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ECONOMY OF FUEL.

(BY J. W. BRAGG.)

As the overall efficiency of all steam power plants must necessarily depend upon the efficiency of the several sections of the plant which go to make up the whole, we must, if we wish to secure a satisfactory return from the fuel supplied to the boilers, see to it that there is no uneconomical working by loss of efficiency through inadequate plant or bad supervision, in the whole course from the coal to the utilization of the steam power. Up to quite recently, we have been ready to congratulate ourselves if we could add one or two points to the efficiency of the prime mover in the engine room, while at the same time, we have wittingly or unwittingly been allowing ten or twelve times the amount we save in the engine room to go to waste in the boiler house. The author does not wish to infer that the plant in the boiler house is not as well designed as the plant in the engine room, but what he desires to draw your attention to is that after an efficient plant is installed in the boiler house, it is handed over to firemen who are compelled to use a considerable amount of guess work in their efforts to secure the best results from the boilers in their charge. In the engine room there is the steam indicator to show how the engine is running, and to show also how it can be made to run more efficiently, but what is there in the boiler house to correspond to this? The fireman has to watch his steam gauge, the level of the water in his boiler, and the top of his chimney stack, and these three guide him in his stoking, but does it not appear advisable that he should know what is going on inside the flues of his boilers just as much as the man in charge of the engines should know what is going on inside his cylinders.

The object of this paper is to explain the action of an instrument which is now available, for recording the economical or uneconomical combustion of the fuel in the furnace, and to show how completely this instrument effects the purpose for which it was designed, and how in a way it is even superior to the steam engine indicator, in that it supplies a continuous visible record of the gases in the flues of the boiler, whereas the steam engine indicator is intermittent in its records at its best. What he would also endeavour to show is that the firemen seeing this continuous record in the process of being made, is enabled to get results from the combustion of the coal and to effect savings which are quite impossible if he trusts to guess work, even though his guess work is the result of years of experience.

We know that for the proper combustion of a known quantity of coal, a certain amount of oxygen is required, just the right amount, no more and no less, and it depends on the amount of oxygen supplied whether we get an economical result from the burning of the fuel in the furnace or not. This oxygen is taken from the atmospheric air, and is supplied by the draught through the furnace and up the chimney stack. At the high temperature of combustion the carbon in the coal combines with the oxygen in the air and forms gas, carbon dioxide, carbon monoxide, and other volatile gases, most of which are of no importance to us for our present consideration. Our attention must be paid to the carbon dioxide as its presence is a sign of complete combustion of the fuel, and a record of the percentage of this gas is an indication of the degree of perfection to which the fuel has been burned, and is therefore a reliable guide to efficiency and economy; if this carbon dioxide, or CO_2 for brevity, forms 21% of the escaping gases we have no loss of fuel at all, the carbon is completely burnt and it rests with the boiler to make use of the heat supplied. Should the carbon dioxide form a smaller percentage of the escaping gases than 21% the loss of fuel increases, and at a very alarming rate if the CO_2 forms a smaller percentage of the gases than 6 or 9%. Plate IV. graphically illustrates this point, and you will see that while the percentage of CO_2 drops from 20 to 9 the loss of fuel is fairly proportionate; after this point the absence of the proper amount of CO_2 shows how serious the case may become. It is a practical impossibilty to obtain 20% of CO_2 in the flue gas, 14% or 15% is the maximum, showing a percentage of fuel lost varying from 12 to 10 as against the possible enormous loss when the amount of carbon dioxide only totals 3 to 6% of the escaping gas, a not unusual condition of things. An instrument then, designed to show the fireman at every minute of the day how much CO_2 he has in his flues, will put him in the position to adjust his dampers so that he can quickly eliminate the conditions which are productive of poor results and bring about those conditions which are shown by a continuous record of a satisfactory percentage of carbon dioxide. Such an instrument, one that is entirely automatic in its action, the author will now explain to you.

