers themselves, where the fumes come in contact with them, causing wasting and decay of the metal.

The calorific power of fuel is determined in the laboratory by burning a weighed sample in a calorimeter. The bomb calorimeter of Messrs. Berthelot & Vieille is one of the most reliable. In this instrument, which is very simple, the powdered fuel is burned by pure oxygen under pressure in an iron vessel under water. The ignition is caused electrically, and the rise of temperature of the water gives the heating value of the fuel.

Control of Combustion.—Combustion is in reality an oxidation of the carbon and hyrdocarbons of the fuel by the oxygen of the air, the result of which is heat, and it is our object when burning fuel in the furnace of a boiler to obtain this heat, conduct it through the heating surfaces of the boiler, and utilize it for the generation of steam. There are two distinct stages through which coal passes during combustion, first the distillation and combustion of the gases, and secondly the combustion of the coke or carbon that remains after the gases have been disposed of.

Take the combustion of bituminous coal, which we have difficulty in burning economically in furnaces owing to the inefficiency of the ordinary arrangements for consuming the gaseous products; assuming fresh coal is shovelled on a bright fire, naturally there is a sudden fall of temperature as the coal absorbs heat from the glowing and incandescent fuel, which liberates the various hydrocarbons, viz., methane or marsh gas, CH_4, ethylene or olefiant gas, C_2H_4, and acetylene, C_2H_2, and as insufficient air generally passes through the fire to ignite these gases, provision must be made for consuming them, otherwise there will be a considerable loss, as in addition to the gases passing away unconsumed, they will have taken heat from the fire to effect their distillation. If we supply sufficient air and the temperature is up to the point of ignition, we shall obtain complete combustion, forming steam and carbonic acid gas. Each volume of methane will require two volumes of oxygen for its combustion, and each volume of the olefiant gas three volumes of oxygen, and acetylene two and a half volumes. Therefore, between two and three volumes of oxygen will be required for the complete combustion of each volume of the gas formed in the furnace; and as the oxygen in atmospheric air only amounts to one-fifth of its bulk, between ten and fifteen volumes of air will be required for each volume of gas.

Now take the coke or carbon that remains on the bars after the gases have been disposed of: the air for its combustion should pass up between the bars and through the fuel, and the union of oxygen with the carbon is complete, and carbonic acid gas, CO_2, is formed; but if the fires are heavy and the layer of coal thick, or the bars spaced too closely together, much of this gas as it passes through the fire takes up more carbon, forming carbonic oxide gas, CO; and unless provision is made for consuming this gas by supplying additional oxygen, a very considerable amount of heat will be wasted, the products of combustion passing off as carbonic oxide, CO, by which less than one-third the heat is produced that would be yielded if the combustion were complete and the products passed off in the form of carbonic acid gas, CO_2. It is necessary, therefore, with thick fires, to admit air above the fuel for the complete combustion of the carbon in addition to the air allowed for the combustion of the gases. The average fireman is no enthusiast on the question of Fuel Economy, and his main object is to get through his watch as easily as he can, and as firing heavily and as seldom as possible entails less labour on his part, it is the course he usually adopts; great care should therefore be taken by those in charge to ensure that the fires are kept at a fairly thin and uniform thickness, and the bars well covered. With thick firing, although the doors are opened less frequently, large volumes of gases are suddenly produced for which there is generally not sufficient air for combustion, and an undue lowering of temperature is caused which may also prevent ignition. I have evidenced this in some makes of water-tube boilers where there is little space for the gases to mingle with the air and burn before reaching the tubes. With thin fires probably sufficient air for complete combustion passes through the fuel, in which case we are independent of the air supply above it.

It is essential for economy that the length of grate should be kept within reasonable limits to enable the fireman to keep the bars well and uniformly covered with coal, as with long grates there is danger that the back parts will be neglected and insufficiently covered, thus admitting cold air to rush in and cool the gases, tubes, etc., with a considerable loss of heat. Many boilers are designed with the combustion chamber space too restricted, thus preventing the gases from mingling and expanding; by increasing the depth of the combustion chamber and decreasing the length of furnace better results would be obtained. It should be borne in mind that no amount of heat will cause combustion of the gases unless air be supplied; but on the other hand, if the gases are not kept up to the temperature of ignition, the oxygen of the air will not chemically react with them and cause combustion to take place.

Air required for combustion.—The composition of air by weight is practically 23 parts oxygen and 77 nitrogen, hence to obtain 1 lb. of oxygen $\frac{100}{23}$ lb. of air are required.

