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Flue Gas Analysis and its Advantages.

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TO BE READ

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CHAIRMAN:—MR. J. SHANKS (Member).

IT is gradually coming to be realised that no steam raising plant, which can lay claim to any importance, is really completely furnished unless automatic CO_2 Recorders are installed, and their favourable influence on efficiency is being so brought home to up-to-date engineers that it will probably not be long before they are specified in contracts in the same way as steam pressure gauges.

Before we proceed to investigate the reason for this, and see what information these Instruments can give us and in what way they may be of assistance, it may be well to consider the general question of steam production, and in so doing we will devote our remarks particularly to the fuel mostly employed in this country for Mill-driving, and, up to the present at least, for marine purposes also, namely bituminous coal, although they will apply in a large measure to other fuels also.

When we wish to produce steam in a boiler we must do so by passing sufficient heat into the water contained therein, and coal usually forms our most convenient medium, containing as it does a considerable amount of heating power in a comparatively small volume, and yet being easy to procure and safe to handle. The heating power or calorific value of any coal can be readily ascertained by one versed in the necessary methods, with the aid of a calorimeter and other apparatus, and in England it is usually expressed in British Thermal Units per pound of fuel, the British Thermal Unit, or B.T.U., as it is commonly called, being that amount of heat which is required to raise one pound of water one degree Fahrenheit in temperature.

The heating value of any given coal being then something definite and fixed, it might readily be thought that two firemen burning equal amounts of the same coal in the same boiler would always produce equal amounts of steam. Most of us know, however, from our own experience that such is not the case, and official tests carefully carried out have shown results varying very considerably. Since there is a reason for everything it may be well worth our while to seek for the reason of this, as our researches may help to bring home to us more forcibly some points to which we have hitherto not attached sufficient importance. Let us then commence.

When coal is being used in a boiler furnace for the purpose of steam production, only a part of its value can be transmitted to the water, and the remainder is lost. If, therefore, one of the firemen shows a higher efficiency, it is evident that since there is a definite amount of potential heat in the coal, he must be increasing the quantity usefully employed by reducing the losses to an equivalent extent. What then are these losses? They can all be accounted for under one or other of the following heads:—

(*a*) Coal not burned, or only partially burned, falling into the ashpit.

(*b*) Heat radiated from the furnace, boiler surfaces, and brick-work if any.

(*c*) Heat in clinker and ashes taken from the fires when cleaned out.

(*d*) Heat passing away up the chimney or funnel.

Now in the two cases which we are considering there will not be serious differences in the first three items, namely, the losses in the ashpit and clinker, and by radiation, and the reduction in loss must be looked for under item (*d*), the better fireman having conducted his management of the fires in such a way as to allow less heat to pass away up the chimney or funnel.

We have now narrowed down the issue considerably, and can make further progress by investigating the nature of these chimney or funnel losses, the greater or less amount of which can account for such considerable differences in boiler efficiency. This will take some little time, and we can best begin by considering the composition of coal,—the fuel which we use for producing the necessary heat,—and the process of combustion.

Coal is composed of Oxygen, Nitrogen, Ash, Sulphur, Hydrogen, and Carbon, of which the two last named are the valuable combustible elements,—Carbon always being by far the greater in amount. In order that their potential heat value may be developed and converted into sensible heat,—that is to say, in order that they may burn and so give up their heat—they must be brought into close contact with a sufficient volume of Oxygen at a temperature high enough to bring about their combination. It is important to remember that, in order to produce complete combustion, all these three conditions must be present at one and the same time, *sufficient Oxygen*, *thorough mixing*, and a *temperature high enough.*

When we say sufficient Oxygen, we are by no means speaking vaguely, or in the dark, for we know exactly what amount is required for a given weight of Carbon or Hydrogen, and fairly accurately what amount of heat is derived from their complete combustion, and, since we know what percentage Oxygen forms of atmospheric air, we can equally well tell what amount of air is needed for these processes.

One atom of Carbon combining with one atom of Oxygen forms CO—Carbon monoxide—and yields heat at the rate of 10,230 B.T.U. per lb. of Carbon. Out of this, however, 5,810 B.T.U. are absorbed in the work of changing the Carbon into the gaseous form, leaving only for our use a net available heat of, 4,420 B.T.U. The addition of a second atom of Oxygen converts this CO into CO_2—Carbon dioxide—and gives further heat again at the rate of 10,230 B.T.U.—*all* available this time, since the CO is already in gaseous form—thus making a total net heat of 14,650 B.T.U. per lb. of Carbon.

There is in all coals, as already stated, far less weight of Hydrogen than Carbon, but its heating power per lb. is considerably higher, viz., 62,100 B.T.U. The available heat for steam raising in a boiler is, however, less than this for the following reason:—the Hydrogen combines with Oxygen in the proportion of two units of the former to one of the latter, forming aqueous vapour, H_2O, in weight nine times as much as the original Hydrogen. Since the flue gases pass up the chimney at a higher temperature than 212° F., boiling point, this H_2O will escape as steam, carrying away its latent heat, which is 967 B.T.U. per lb. Nine lbs. will therefore rob us of 8,700 B.T.U. leaving a net available heat of 53,400 B.T.U. per lb. of Hydrogen. (These values of Carbon and Hydrogen are according to Bryan Donkin,—some other authorities give values slightly different).