Plate V. shows the complete instrument, the total height of which is 6ft., the width 3ft. and the depth 2ft. 6in., and which can be placed in any convenient position in the boiler house where the fireman can see the record without trouble; this record is a chart registered by the instrument on a card in such a way that the percentage of CO_2 in the gas is visible as the record is being made. The amount of attention and the expense in connection with the working of the apparatus is very small, and a few days at the outside of experiment with this instrument will determine the exact draught pressure suitable for the highest obtainable combustion, and the fireman will regulate his dampers to secure this pressure; it will also assist the fireman in ascertaining the best method of firing and what thickness of fire is best. The operation of the instrument is as follows:—The automatic action is secured by means of the motor, Plate VI., which consists of a tank " A " with an inner jacket " B," the jacket being filled with water, a bell " C " dips into this water seal and is counterbalanced by a weight " D" over the pulley " E." A tube " F " enters the tank "A" at the bottom and is carried up above the water level as shown at " G " and this tube " F " is connected through the pipe " H " to the bottom of the stack or to some suitable position where there will be a good draught; the draught of the chimney exhausts the air in the pipe " H " and through " F " and from under the bell " C "; this causes this bell to descend into the tank, as it descends into the tank the pulley " E " is caused to revolve by the string; on the face of the pulley are fixed two studs "J.1." and "J.2." which project far enough from the face to act upon the lever of the valve " I "; when the bell has descended to its lowest point " J.1." throws the lever over, closes the underside of the bell off from the chimney and admits atmospheric pressure beneath it; in consequence it rises under the action of the counterpoise " D " until the stud " J.2." throws the lever over in the opposite direction and opens the bell to the action of the exhaust through the pipe " H " to the chimney; the same movement takes place time after time, and is regulated by a clamp " L " on the pipe " H " by which the suction from the chimney is diminished at will. Passing from the pulley "J.1." are two strings which pass over the smaller pulleys shown; these strings actuate two plungers attached to the side of the motor, as shown in Plate V., constructed on the same lines as the motor, that is to say, with seals in the outer jackets; the duty of these plungers is to force the flue gases into the working parts of the recorder. The connection is made from the flue on the furnace side of the damper with ordinary wrought iron pipe which is led to the suction valves of the pumping apparatus. The two plungers moving up and down alternately press the flue gas into the registering apparatus, the flow being through the pipe " H " as shown in Plate

VII., and down through the tube "I" into the glass vessels "J.1." and "J.2.," which glass vessels are in communication with a flask "K" by means of a flexible tube "L"; the flask "K" is attached to the counterpoise as shown in Plate V., and moves up and down with it.

In order that a fair sample of the gasses to be tested should be secured, the end of the suction pipe should be carried well into the flue of the boiler, and although this may not secure an accurate sample of all the gasses passing through the flue it may be taken that results show that the end aimed at is accomplished. If the smoke issuing from the funnel of a steamer is observed, it will be noticed that there is a continuous swirling motion, and the author thinks we may fairly conclude that the gasses as they travel along in the flues, swirl in something the same way, and are fairly well mixed and consequently the sample secured through the suction pipe is a fair one.

Suppose that the bell of the motor is moving downwards, and consequently drawing the counterpoise and the flask "K," which is filled with glycerine and water, upwards, the flue gas being at the same time pumped into the vessels "J.1." and "J.2" as described:—as the flask "K" ascends, the liquid in it falls, and the level of the liquid in "L" and the vessels "J.1." and "J.2" rises:—as the liquid rises in "J.1." it covers the admission from the pipe "I" into the glass bottle "J.1." and thus cuts off any further supply of gas for the time being, a part of the pumped-in gas escapes through "J.3" into the atmosphere and when the liquid rising in the vessel "J.1." seals the inlet from "I" and the outlet in "J.3," exactly 100 centimeters of flue gas are enclosed in "J.1." and "J.2." As the flask "K" continues to rise, and consequently the fluid in "J.1." and "J.2" to rise also, this 100 cubic centimeters of gas is forced up through the curved pipe "M" and brought into contact with a solution of caustic potash with which the vessel

"N" is filled; connected by a neck piece to "N" is another glass vessel "O," the level of the liquid "N" being originally the same as the liquid in the leg of the vessel "O"; as the flue gas is forced through the pipe "M" on to the surface of the potash it displaces some of the liquid and forces it up into the vessel "O" and the air which is compressed in "O" acts on the inverted bell "P" which is suspended by a thin cord and counterbalance; the pressure on the bell "P" causes the lever "Q" to swing upwards and carries with it the pen "R" which is attached to the end of the lever; this pen rests against a circular drum fitted with clockwork, and carrying a chart calibrated in percentages of CO_2, reading from "O" at the top to 20% at the bottom, and arranged for a continuous run of 24 hours.