From their atomic weights, it is seen that for complete combustion 1 lb. of carbon would require $\frac{32}{12} \times \frac{100}{23} = 11{\cdot}6$, or say 12 lb. of air, but in practice we must allow double this quantity, viz., 24 lb. in order to insure perfect admixture. Thirteen cubic feet of air at 60° F. weighs 1 lb.; we shall therefore require nearly 700,000 cubic feet of air for the combustion of one ton of coal, about 200,000 cubic feet of which must be admitted above the bars for the combustion of the gases, as if it were allowed to pass through the burning coal on the grate it would be deprived of a great portion of its oxygen, and its value for burning the gas be depreciated. It is, however, the object of the engineer to reduce this quantity of air to a minimum, as a large amount of heat is wasted in heating it up to the temperature of the flue gases. The total amount of heat produced by the complete combustion of 1 lb. of carbon is found by experiment to be 14,500 thermal units, but if the supply of air is deficient or injudiciously applied so that CO is produced, the amount of heat produced is only 4,400 B.T.U. instead of 14,500 heat units which would have been yielded if the air supply had been adequate and CO_2 formed. We see then the importance of admitting sufficient air to the furnace as an aid to combustion; but, on the other hand, if an excess of air is admitted, the gases will be cooled and will not chemically combine and ignite; the presence of smoke, therefore, does not always indicate that there is insufficient oxygen. Again, absence of smoke does not necessarily mean that we are burning our fuel economically as CO like CO_2 is invisible and we may be losing a considerable number of heat units without being aware of the fact. There are numerous coal-consuming appliances on the market designed to promote more perfect combustion, such as air-regulating devices for furnace doors, induced currents of air introduced at the bridge of the furnace, etc., and various other arrangements which have been used with more or less success. It is, however, to the bridge of the furnace that we must look as the correct place to introduce air as an aid to combustion, provided it be admitted at the right time, at sufficient temperature, and in correct proportions. The enormous volume of air that is necessary for the combustion of one ton of coal has been referred to. Much of this air in its passage through the furnace at a high velocity does not come in actual contact with the burning fuel, and gets no chance of being thoroughly mingled with the gases. These gases to a great extent pass along in contact with the comparatively cool plate of the furnace crown and do not obtain sufficient heat, and in some cases are even reduced in temperature by coming in contact with the cool plates or the colder air supplied for combustion, in consequence of which they fail to ignite before passing out of the combustion chamber, thus a considerable loss of furnace efficiency occurs.

A thin sheet of heated air admitted under pressure at the bridge directed upwards and towards the furnace door should tend to trap the gases and cause them to be thoroughly mingled and consumed, and by adopting this method we should be enabled to decrease the amount of air admitted above the bars, as it would be more thoroughly mingled with the gases. I will therefore bring before your notice an appliance which I have found very successful both for the prevention of smoke and for securing more perfect combustion. The apparatus is called the "Fumicide Smoke Consumer and Fuel Economizer," and has been in use on boilers which have been under my observation for the past two years with excellent results. The smoke consumer consists of a rectangular box set in the bridge of the furnace into which a steam jet forces air, the mixed superheated steam and air being discharged through a long slit in the box back towards the furnace door. The jet is in the front of the boiler, the air and steam being carried to the box on the bridge by a cast-iron pipe. Realizing the great objection, from an economical point of view, of inducing an air blast by means of a steam jet, we have lately made experiments on one of our Cornish boilers with a fan for the purpose of creating this blast. We have erected one of the Sturtevant Engineering Company's small monogram blowing fans direct coupled to an electric motor. The accompanying sketch shows a simple method of running galvanized sheet-steel piping to the cast-iron pipe which is connected to the superheater box of apparatus. An air gate is fitted in a convenient position to enable the fireman to regulate the air supply to the smoke consumer. By adopting this arrangement we estimate roughly to have gained a saving in working cost of apparatus of 50 per cent. over that of the steam jet. We have made tests of the flue gases and obtained an average of 12½ per cent. CO_2 whilst using the fan, and 10½ per cent. CO_2 whilst using the steam jet. With the apparatus shut down altogether an average of only 6 per cent. CO_2