From these investigations we clearly see the importance of introducing to the boiler furnaces enough air to provide sufficient Oxygen to fully develop the potential heat in the combustible elements of the coal, since otherwise we may sustain considerable losses.

To take the Carbon first, any particles for which no Oxygen is provided will carry away their *whole* heating power to waste and leave the chimney top in the visible form of smoke, thus, in addition, incidentally creating a nuisance. Those portions which secure to themselves one unit of Oxygen per unit of Carbon will give up, as we have seen, less than one-third as much heat as they would under perfect conditions, and only from that part of the Carbon which unites with sufficient Oxygen to form CO_2 do we derive the full benefit of its heating power.

Most authorities agree that when the air enters the ashpit of the boiler and reaches the lowest layers of the fire, CO_2 is first formed:—as the gases then pass through the mass of incandescent fuel in the furnace and come into contact with the carbon, this latter seizes hold of one of the atoms of oxygen in the CO_2 and reduces it to CO, the product of *incomplete* combustion. If this gas afterwards meets with a further stream of air before it has been cooled down below the temperature necessary for combustion, it is reconverted to CO_2, the product of *complete* combustion.

With regard to the Hydrogen we need only say that, whereas its complete combustion produces a comparatively large amount of heat, this heat is entirely lost if a deficiency of air prevents its meeting with the requisite Oxygen, the Hydrogen then passing away absolutely unconsumed.

In order therefore to prevent any likelihood of these various losses through incomplete combustion we shall be wise to take care to admit plenty of air. The next point to consider, is what the consequence will be if we go to the other extreme and admit a great deal too much air, and we shall soon find that we then sustain even greater losses in two different ways.

In the first place, a smaller proportion of the heat in the gases of combustion will be usefully employed in heating the boiler water, and more will be wasted up the chimney, on account of the cooling effect of the superfluous air, and the cause of this is very plain. As a ball will run downhill more or less rapidly according to the steepness of the hill, so heat will be transmitted through a boiler plate more or less quickly according to what is called the heat gradient, that is the difference in temperature between the hot gases on the one side and the water on the other. Therefore the furnace gases, reduced in temperature, will, during the short time whilst they are being rushed along in contact with the boiler heating surfaces, succeed in passing a smaller proportion of their heat into the water than would have been the case had so much excess air not been admitted, and, therefore, at the finish, more heat will of course be left to go to waste up the chimney.

In the second place we must remember that the air which we admit to the furnace *at atmospheric temperature* contains in addition to the useful Oxygen the inert gas Nitrogen, to the extent of more than three-quarters of its entire weight. Now the whole of this Nitrogen, and also the gases of combustion, leave the chimney at a *greatly increased temperature*, carrying away a large amount of heat, and it is very evident that the larger the excess of air we admit, the greater will be the volume of the escaping gases, and the greater therefore the amount of heat carried away to waste at any given temperature.

Now then, we are better able to understand how it is possible for the one fireman, with the same amount of coal, to produce more steam than the other one, for he evidently manages his air supply better, as compared with the coal burned, either through knowledge or instinct or good luck. The less fortunate fireman sends more waste up the chimney, either through admitting too *little* air, thus losing a part of the value of his coal through incomplete combustion, or else through admitting too *much* air, whereupon the increased volume of gases carries away a larger percentage of heat.

Staying now for a moment to review the position we appear to be in somewhat of a difficulty, and to find ourselves between Scylla and Charybdis, for if we have a shortage of air we suffer loss, and if, on the other hand we have an excess of air we may suffer even greater loss. Evidently, the only way to secure economy is to avoid both extremes, and to so arrange matters that the air supply is just about sufficient for the coal burned. But how are we to know when this is the case? for neither the air nor the gases can be seen, unless the latter be smoky, and there are so many points to be considered. The kind of coal, its size, the thickness of the fire, the spaces between the firebars, the width of the firebars, the openings in the furnace door, the strength of the draught,—all these things will affect the question of the proper balance between air and coal, and in what way can we judge of the final result of all these factors combined?

From this difficulty, chemistry points out a way of escape. We have seen that most of the heating power of the coal lies in the Carbon which it contains, and also that we develop the whole of the heating value of that Carbon when we convert it into CO_2—Carbonic acid gas—by bringing it into contact with that quantity of air which will supply enough Oxygen to combine with it and cause complete combustion. A little calculation will show that, when we use the amount of air which is theoretically necessary for burning bituminous coal, the resulting gases will contain about 19 per cent. in volume of CO_2. It is true that practically 21 per cent. by volume of the air is Oxygen, but it must be remembered that bituminous coal does not consist of Carbon only, and the Hydrogen which it contains combines with some of the Oxygen of the air, thus accounting for the difference, which one may fairly correctly assume to be 2 per cent. or thereabouts, thus leaving a theoretical maximum of 19 per cent. Experience proves that in boiler practice it is wise to allow a little excess of air to enter the furnace in order to give the Carbon a better chance of picking up the Oxygen which it requires, since the time at its disposal on its rapid path through the flues is very short, and the mixing might not otherwise be absolutely thorough. This will bring down the percentage of CO_2 at which it is advisable to aim for perfect working to about 15 per cent., so that at last we have a clear basis of calculation to work upon,—the percentage of CO_2 in the escaping flue gases will plainly show whether the coal in the boiler furnaces has been economically burned or not, and the next step is to find out a way of testing those gases.