The vessels "N" and "O" are of such a size and shape that if none of the gas that is pumped through the pipe "M" is absorbed by the caustic potash, the pressure of the air in "O" is just sufficient to raise the bell "P" and therefore the pen "R" to the zero line at the top of the chart. If, however, any CO_2 is contained in the mixture of gases forced through the tube "M" the potash in the vessel "N" will absorb the CO_2, and, therefore, there will be less displacement in the liquid in "N," less displacement of the air in vessel "O," and, therefore, less pressure under the bell "P," resulting in a smaller travel of the pen "R" on the chart.

If there is complete fuel combustion, that is to say 21% of CO_2 in the flue gas, there will be no displacement of the liquid in "N," and therefore, no travel of the pen "R." The motion of the motor of the driving mechanism is arranged to reverse at the moment the pen has completed its upward stroke, the counterpoise of the motor begins to descend, and with it descends also the level of the liquid in "J 1" and "J 2," the the potash in the vessel "N" falls back also to its original level and whatever gas is left in the glass tubes is drawn out and passes into the atmosphere.

When the level of the sealing liquid in "J 1" and "J 2" has fallen below the level of the inlet from the tube "I," a new supply of fresh gas is pumped through the instrument until the returning seal entraps a fresh portion for analysis. The process is repeated time after time, and on each occasion the percentage of CO_2 is registered on the chart by the pen rising on the diagram; this forms a clear vertical line and the tops of these lines form a continuous curve which will show the percentage of carbon dioxide generated at any time during the day or night.

It may appear that the spent gases remaining in the glass vessels "J 1" and "J 2" would vitiate the next record made by the pencil, but if the form of the vessels "J 1" and "J 2" is carefully observed it will be seen that precautions have been taken to overcome this difficulty, the action is as follows :—As the flask "K' falls and the liquid in "J 1" and "J 2" falls also, gas from the pumps continues to be forced in through the pipes "H" and "I" and as the liquid at the bottom of the vessel "J 1" will not allow the gas to travel downwards it must necessarily flow upwards in "J 1" and down "J 2" and secure exit through "J 3," thus sweeping all the spent gases of the last record in front of it; the remaining portion in the small curved tube "M" is exhausted also, and thus a complete supply of gas of the proper constituency is imprisoned for the next record.

When the entrance into the vessel "J.1." is sealed by the fluid, the discharge from the pumps, not being required any further during that stroke for analysis, passes out into the atmosphere through an escape valve placed underneath the pumps, as shown on Plate V.

In order that the gases to be analysed may be free from impurities when passing through the instrument, a filter is supplied with the apparatus, and inserted in the supply pipe, the filter is filled with wood-wool shavings, inserted by layers of saw dust.

The potash solution is changed usually about every ten days, and can be made up by the engineer in charge, the point which he must note being, that the specific gravity shall be 1·27.

It is not necessary to have an instrument for each boiler as in most cases it is quite sufficient to take readings from the various boilers of the plant, one recorder can be utilized for a battery of, say, eight boilers, by means of a system of branch pipes tapping each boiler flue, and running into one main pipe which is led to the recorder; the branch pipes are fitted with cocks so that the gases from any boiler may be analysed at will. Before reaching the apparatus the gases are passed through the filter to clear them from impurities.

The simplicity of the design of this instrument, and the accuracy of its records is obvious; practically no attention is needed to keep the apparatus in order, the only points to be attended to, are that the clock shall be wound, the diagram paper renewed, and the levels of the potash and the sealing liquid adjusted.

The diagrams, Plates VIII. and IX., serve as an illustration of the benefit to be gained by the use of this instrument, and are interesting as demonstrating the difference of CO_2 contained in the flue gases when the fireman was working under varied conditions. In the first diagram he is stoking in an ordinary way, perhaps rather carelessly, with the result that approximately 40% of the thermal value of the fuel is lost; the other diagram shows the improvement which may be effected if the record of the CO_2 is carefully watched, and the result is a saving of about 19% over the previous case. The upper chart of Plate IX. shows the record taken from a stoker-fired boiler, while the recorder was covered up to prevent the fireman seeing the record, the average percentage of CO_2 in this case is 6 2, which means 26% of fuel lost. The lower diagram shows a record taken from the same boiler with the fireman watching the recorder; the average percentage of CO_2 in this case is 11·4, which means a 16 percentage of fuel lost. This last diagram is by no means an ideal one, and by a careful inspection of the diagram as it is being formed, the fireman can so adjust his dampers that a more regular and satisfactory curve is formed on the recorder.