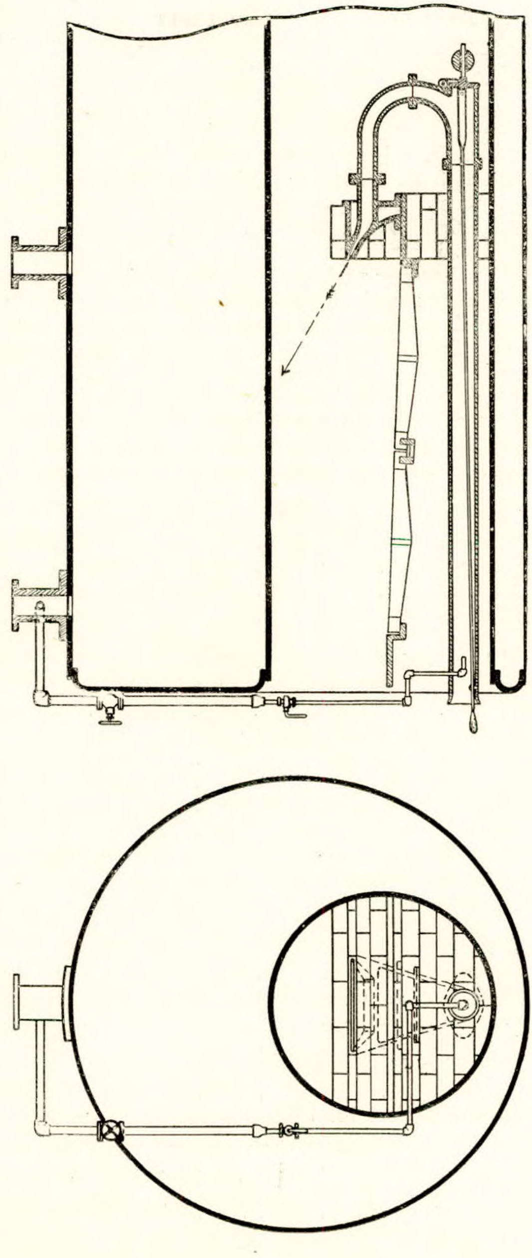

Fig. 1.

was obtained. Appended are particulars of tests made in July, 1907, on a Babcock and Wilcox boiler, fitted with the Fumicide apparatus, which may prove of interest to members.

Description.—Two water-tube boilers set as one unit fitted in 1891: 90 tubes each, 3 in. external diameter, 16 ft. long, with 2 steam drums, each 3 ft. diameter and 19 ft. 6 in. long. The trial was with a running start and finish, the fire being approximately the same at start and finish. Hand stoking, fairly good. The draught was natural. Total grate surface, excluding dead-plate, 20 sq. ft. Total effective heating surface, 1,230 sq. ft. (approximate). The boiler was in ordinary running condition, and had not been recently cleaned. Fires had been cleaned at 8 a.m., and were cleaned once during the test. The feed-water was heated by exhaust steam in a feed-water heater from a temperature of 140° to a temperature of 194°. Coal weighed on weighing machine in lots of 100 lb. Feed measured in tank calibrated by standard can. Temperature of flue gases measured by electrical pyrometer. Steam gauge checked against standard. No determination made of priming.

Duration of trial from 10.12 a.m. to 3.42 p.m.	5½ hours.
Description of fuel	Mixed colliery slack.
Fuel fired per hour	697 lb.
Moisture in fuel as fired	9·87 per cent.
Ash in fuel as fired	11·06 per cent.
Calorific value of fuel as fired (lower value)	10,318 B.T.U.
Carbon value of 1 lb. of fuel as fired . .	0·712.
Average temperature of flue gases leaving boiler	512° F.
Percentage of CO_2 in flue gases (very approximate)	11 per cent.
Temperature of outside air . . .	67° F
Barometric pressure—29·8 in. mercury .	14·7 lb. per sq. inch.
Temperature of air in boiler house . .	108° F.
Draught at gas exit from boiler . .	0·3 in. of water.
Weight of steam used per hour in two steam jets for apparatus when full open .	316 lb.
Feed-water evaporated per hour . .	5,340 lb.
Mean temperature of feed to boiler . .	194° F.
Mean steam pressure by gauge . . .	103 lb. per sq. inch.
Water evaporated per lb. of fuel as fired (gross)	7·66 lb.
Factor of evaporation	1·059.
Equivalent evaporation from and at 212° F. (gross)	8·11 lb.
Net water evaporated per lb. of fuel as fired, allowing for steam used in two jets, as above—line 14 . . .	7·20 lb.
Equivalent net evaporation from and at 212° F.	7·63 lb.