Here it is that a little knowledge of chemistry help us, for that will tell us that a solution of caustic potash of suitable strength will absorb CO_2. If then we take a measured volume of the gases, bring them into intimate contact with caustic potash, and then measure them again, the reduction in volume which we find to have taken place will represent the volume of CO_2 originally present. There are various types of hand apparatus for carrying out this operation, for which a certain amount of practice and a great deal of care are needed if the results are to be reliable.

Such tests by hand, however, are obviously only suited for occasional use, and they can only show the condition of the fires at the time when they were carried out. For the idea to have much practical value for industrial purposes it will be easily realised that an instrument operating continuously and automatically was absolutely necessary, and the demand has brought forth such an instrument, the Automatic CO_2 Recorder. The quantity measured each time is 100 c.c., so that the results are percentages of CO_2, and they are recorded on a revolving chart at intervals of several minutes throughout the whole of the working hours, day or night. These records therefore are of great value to the various persons who are interested in the efficiency of the boiler furnaces. They act as a constant guide to the firemen, helping them to discover the best methods of furnace management, relieve the engineer of much responsibility, and keep watch for him when he is occupied elsewhere, and finally show the employer whether the coal, for which he has to pay, is being used to the best advantage.

And now let us consider briefly a few points with special regard to the use of these instruments at sea. In the first place, since liquids are employed—namely, water for the purpose of operation and caustic potash solution for the absorption of the CO_2—it is necessary that a horizontal position should constantly be maintained, and furthermore, considerable vibration would be a decided disadvantage. Any difficulties in these respects are therefore met by suspending the Recorder from a bracket attached to a bulkhead, making use of a strong spring and a universal joint.

The gases to be tested can usually be taken most conveniently from the up-take of a boiler at a spot where the gases from its several fires have combined in one common stream. A small pipe is run from the up-take of each boiler which the Recorder is to control, to a spot close to the instrument, which must of course be located in a clean place, the final connection being made by means of a short length of rubber pipe which is temporarily joined, by some simple and convenient method, to whichever line of piping it is desired to test.

In this way a Chief Engineer—whose responsibilities are widespread, and who has too many matters to think about to devote overmuch consideration to any particular one—can, by the expenditure of only a reasonable amount of time and attention, have clear and lasting evidence of the efficiency with which his boiler furnaces are being managed. First of all he will see whether the general methods which are followed are fairly satisfactory—then, by switching over at intervals from one connection to another, he will be enabled to tune up the various boilers in rotation, and test any individual one at will.

The feeling that they may be under test at any time tends to keep the stokers' work at a higher level, and the fact that the visible results can be inspected and discussed helps to increase the intelligent interest of all concerned. A careful study of the records, side by side with the knowledge of the conditions existing at the time, may often yield much information and result in the discovery of faults which might otherwise have remained unknown. As has already been mentioned, a number of factors exercise an influence on the furnace efficiency, but a faulty state of things with regard to any single one of them will be quite evident upon examination of the CO_2 Record, which will point to the need for an alteration in one direction or the other. The explanation of this is that every one of these factors affects in some way or other the flow of air for purposes of combustion, and, as we have seen, the *whole question of efficient combustion rests on the correct proportioning of air supplied to fuel burnt. The CO_2 record, therefore, gets straight to the point by showing the result of all the factors combined, and so may well be called the pulse which shows the healthy condition or otherwise of the whole system.*

One aspect of the matter which we have so far passed over is the bearing which CO_2 Recorders have upon Smoke Prevention. Many steam users are quite convinced from practical experience that a smoky chimney is more economical than a clear one, and unfortunately the conditions usually existing appear to justify their belief, although it is only a case of a half truth being worse than a lie.

We have shown that the highest efficiency will exist when a slight excess of air is admitted to the furnace, thus bringing about complete combustion, when the flue gases will be clear, but that, if we lessen the air supply the combustion will be incomplete and smoke will ensue with resulting losses. If, on the other hand, we increase the air supply more and more the gases will remain clear, but the loss of heat up the chimney or funnel will gradually become greater and greater, until at last, it may far exceed that caused by incomplete combustion accompanied by smoke.

The half truth then which is more dangerous than a lie, is the fact that a chimney, smoky through shortage of air, may be less wasteful than one, clear through *large* excess of air, although one clear with a *slight* excess gives the very highest efficiency.

Now it is scarcely possible to distinguish between these two conditions of clearness without the help of a CO_2 Recorder, the chart from which will enable one to steer between the two extremes and keep near to the smoke line, without, however, passing over it to any serious extent. A safe rule to adopt with marine boilers is to endeavour, when sampling gases from the spot suggested, namely the up-take, to produce a record varying from, say 10 to 13 per cent. of CO_2. It is true that we stated that 15 per cent. represented practical perfection, but it must be remembered that there will be some slight unavoidable inleak of air round the smoke-box doors, which will dilute the gases in proportion to its volume, care must of course be taken to keep it as low as possible, but it is extremely likely that it will be sufficient in quantity to bring down the advisable maximum at least from 15 per cent. to 13 per cent. At 13 per cent. then, under such conditions, one may very well anticipate that smoke will not be produced to any extent, and between that point and 10 per cent. the loss through excess air will not be unduly great.