It would appear then that with an apparatus of this description the fireman is in a better position to reduce the loss and waste fuel, and perhaps it is only fair to the fireman himself that he should be provided with an apparatus of the kind to put him into a position that he can use to advantage the high class and well designed boilers which are placed in his charge; without the apparatus his work must necessarily be either regulated by rule of thumb or by guess; with the apparatus he has something definite upon which to work, something to show him when he is going wrong, and something to confirm his action if he is working in the right direction.

The instrument is of service not only for hand-fired boilers, but also where mechanical stokers are installed; the regulation of the draught by the dampers is as important in one case as in the other, and although the mechanical stokers handle coal more economically than the average firemen, they do not entirely eliminate the personal element, and the fact of their being installed is not of itself a guarantee that the best results are secured.

Finally, the chart is a record to the station engineer as showing how far the fireman has attended to his duty during his watch, and it may also be the means of showing him how an alteration may be made to his flues which will be productive of better results.

[Note—The instrument described in this paper is known as the "Sarco," and is manufactured by Messrs. Sanders, Rehders & Co., Ltd., 108 Fenchurch-street, London.—Ed].

MR. RUSSELL SINCLAIR said he had much pleasure in moving a vote of thanks. He considered we were indebted to the author for the clear explanation of the instrument. He would like to enquire if there is any lapse of time in producing the record on the diagram, so that suppose a man has put an extra shovel-full of coal would it show it immediately on the diagram. It seemed to him that the method was slow, but it could not be called a defect The record was only an attempt to arrive at an indication of what was happening generally. He supposed that the fireman or engineer would soon get to know how much time would elapse before the instrument would register. He considered the instrument was well worth investigation. It proved that we have not placed enough interest in the stokehole, which might now become the centre of interest. The combustion of the fuel seemed to be where the greatest economy would likely to be obtained. He had much pleasure in moving a vote of thanks.

MR. W. H. GERMAN said he had much pleasure in seconding the vote of thanks, and would say that he felt personally much indebted to the author for the very lucid explanation he had given. He had seen a similar instrument at the Ultimo Power House. It was demonstrated to a number of us ; but he could not say that he really understood it. To-night he felt he had explained to him that extremely ingenious instrument. The author stated that it was intricate, but it was not so, it appeared quite simple ; it was a marvel in engineering. He thought that it would be an instrument of a rather dangerous nature in the hands of people who did not use it scientifically and with the real object of ascertaining what was in the flue, it appeared to him that if the pipe was abnormally long between the flue and the instrument you might analyse gases that were in the flue a quarter of an hour before. It might be difficult to form an idea of the period at which the records were taken, the size of the pipe and the length between the flue and the instrument might materially affect the records. He had much pleasure in seconding the vote of thanks.

Mr A. J. Arnott desired to support the vote of thanks. It was a paper that was entirely educational, and it brought before them a subject that some engineers especially have had to study more closely within the last few years. It is being recognised that we have to pay more attention to the stokehole than has been done in the past. Mr. Bragg pointed out, and he was correct in saying that 10% loss, in fact more than that, existed in many boiler installations, owing to neglect to attend to the quantity of CO_2 in the flue gases. It had been stated that the mechanical stoker is an aid to the proper mixture of the gases, and it is readily understood the reason that it should be. The difficulties raised with reference to the sampling of gases, he thought, could be quickly ascertained if the man in charge had any brains and used them. This instrument was only an aid to the attendant. He would take greater interest to ascertain the best position for his dampers, the thickness of the fires, and so on. If the sampling of gases, say, from the centre of the flue was not in accordance with his idea of things, it was a simple matter for him to put his suction pipe lower or higher. He had no doubt a very fair average could be obtained in a day's trial to ascertain the exact position of affairs.

Mr. J. W. Bragg, in responding to the vote of thanks, said he had endeavoured to explain all the parts as clearly as possible, but there must be points which are still not quite satisfactory to some of them. Mr. German mentioned one with regard to the securing of a proper sample of the gas. The instrument is placed as close as possible to the boiler, also the pumps have a large diameter, so that the volume of gases sucked in by them during each stroke compared very favourably with the amount of gases contained in the pipe, which was only a $\frac{3}{4}$ inch gas pipe.

Another question asked was, how long it would take before the instrument would show the fireman whether he was working on right lines or not, after adjusting his dampers, or changing his method of firing? He would see the effect on the chart in about 1 or $1\frac{1}{2}$ minutes, and this was quick enough to show him if he was doing right or wrong. If there were any other points which had been overlooked, he would be very pleased to explain them.