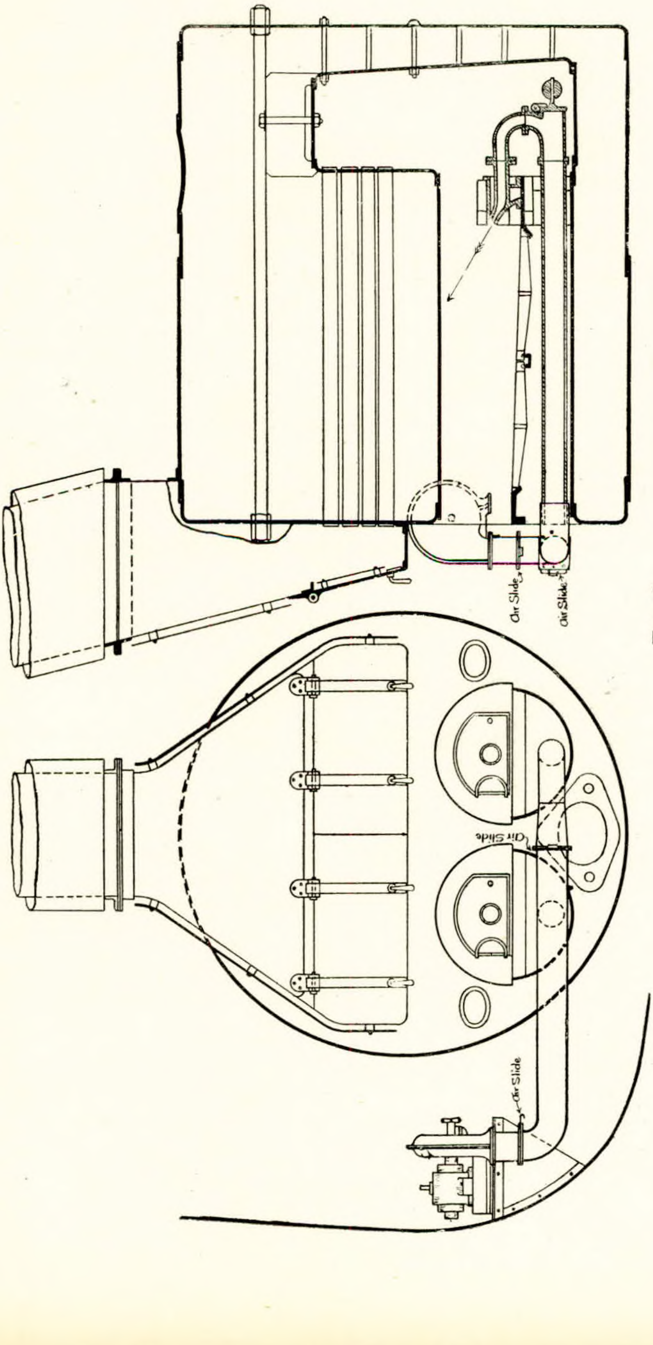

FIG. 2.

Gross thermal efficiency of boiler . .	75·9 per cent.
Net thermal efficiency of boiler . . .	71·4 per cent.
Fuel burnt per square foot of grate area .	17·4 lb.
Water evaporated from and at 212° F. per square foot of heating surface per hour (gross)	4·61 lb.
Percentage of steam used for two jets to total steam	5·9 per cent.
Cost of evaporating 1,000 gallons of water with fuel at 12*s.* per ton . . .	89·25*d.*

Carried out by Messrs. Burstall and Monkhouse, Consulting Engineers, of Old Queen Street, Westminster.

CHAIRMAN : You have heard Mr. Fitch's paper, and it is one which calls for some discussion. We all have our own ideas on the subject of coal and the proper method of burning it, and we shall now be pleased to hear the opinions of the members.

Mr. P. SMITH : I wish to congratulate Mr. Fitch on the paper he has just read. The paper itself is not a highly contentious one, but it is sufficiently important to form the basis of a very interesting and instructive discussion. It is not my intention by any means to attempt to criticise the theoretical portion of it, and I will confine the few remarks I wish to make to the more practical part. Everybody here knows that in our cities and large towns there are very important bye-laws concerning the emission of black smoke from the chimneys of our large factories, workshops, etc.—in fact it means that every steam user has to guard against the penalties which are inflicted to prevent this. That means they have to guard against it either by incurring considerable expense in procuring an expensive smokeless coal, or fitting an arrangement for the prevention or combustion of smoke, as the case may be. A number of these appliances have been invented, patented, and put on the market as far back as twenty or even thirty years ago, and, of course, all these inventions have their advantages and disadvantages. I entirely agree with the author of this paper when, after telling us of the enormous quantity of air necessary for the combustion of a ton of coal, he goes on to state : " Much of this air in its passage through the furnace at a high velocity does not come in actual contact with the burning fuel, and gets no chance of being thoroughly mingled with the gases." I think the author is quite correct in stating that, because no matter whether with forced draught, induced draught, or natural draught, air will naturally take the straightest course to the chimney, and to counteract that the author suggests that the air should be carried direct to the bridge. I agree with him in that because in this illustration we see before us, the air is carried along the bottom of the furnace to the bridge, is discharged from thence at an angle, strikes the top of the furnace, and is then deflected downwards. In that arrangement it seems to me that the air discharged must naturally obstruct, to some extent, the rush of the air induced, and cause it to mix with the products of combustion, thus causing the actual combustion to take place in the furnace instead of being carried into the combustion chamber or even further, where the useful effect might be considerably less. To carry this arrangement into effect seems, from the explanation he has given, to be a very simple matter, and I am prepared to say it is very effective, as I have seen this arrangement at work. I have looked at it occasionally for the last two or three years, and I consider the effect has been wonderfully good and efficient. Of course, in reference to the statistical test put forward, I do not think the author claims that it economizes space at all. He states that the fuel burnt per square foot of grate area is 17·4 lb.; that is just what we would expect from a well-constructed boiler with natural draught. However, we can gather, and I know that it is a fact, that where this system is introduced, and it is being introduced in several places in London, Birmingham and other large cities, the results have been very successful. The place where I saw it at work, I may state, is Queen Anne's Mansions. That is a building situated in Westminster, a district where the authorities are very particular in preventing the emission of black smoke. Before this system was introduced they used to burn a high-priced coal; now they can burn slack, and, I do not know whether I am correct in stating so, but I believe a saving in coal consumption has been at least 30 per cent. Of course, as I said before, this arrangement, like others, has its advantages and disadvantages. I have pointed out the advantages, and I would now like to point out the disadvantages. The principal disadvantage is the steam jet. High pressure steam ejected through a small orifice in an installation of boilers causes a

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very great noise ; the more jets the more noise, and if applied to a marine installation, of course it would be very objectionable, because of the loss in fresh water. No doubt in a shore installation there is a considerable loss also, but this can be more cheaply made up. The author, however, states in his paper that a fan is sometimes used, which I have seen at work, and no doubt the fan gives a much more efficient result. I have examined both systems, and I think the use of the fan is a great improvement. The next disadvantage is the obstruction in the ashpit with this 4 in. tube passing along the bottom, but I think that could easily be got over by putting a false bottom in the ashpit, or putting a casing over the pipe.