The records will help to bring about a healthy rivalry between the various shifts, and it might be of advantage to devise a system of bonuses to encourage the stokers to show good results. Furthermore, the question appeals to them personally when they once realise that the more efficiently they burn the coal the less they have to throw on.

A consideration of all these points is of great importance in connection with boiler practice anywhere, but for various reasons it appears to be so to a superlative degree where installations on board ship are concerned.

In the first place, the price of coal, which has to be shipped in different parts of the world, is frequently very high, and with the price, the value of economy of course increases in proportion. Now the amount of coal burned throughout the course of a year on any vessel is comparatively very large, so that quite a small percentage of saving through increased efficiency would total up to a considerable item annually.

But there is another point which, on some boats, would be even more advantageous than that, and which a chief Engineer was good enough to mention to the writer.

Take the case of a fast liner on which the rate for cargo was very high. If the proper use of CO_2 Recorders permanently raised the efficiency of the boiler furnaces, a less quantity of coal would suffice for each voyage, so that not only would there be the resulting economy in coal, but also valuable space which had formerly been reserved for fuel could be utilised for cargo, and the return on the capital expenditure on Recorders would be exceedingly large.

With regard to the beneficial influence of the Recorder on the smoke question, it is obvious that, apart from economy, the avoidance of any considerable amount of smoke from the funnels would be desirable, especially on passenger boats.

Then again the Recorder has a very direct bearing on the serious question of leaky tubes in marine boilers. The more irregular the firing the more extreme and rapid will be the variations in temperature, resulting in undesirable stresses through expansion and contraction. But irregularity in firing would be accompanied by irregularity in the CO_2 Record, which would plainly show what was happening, and call attention to the need for alteration in the methods of the stokers.

Seeing that the proportion of the heat value of the coal carried away by the escaping flue gases naturally varies with both their temperature and their volume, and the latter, as we have seen, bears a direct proportion to the percentage of CO_2 contained therein, a knowledge of these two factors—the temperature and the CO_2—will provide a basis for a calculation of the losses at any given time. A very useful chart worked out on these lines for ready reference is given in Bryan Donkin's "Heat Efficiency of Steam Boilers," and a glance at it will show in a very graphic manner what a serious thing it is, from the point of view of economy, to work with an unduly large excess of air, for it will be seen how the losses increase at an ever accelerating rate as the percentage of CO_2 sinks lower.

In connection with this chart, it is interesting to mention a series of tests made under practical working conditions for the purpose of comparison. The boiler in use was provided with a special furnace which placed the air-supply most thoroughly under the control of the fireman, who was instructed so to manage his firing as to produce good and bad records throughout alternate days. The coal was carefully weighed for each test, and the water measured, the temperatures of the flue gases were taken and the average percentages of CO_2 reckoned. In each case it was found that the actual difference in coal used to evaporate a given quantity of water under the good and bad conditions, corresponded very closely with the figures shown on the chart.

Take for instance the two days' charts of which CO_2 Records are shown in the reprint from *Engineering*, on the subject. On the first day, the average CO_2 was rather less than 8 per cent., and on turning to the chart, we find that, seeing that the temperature of the gases was approximately 500° F. above atmospheric temperature, the amount of the heat value of the coal being carried away was about 24 per cent. of the total. On the second day when the CO_2 was just over 15 per cent. this loss is found on the chart to be only 13 per cent., a reduction of 11 per cent. thus being shown.

The discrepancy between this economy of 11 per cent. on theoretical reckoning and the saving in coal actually observed was very small, for, whereas on the first day a certain quantity of water was evaporated by 100 lbs. of coal, on the second day $89\frac{1}{2}$ lbs. sufficed for the same duty. In passing, we may notice that the run from 9 o'clock to 1 o'clock on the second day shows most excellent, in fact, practically perfect results, evidence of a rapid cleaning of the fire being noticeable where one short stroke occurs. Earlier in the day, however, and in the afternoon, the anxiety of the stoker to produce a good record led him to extremes, and he cut down the air supply too much, for 17 per cent. of CO_2, even at the down-take of a Lancashire or Cornish Boiler is unduly high, for any advantage which might be looked for from the last 1 or 2 per cent. would in most cases be more than counterbalanced by the loss resulting from incomplete combustion through shortage of air. It is just possible that in this particular instance no such loss through incomplete combustion did really occur, for, as already mentioned, a special boiler furnace was in use, and this ensured a more than usually thorough mixing of the air with the gases emitted from the fuel, so that it was fairly safe to work with only a small excess of air above that theoretically required. It is, however, almost invariably wise to keep down to such figures as those given earlier in this paper.

From all that has been said it would appear to be quite justifiable to claim for the Automatic CO_2 Recorder a foremost place among those instruments which are recognised as useful aids to the Steam Engineer. It cannot now be regarded as being merely of theoretical interest, seeing that one can point to a Combine in this country which has 35 distributed throughout its various works; Power Stations abroad with 14 and 18 respectively, and a well-known Steamship Co. which has installed these instruments on all the seven liners of its fleet after making a lengthy trial on one.