Mr. W. Vesey Lang : Mr. Smith mentioned that he had been familiar with this system for two or three years ; did he refer to marine boilers. I do not know so much about how it would act on a land boiler, but in a marine boiler I should imagine the pipe in the combustion chamber would burn away very quickly.

Mr. S. J. Ross : I should like to ask the author if there is any arrangement for shutting off the steam when the firedoor is opened. To my mind there appears to be a danger of the flame being blown back and scorching the fireman if there is no such arrangement.

Mr. W. Stormont : I should like to ask Mr. Fitch how a pressure of 5 ins. would affect the draught in a chimney 140 ft. high, which would represent 1 in. water in the glass.

Mr. E. W. Ross : This system has apparently been used in a land boiler under intermittent service, while in a marine job it would be used continuously night and day. I should think that would make a difference in its life. For forced draught, the pipe running through the ashpit would, in my opinion, be a serious objection, taking up air space underneath the bars, and being placed close up against them ; heavier expense for renewals would be incurred than in ordinary forced draught with the air suitably adjusted. The danger of the tube being burnt away at the bridge has been pointed out. Firemen as a rule are not careful of the bridges, and I should think that the renewals in these also would be serious unless the arrangement was protected from slices. For marine work the idea of using steam would not be allowed. The forced draught fan would be the only practicable method of forcing the air through. Would the narrow orifice of $\frac{1}{2}$ in. not become soon obstructed, and the system thus rendered totally ineffective ?

Mr. J. C. Brand : I also wish to congratulate the author on having brought before us a very important subject. As he rightly states, the engineer does not concentrate enough attention upon the stokehold ; he does not sufficiently test his apparatus. The first losses are in the stokehold, the final losses in the engine-room. How often do we find the engineer testing the funnel gases ; how often do we find him taking the temperatures ? In my opinion it is essential that a log should be kept in every engine-room, containing not only the performances of the engines but of the boilers also. As Mr. Fitch states, it is highly important that sufficient oxygen should be passed into the furnaces to consume the volatile gases, but the method of doing so is another question. Exception has been taken to the position of the tube ; now even in a marine boiler with the gases ascending, the lower portion of the box is in a partial vacuum, where the temperature is little above that of the surrounding water. It seems to me the back is the place for it. The plates in the lower parts of the smokebox are generally in good order, with the exception of the wasting or rusting that takes place. In connexion with the apparatus put before us, speaking principally for marine boilers, the objection is in the volume of the inrush of cold air, which would not be broken up and not sufficiently missed. In the Howden system it passes through a number of tubes and is broken up and heated to about 220 ° or 230° ; the air in this system passes through a comparatively short length of tube and is not heated to more than 120° or 130°. That volume of cold air is deflected right up to the furnace crown, launches back and is deflected on to the glowing fuel. To my mind its principal value is in acting as a brake to the gases, that is, it creates a disturbance among the gases and gives a better mixture, in fact sets up currents and mixes the gases thoroughly ; the advantage lies more in that than in the introduction of the oxygen. I should also like to raise issue with the author in the statement that " the air for its combustion should pass up between the bars and through the fuel, and the union of oxygen with the carbon is complete, and carbonic acid gas, CO_2 is formed. Assuming the formation of CO_2 on a lower layer of bars where the union between the incoming air and the carbon is complete, Mr. Fitch asserts that in passing through the unburnt layer the gas takes up more carbon. In that case C_2O_2 would be formed, which is not a chemical mixture. It would perhaps be more correct to state that one proportion of the oxygen would be burnt out in passing through the succeeding layer of fuel, and this one proportion of oxygen being taken away, CO would be formed. Passing up again it meets the air coming over the fuel and forms CO_2, that is, if there is perfect combustion. The tests mentioned by the author do not seem to have been very carefully carried out. Several points might have been improved upon. I should like to ask what was the average temperature of the flue gases.

Mr. Fitch : 512° F.

Mr. Brand : Was there any record kept of the temperature of the gases entering the boiler at the bridge ? It does not state that there was any apparatus for that purpose.

Mr. Fitch : An electrical thermometer was used.