Like all other Recording Instruments, the CO_2 Recorder cannot of itself accomplish anything, but at least it will tell during the whole of the time when it is in operation, a plain unvarnished tale of what is happening in the department which it has to control, and enable the Engineer to see whether all is well, or whether conditions are such as to need attention and improvement. Upon due consideration he will surely feel called upon to investigate its merits and possibilities thoroughly and practically, for without its clear and constant guidance how can he hope to reach and maintain the highest level of efficiency?

DISCUSSION.

Monday, October 6, 1913.

CHAIRMAN:—MR. J. SHANKS (Member).

CHAIRMAN: You have heard Mr. Jones read his paper, and he has also given us a very clear and concise description of the recorder. There is scope for an interesting discussion on this subject. The combustion of fuel is one of the most important questions that marine engineers have to deal with. We all know the great loss that takes place on board every ship through incomplete combustion, and this is a means, I understand, of putting clearly before the engineer a record of conditions which should not exist, and also to show him when the best conditions are being attained. I should be very pleased if someone would open the discussion.

Mr. J. CLARK: Mr. Jones no doubt knows that this is not the first occasion upon which we have had a demonstration with an automatic CO_2 recorder. A demonstration took place at the Institute four or five years ago with another type of instrument, the action, I suppose, being practically the same. I should have liked Mr. Jones to have given us some information how to keep the gas pipes clear; this is a point which requires great consideration in putting an instrument like this on board ship or in a factory where a long length of gas pipe may be required. The suction set up by the action of the water is not sufficient to keep the gas pipe clear, and the result is that time and again one sees valuable instruments put out of use. This is by no means a simple point, and it is as important as the working of the apparatus itself. Mr. Jones has thrown a good deal of light on the subject of combustion, but he has not touched upon the question of oil fuel, and that is a subject which is coming more and more to the fore. Another feature I should have liked to have seen dealt with more in detail is the quantity of air required for combustion. We know in a general way that so much air is required for combustion; our papers, however, are widely distributed, and sometimes it is not very convenient for members to refer to text books stating these little facts. It is always good, I think, to have such information given, in spite of the objection that there would be a tendency to fill the paper with calculations. For instance, Mr. Jones refers to "a little" excess of air, and I am not quite clear of what is meant by a little excess, because, speaking from memory, I believe that to get a percentage of 15 per cent. of CO_2 gas would mean that there was an excess of about 30 per cent of air, and that is by no means a little. With regard to the question of smoke, some very true statements have been given in Mr. Jones' paper on this subject, especially his remarks on cases where no smoke is emitted; but I do not think an automatic recorder is a machine for preventing smoke. I rather think that it is not; it is a question of fuel more than of carbonic acid gas. Generally speaking no one can take exception to the theoretical deductions in this paper; the difficulty is in practice. One may attempt to consume fuel on the best theoretical methods, and not get the best results. In addition to the losses mentioned, another great source of loss is dirt; dirty tubes, dirty shells; over and over again it will be found that there is a big loss due to the condition of the heating surfaces, and the means of transmitting the heat. No doubt heat gets away as Mr. Jones says, passing up the chimney or the funnel; but I understand his reference is to that due to incomplete combustion. It may be of interest to refer to the demonstrations that we witnessed at the West Ham Technical Institute on the last occasion on which we considered this subject; I see that on starting up the automatic recorder the gas varied from 1·57 per cent. (due to a good deal of air in the pipe system) up to 13 per cent. I think that machine was adjusted to produce 30 analyses per hour. I presume this machine could be adjusted to give a similar number.

Mr. Jones: We do not find it necessary to give more than 14 or 15 per hour; in fact, the one connected to our own boiler plant is seldom run at more than 10 or 11, and it then gives us all the information we need.

Mr. Clark: The paper has been a very interesting and valuable one, and one or two points have been made clearer to me than they were before.

Mr. E. W. Ross: Could salt water be used for working the instrument?

Mr. Jones: The Bibby Company, who have an installation on each of their boats, started them on fresh water, but said this would be too expensive, so they tried them with sea water and have found this to be quite satisfactory.

Mr. O. B. Richardson: How often does the caustic potash require to be changed?

Mr. Jones: The usual practice is to change it once a month.

Mr. Wm. McLaren: I have certainly derived a good deal of information from the paper, and from the demonstrations which have been given. The instrument is a specialty, and evidently there are not very many in use; but if, as Mr. Jones says, it is a smoke preventer, he has only to approach the sanitary inspector in any locality and the machine would soon be adopted to a greater extent. I am not inclined to think, however, that it is a preventer of smoke. This machine draws off the gas from the chimney; but if a fireman is alert at all he can tell by looking at the furnace and chimney head generally by seeing it reflected on a piece of a looking glass or window whether the combustion is good or not, and he can manage to deal with the smoke in that way without relying on a machine of this description. I have one recorder in my mind which never makes a straight line even when on atmospheric pressure, and I have therefore a doubt whether it makes a true record of the condition of the flue gases. Mr. Clark, I think, referred to the length of the tubing or piping from the boilers to the recorder, and if that is inclined to become dirty it would certainly have a bad effect. It would be advantageous for each furnace to have a filter for itself, as I understand is recommended. There is also the cost of the recorder to consider; I should think it would cost about £30 to £40, but of course if it performs what is claimed for it the money would be well spent. I think it is an instrument which it is well for us to consider and to criticise, for it is a step towards bringing us to a higher stage of efficiency in the boiler and plant. I should like to add my thanks to Mr. Jones for his excellent paper.

Mr. F. O. Beckett: I had not the pleasure of hearing the greater part of the paper read, but I should like to put a question to the author. The demonstration given, I understand, is for normal good coal such as the ship will usually have. I should like to ask what benefit would be derived by an indication from the recording part of the instrument when the engineer is called upon to use Indian coal in furnaces which are at the time using Welsh coal. I have come across engineers who burn 20 tons of coal a day going out and 45 tons a day on the home journey. Would the instrument be a guide under such conditions; would it show that it would be necessary to adapt the furnaces for 45 tons instead of 20 tons? allowing for the fact of taking one or two bars out—I am speaking of natural draft. Many vessels are delayed in the Red Sea through using Indian coal, and it would be of great benefit if the instrument could be utilised to prove to the owner that it was necessary to use the larger amount of coal, or that it wa necessary to put the ship into port, say at the Red Sea, in order to get more coal.

Mr. A. G. Rainey: I should like to ask the author if, in the event of getting a low percentage of CO_2 on the record, there is any indication to tell whether it is due to an excess of air or a shortage of air?

Chairman: Before calling upon Mr. Jones to reply I should like to ask him a question in connection with the application of this instrument to forced draught. Every marine engineer knows of the damage that is often caused through insufficiency of the supply of air in the combustion chamber followed by flaming in the uptakes, and I should like to know if this machine can give an indication at once to the engineer when these serious detrimental conditions exist, so that he can take steps at once to rectify them?

Mr. Jones: In reference to Mr. Clark's remarks, he is quite right with regard to the importance of the filter. We realised this to such an extent that we delayed putting the instrument on the market for six months until we had a satisfactory filter, so that his statement that the filter is of quite as much importance as the machine itself is quite in accordance with our own views. With the type finally adopted and since introduced there is no difficulty whatever; nothing solid can pass through the filter, and nothing can get into the pipes. We left nothing to theory. One of the experiments was of this nature: we put up a short length of piping, and ran the recorder for a considerable time. The pipe was weighed before starting and also weighed afterwards. A very slight increase in weight was recorded, which I think can be easily understood, as a certain amount of corrosion took place. That corrosion produced an accretion on the iron which accounted for the slight increase in weight. With regard to the question of testing the machine with oil fuel, we have not been able to test it practically. I should imagine that when burning oil fuel the highest practical CO_2 percentage would be two or three degrees lower than the standard for bituminous coal, because oil contains a larger proportion of hydrogen. A certain part of the oxygen in the air would combine with the hydrogen and disappear in the form of moisture, and so much less oxygen would be left to combine with the carbon and form CO_2. Therefore if it were used largely for oil fuel it would be necessary to have a new standard; instead of 15 per cent. it would possibly have to be something like 12 per cent., otherwise I do not think there would be much difference. In connection with the remarks on smoke prevention, I would like to point out again that the instrument is not a smoke preventer, nor an economiser. It is an indicator, and the question of prevention must remain in the hands of the operators. It does not make a saving directly, the saving is effected through the operator being guided. By looking at the indicator he will know when to take steps to prevent smoking, and if such a course is necessary. I tried to make it clear that smoke is produced by a shortage of air, and if there is a shortage of air the CO_2 gets too high. 15 per cent. is the economical figure. If a man tries to get it higher he will form smoke, and the indicator shows that the figure is too high. As to the amount of air necessary, I had intended, as far as possible, to avoid figures. If I were to give the exact figures it would not really mean much to the practical man, as he has not at hand the means of knowing the weight of the air. That is one of the advantages of the recorder. As long as the final result is right, the amount of air admitted is right. As to the question of 20 per cent. being a slight excess, it is a slight excess compared with the excess which usually occurs. Certain installations may be very great sinners with regard to smoke, but the waste is not usually on that side. Many manufacturers point to a chimney and say that they never get any smoke from it, and consequently there is no waste. They are surprised when I say that a clear chimney *may* mean high efficiency but that it does not generally, because it generally means that there is a very large excess of air. May I put it in this way. Supposing a case of a works in which there is a Cornish boiler—of course it would not be a large works in such a case. If the chimney smokes it is a true indication that the fire is suffering from want of air; but that is the only case where the chimney is a true indication. Supposing there are two Cornish boilers and the chimney is smoking. It only shows that one is smoking, while the other may be suffering from a large excess of air. If there are, say, two Lancashire boilers, the chimney indicates nothing excepting that one fire or more are smoking. If the chimney is clear, it may be clear right away from the smoke line with a large excess of air, and under such circumstances it is far from being economical.

Mr. W. McLaren: A case was brought before my notice some time ago where there are two Cornish boilers. Some painters were working at the chimney head, and they took it upon themselves to suspend a bucket of sand about two feet down the chimney. Only one boiler was working at the time, and, strange to say, it was a better steaming plant with that one boiler working than it had been previously with the two, due to the effect of this bucket stopping the excessive draught.