Mr. Brand : I should like to state, in connexion with this, that the use of a CO_2 Recorder in testing funnel gases is of great value, and forms a good check on the firemen. Certainly it is not very well adapted for marine use, but for land work it is excellent. The percentage of CO_2 in flue gases is stated as 11 per cent. That, I think, is a fair average—the maximum is $21\frac{1}{2}$ to 22 per cent. Certainly this is a subject that needs ventilation, and the more it gets the more interest marine engineers will take in it, and the more efficient they will become both in their profession and to the owners.

Mr. J. Clark : I think Mr. Fitch has done us a good turn, for which we ought to be very thankful. He has brought forward rules for sampling fuel. Having something to do with the fuel testing of the Institute, I think it is a good thing that such rules have been placed on record, because samples come up to the Institute sometimes in little boxes or tins, and no statement accompanies them as to how they are sampled. I do not mean to say that this would help the analysis, but it would be of interest to put on record the method of sampling. I notice he speaks about halving the quantities, but I have always understood that quartering is considered to be essential. We all know the effect the work of the firemen would have upon the bridge described, and I would like to ask Mr. Fitch if he has had actual experience with such. I think it was Hampton who, in 1850 or 1856, first introduced the split bridge, but in his case the air was deflected towards the outlet. I have known of cases where a jet impinging on tubes has seriously damaged the tubes, and it seems to me that it is only a matter of time, if the jet is doing any real good, for it to create intense local heat, and probably to damage the furnace crown. It may be that the air blast pressure is not sufficient to seriously impinge on it, but as shown on the drawing it looks as if there would be that tendency. Then I do not know that the air supply is altogether satisfactory. It is stated that double the air supply is necessary, but in good practice, where efficiently looked after, I do not know that it needs 24 lb. : I think 50 per cent. is ample to give good work. Mr. Fitch, in his paper, brings forward some comparative tests as to the CO_2 produced, varying from $12\frac{1}{2}$ per cent. down to 6 per cent. Now 6 per cent. is far too low, and downright bad work, and the statement of 6 per cent. without the apparatus should not have been produced. 10 per cent. and $10\frac{1}{2}$ per cent. are common figures, and I do not think credit should be given to the apparatus by stating the figure as low as 6. With regard to this test, given at the end of the paper, Mr. Brand raised a question about it, and I think the determination certainly might have been better. The fuel value as given there is decidedly low, very low indeed for slack, it seems to me, without wishing to question the calorific value of the fuel. The boiler efficiency ought to be much higher with gas averaging 10 or 11 per cent. I was not quite clear as to what was meant by the calorific value of the fuel as fired at " lower value." I presume it means deducting the ash, but not the moisture. I am glad Mr. Fitch mentions the uneconomical method of the steam jets for blast, because undoubtedly they are most uneconomical ; they are not long in use before they consume more steam, which is wasted by reason of the wearing and consequent enlarging of the aperture. He might have given some information regarding the different systems of draught, in a question of economy in fuel consumption. There are various methods in use, the forced draught, induced draught, and natural draught, and each has its own grounds for consideration. Then in addition to that there is the method of working the fuel; what suits one fuel will not suit another, and, as Mr. Fitch remarks, some fuels give off more smoke than others. Undoubtedly the admission of air over the furnaces generally does a great deal of good, but it requires to be controlled.

Mr. J. H. FERGUSON: I would like to mention that as soon as a steamer is at sea the smoke nuisance ceases to trouble. There is one inducement to do away with it, and that is the by-laws of the local authority, if representation were made as to the economy effected by reducing the smoke, the steamship owner might have some difficulty in believing it, and if the chief engineer wanted an apparatus for testing, he would probably be asked if he wished a chemical laboratory just to do away with smoke. Some owners are not very anxious to supply even an Indicator. Of course the better class lines would probably be willing to supply an apparatus, if satisfied that it would be intelligently used.

Mr. W. WATSON: With regard to the test mentioned by the author, I think it would have been a little more satisfactory if the duration of the trial had been somewhat longer. I think the usual custom in making the trial of a boiler and evaporating appliances is certainly to make it over a longer period than 5½ hours to get really reliable results.

Mr. J. S. GANDER: I should suggest that the apparatus in the back end would be rather inconvenient in case of any repairs being necessary to stay nuts, etc. With reference to the bridge, as a rule these bridges, so far as I have seen, do not last very long, and I think the whole apparatus with unskilled firemen would be liable to be knocked to pieces in a short time. With reference to Mr. Brand's remarks about the CO_2 passing through picking up carbon, I think it forms carbon monoxide, CO. I should like to be put right on the matter if this is in error.

Mr. W. BRITTON: I have not heard the paper read, but so far as I can gather I think there is something in this system. Some years ago I had some trouble; as a remedy I introduced a 2 in. pipe at the back of the bridge, injecting air at natural draught, and it made so much difference that we used Scotch coal instead of Welsh, and got the same results without smoke.

I therefore think that a system designed for this purpose must produce good results.

Mr. J. Howie: This paper is both concise and clear; the facts are put together in a very handy way. It may be divided into two sections, theoretical and practical. Mr. Brand has taken some exception to the former, and with regard to the practical part Mr. Fitch has been careful in his expressions. I agree with Mr. Ferguson in his comments. The length of the grate has been mentioned. Long grates are often used on trial trips, but in ordinary work it is better to shorten the bars. The principle on which the system is based is not new. One method of applying it is to have holes in the bridges, to carry air into the back ends. If there is a saving of 50 per cent. between steam and air, the promoters would be wise in dropping steam altogether and going in for a fan. The boiler described at the end of the paper is evidently a sixteen years old type, but I do not see anything striking about the results. The firing is evidently good for the quality of fuel used. The CO_2 is given as 11 per cent., which indicates that the firing is fairly well done, but I think something better is wanted for a water tube boiler in evaporation per hour; true, the boiler is sixteen years old, and the cubical contents of the combustion chamber or air space are better to-day than at that time. I remember about nine years ago listening to a paper by Mr. Milton, who compared the cubical contents in the water tube boiler with the Scotch boiler, and gave preference to the Scotch boiler for value in combustion and economy.

Mr. P. Smith: I would like to point out that this is not a forced draught system, neither can you call it an induced draught system; it is purely natural draught with the introduction of a jet of air injected into a hollow bridge, which retards the rush of air and compels it to mix with the products of combustion. So that in looking over the statistics given here one cannot say that it economizes space, or that it effects the consumption of a greater quantity of coal per square foot of grate surface. The only thing that can really be claimed is, that instead of having to consume a coal of high-priced quality, one can burn slack. I think in the installation I saw there was a saving of at least 30 per cent. in the coal bill, probably more, but at any rate not less. It seems to me, therefore, that it should be regarded as a natural draught system with this arrangement introduced.

Mr. B. H. Budding (Member): Was the water pressure in the gauge 5 in. or ·5 in.? Mr. Fitch: 5 in.

Mr. Budding: In that case how do you get your draught? I take it the 5 in. pressure there is really stopping the current of air through the bars, and you do not get the actual combustion of fuel you should have. With regard to the bridge, of course the bars would be fixed; you could not possibly have any moving bars. Then again in clearing away the ashes the fire doors would have to be opened every time. Would it not be better to put it further back, having the bridge so arranged that when drawing the ashes it would be possible to push them underneath, closing the draught and preventing it going up the uptake? I am afraid the tube at the back is liable to get damaged in cleaning out with the rake.

Mr. Ferguson: I might refer to another advantage that may be derived from the system. In some parts of the world coal is supplied of a very inferior quality, brown lignite, and there is generally a difficulty in adjusting the air supply without means of this kind, the result being that part of the gases take fire in the smokebox, and even at the mouth of the funnel. These are difficulties that have to be overcome by those on the ship, and there are some very awkward moments when the smokebox catches fire, not through the accumulation of soot, but through the gases completing combustion in the smokebox instead of in the combustion chamber. Then again, as regards the bridge and the iron mouthpiece, if the bricks of the bridge were made in three large pieces, with the centre one like a keystone, it would last longer. There would be fewer firebricks necessary, because these three pieces would be wedged tightly into the back end so that there would not be any chance of them being knocked down. I have seen furnaces last, when wedged up in this way, for three months, where they would not last three weeks in the usual way, with the usage the firemen gave them. If the bridge were formed in three pieces, and also if the nozzle came out on the top of the bridge instead of the front, there would not be the probability of clinker filling it up. Of course there is the difficulty of clinker clinging to the front of the bridge in any case, and there is every chance of it blocking the aperture up altogether as it is now situated according to the sketch.

Mr. Wm. STORMONT : Another thing I would like to draw Mr. Fitch's attention to is that, if the damper was closed down and the fires banked up, the space over the firebricks and in the combustion chamber would become filled with carbon monoxide. Now on the door being opened with a pressure of 5 in. in the glass it would drive that carbon monoxide out into the stokehold, and under these conditions it might be dangerous. In a marine installation 1 per cent. of carbon monoxide is dangerous to human life.

Mr. P. SMITH : I question whether that is correct; I do not think a steam jet could possibly give 5 in. of water pressure. I think Mr. Fitch must surely mean ·5 in.