Mr. Jones: I do not think that is surprising, as the plant was saved from a large excess of air. People say to me: "We have a splendid draught," and I find that they have four or five times as much as they require. It is only necessary to have sufficient for the purpose. A boiler expert told me he went to a large works where there was a strong natural chimney draught, which, however, for some reason had been increased by means of a fan. On testing the gases he found that they never got above 3 per cent. of CO_2. It is very seldom one comes across so bad a record, and it was entirely caused by excess of air. He took the fan away and improved matters very much. With regard to dirty surfaces, that is a problem we do not pretend to tackle, although it is a serious one. Mr. McLaren spoke of the expenditure being a good one. In vessels making long voyages, the expenditure on coal forms a large proportion of the expenses. In the case of a vessel making three trips to Australia in the twelve months, burning 10,000 tons of coal per voyage, it would mean an expenditure of £30,000 on coal at £1 a ton. Such an expenditure should warrant the small expense of providing recorders to show that the fuel was being used to the best advantage. In reply to Mr. Rainey's question, an excess of air means a low percentage of CO_2. Whereas 15 per cent. is the economical standard, if twice as much air is admitted the percentage will be $7\frac{1}{2}$; if four times as much the percentage will be $3\frac{3}{4}$, and so on. A shortage of air will produce CO, but CO will take from the free oxygen which always remains and the free oxygen will therefore be less, but the CO_2 will be proportionately high.

Mr. RAINEY: I have noticed when testing with the Orsat machine that when there is a poor test, it will generally be found that there is a fair percentage of both CO and oxygen. If the CO percentage is low I have generally found on a boiler test you get just a trace of CO and oxygen.

Mr. JONES: With a high CO_2?

Mr. RAINEY: When you get a low CO_2 test you sometimes get a high percentage of oxygen and sometimes a high percentage of CO.

Mr. JONES: That would probably be due to the mixing not being thorough.

Mr. RAINEY: They were forced draught fires. It was not coal we were burning, but breeze. I do not know if that affected it, but when there was a high percentage of CO it always brought down the CO_2. The only explanation I could give is that the excess of air admitted prevents the complete combustion.

Mr. JONES: The want of sufficient temperature would be an explanation in that case. With regard to the point mentioned by Mr. Beckett, I may say that the difference in percentage of CO_2 obtainable with different kinds of coal should not be enormously great, and although Welsh coal might be burnt on the outward voyage and Indian coal on the homeward, the record would always show when the engineer is arranging his air supply to the best advantage. If he can get a fairly high record he cannot do much more. If an extra large supply of the Indian coal must then be used the fault must lie in the coal.

Mr. JAS. ADAMSON (Hon. Secretary): In our fuel tests good Welsh coal has usually worked out at 14.5, and samples of Indian coal at 10 to 12. That is approximately the proportion. On the other hand Indian coal sometimes gives as good results as average Welsh, it varies greatly in quality.

Mr. JONES: That would not give so great a difference as Mr. Beckett mentioned. In connection with the remarks of Mr. Shanks on the subject of flaming, I take it that if the combustion is fairly complete with a sufficient supply of air there will not be that tendency to flame. With a better air supply in the furnace the more complete should be the combustion. If any air leaks in at the smokebox doors the temperature may still be high enough to cause combustion in the uptake. It must occur through incomplete combustion in the furnace. Possibly there might be a tendency to smoke when the fires are pushed higher than they should be.

The meeting closed with a vote of thanks to Mr. Jones, on the proposal of Mr. Clark, seconded by Mr. E. W. Ross.

Description of the "Auto" Co_2 Recorder.

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THE extent to which a careful regulation of the air supply to a boiler furnace affects the economy of fuel is, unfortunately, not always sufficiently appreciated. It is, however, a matter well worth consideration. In all probability there are few stokers who really, under ordinary conditions of firing, trouble them-

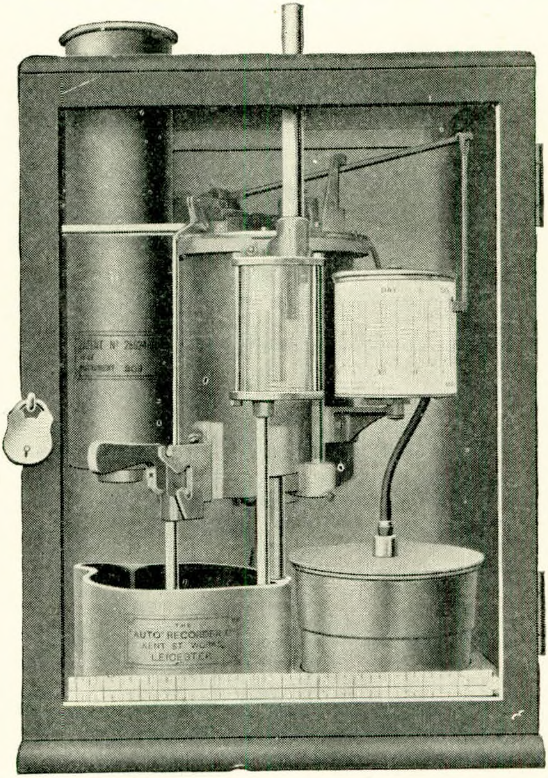


FIG. 1.