Mr. FITCH : I was glad to hear Mr. Smith's remarks, as he took an interest in this apparatus when I saw him some time ago, and it appears he still thinks it is a good appliance and might be used to a greater extent for preventing smoke, and also in securing economies. In reply to Mr. Vesey Lang, I may say the system has not been fitted to marine boilers to my knowledge, but I do not see why it should not be so fitted if it has effected economies in land boilers. Although at sea one can make as much smoke as one likes, at the same time a percentage of unconsumed carbon is being lost up the funnel. We have not experienced any trouble or danger due to flame blowing back, as suggested by Mr. Sidney Ross. Certainly when the fireman opens the door a slight flame comes out of the furnace mouth, but not to any extent. He also refers to the burning away of the brickwork of the bridge where the slot protrudes. These bricks project about 1 in. We find that the bricks built in this position prevent the ironwork burning away. The ironwork in our boilers has been in for considerably over two years, and is still in good condition. I was in looking at the furnace the other day, and could not see any deterioration of the cast iron work of the slot. As to the possibility of the burning away of the bars, I have not experienced any difficulty or disadvantage. There is 5 in. of water pressure in the box, while that of the funnel draught is 3 in. of water. The jet of air is forced on to the furnace crown and then deflected on to the burning carbon. Mr. Brand refers to the effect of the cold air striking on the furnace crown. To meet that difficulty the cast iron bend pipe behind the bridge has been given as much surface as possible, and is extended nearly the full width of the apparatus, which insures the air being heated before its admission into the furnace. It would be rather interesting to know the temperature of the air coming out of the slot, but I have not been able to get that. It is quite correct that this jet of air acts as a check to the gases, causing them to be thrown back and thoroughly mingled before passing over the bridge and up the funnel. With regard to the combination of the gases which takes place on the air passing through the bars I was under the impression that the process was that described in the paper. Mr. Clark refers to quartering in connexion with the sampling of the fuel. That paragraph was quoted from the paper read before the Liverpool Society, but I have no doubt one quartering portion would be quite sufficient for ordinary purposes. He also refers to the jet of air striking the furnace crown, causing intense local heat and burning away the metal. We have not experienced any deterioration of the furnace crown in that way. With regard to the quantity of air in practice for the combustion of 1 lb. of coal, he states that 24 lb. is too much. When I stated that figure I meant it to be approximate. I think some people use 15 lb., but I am under the impression that it is generally more than that. The amount of CO_2 mentioned, 6 per cent. when the apparatus was closed down, he considered was too low as a comparative figure, but I think if one were to go to a good number of boilers both at sea and on land, where no apparatus was fitted, the percentage would be found to be nearer 6 than 10. With regard to the calorific value of the fuel, which he also thinks is very low, I am unable to give any further particulars, as I was not present when the test was made. But I may state that when coal is burned in a calorimeter, the result comprises the total heat produced, including the latent heat of the steam (from the hydrogen), and is, moreover, the figure for the value of the dry coal, and not the coal in its natural state of moisture. When, however, coal is burned in a furnace, water is produced by the combustion of the hydrogen. There is also water in the coal ; and this disappears as steam, and is therefore lost. The low or effective calorific power represents then the value of the coal under working conditions, and is naturally the one to guide us in selecting or purchasing a coal upon its calorific basis. The high result is misleading, and should never be used as the basis. It is quite correct that heavy smoke at sea may not be a nuisance, but I think if we reduce the smoke as much as we can, and burn it, we are effecting a saving. It represents so much carbon passing out of the funnel, and if it is burnt in the furnace, of course, a certain amount is gained. Mr. Watson thinks the trial was rather too short, but on that point again, as I was not present when it was made, I am unable to say much about it. Mr. Britton referred to a method of admitting air to the bridge as an aid to combustion; it appears from an old book I was reading lately, that this is a very old method, but of course it is not on the same system as this. I think there is no other apparatus on the market exactly the same as this. Most of them have small jets, and it appears that the gases pass between these jets in crossing over the bridge. I have not seen a long slot such as this, with a sheet of air that absolutely traps the gases and causes them to be entirely consumed. The fan is not always adopted in place of a steam jet, as electricity is not always available for driving the small motor working the fan. In a power station, where there is plenty of current available, it is a simple matter to couple up the motor to the fan, and this appears to be a very convenient method of working, certainly a very economical one. It is not claimed that this apparatus in any way forces the draught or burns more coal per square foot of firegrate per hour: it simply prevents gases passing away until consumed. Mr. Budding referred to the pressure in the superheater box. I am quite certain that we had 5 in. of air pressure in the apparatus, because I had a U gauge fitted to a hole which led out through the brickwork, and was very careful in getting the pressure, desiring to know the quantity of air required to cause this pressure in the superheater box. He also refers to the damage to the air pipe that might be caused by the firemen in drawing ashes, as applied to marine work. I think he refers to the Scotch boiler, where the air pipe is led up to the front of the furnace. Of course there would be a slight disadvantage: a heavy cast iron pipe would be required. The pipe looks rather large in the drawing, but in practice it does not appear to be so much out of proportion to the furnace. Mr. Ferguson advocated that the bridge be made in three sections. I did not quite follow his meaning, but I think he meant to put the slot at the top of the bridge instead of at the angle it is shown. If that were done there would be a greater liability of ashes dropping into the slot than there is at present. Mr. Stormont referred to the possible danger of carbon monoxide being driven back into the stokehold. I am unable to say anything about that, other than that I have had no actual experience of such a thing. Of course it would be a serious matter if it did occur.

CHAIRMAN : The discussion on this paper has been very interesting, and I think useful to us. Any further questions could be sent to the Secretary, when Mr. Fitch will, I feel sure, be pleased to answer them. He has given his experience and placed his views before us.

The usual votes of thanks were then accorded and the Meeting closed.