selves much about it. They know that, as a rule, they must try and prevent the formation of smoke as much as possible, and having done this they are content. They are, perhaps, fully aware that a shortage of air will cause a smoky chimney and loss of fuel, and, therefore, they give a plentiful supply of air;

not knowing, and in some cases not caring, what effect too much air may have, for any excess of this kind also has a bad effect on the fuel economy, and probably much more waste is occasioned by this excess than by a shortage. The latter is soon apparent from the volumes of black smoke that may issue from the chimney, whereas it is practically impossible to tell from ordinary observation whether too much air is being admitted. It is not at all improbable that a 10 per cent. loss of coal from this cause is quite common, while in certain cases the loss may reach as high an amount as 20 or even 30 per cent., the loss, of course, being due to the fact that a large amount of unnecessary air is heated, and is discharged up the chimney at a high temperature. The only certain and practical way in which it can be ascertained whether the proper amount of air is being admitted to the furnace is by analysing samples of the flue gases in order to find out what percentage of CO_2 they contain, for this percentage represents clearly whether more or less air is entering the furnace than is required. In ordinary boilers, if the flue gases contain 15 per cent. of CO_2 the highest result from the combustion of the coal may be expected, whereas if the gases contain only 10 per cent. it has been found that the loss of coal amounts to about 1 cwt. per ton, and with 7 per cent. to about 2 cwt. per ton. It is therefore desirable that some simple means should be adopted whereby the percentage of CO_2 in the flue gases can at any time be estimated.

An instrument for effecting this, and known as the "Auto" CO_2 recorder, has been designed and constructed by the "Auto" Recorder Company, of Kent Street Works, Leicester, and is now in successful operation in connection with a large number of boiler installations in this country and on the Continent. It is illustrated in perspective in Fig 1. on page 326, which view gives a general idea of its arrangement, and also of its size, as a reference to the 2ft. rule at the bottom of the figure will enable the proportion of the various parts to be obtained. Two sectional views of the apparatus are given in Figs. 2 and 3, but these views are not strictly correct so far as the arrangement of the various parts is concerned; and are given in diagrammatic form, because in this way it is easier to describe the various parts and to make clear the action of the instrument. Figs. 2 and 3 show the action of the apparatus at two different periods of one cycle. This action is as follows:—

A small stream of water is allowed to run into the tank A through the small funnel B, which only allows sufficient water to pass to work the instrument at a suitable speed. The water runs from the tank A through the valve C into the chamber D, our references at present being to Fig. 2. When the chamber D is filled up to the pipe E, the water overflows down the pipe F and under the float G, which it raises, thereby moving the valve C upwards and shutting off the water supply from the

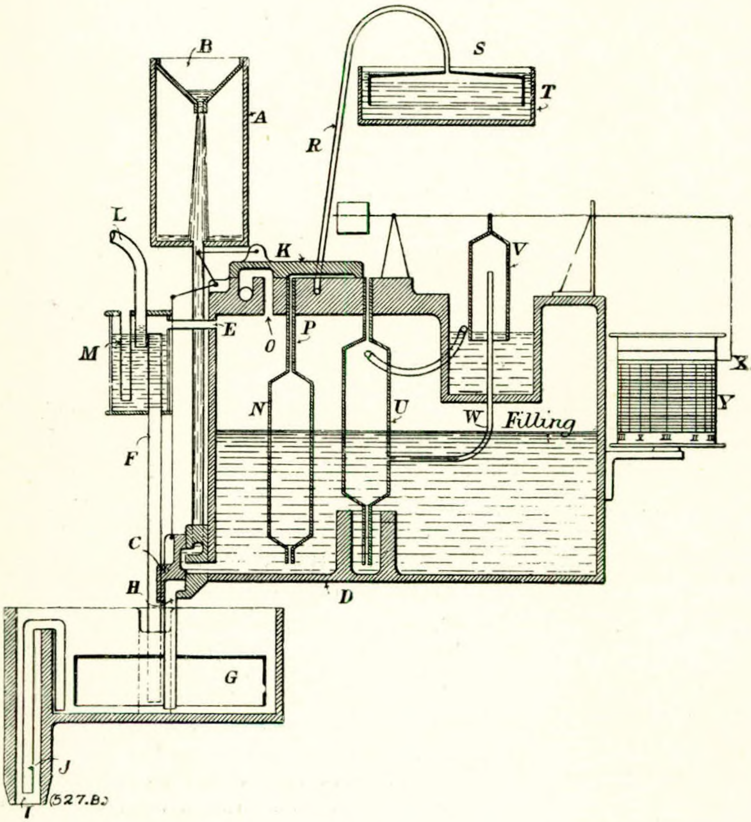


FIG. 2.

tank A into the chamber D. This motion of the valve C opens a communication from the chamber D through the pipe H, the water rising over the float G until it flows down the pipe I and the chamber D is empty. The pipe J then acts as a syphon and drains the water from under the float G, which is then allowed to fall again, and the chamber D to be once more filled. By this means the chamber D is alternately filled and emptied, and, as the float is connected by a system of levers to the distributing valve K, the water flowing through is the prime mover of the instrument.

The operation of gas analysis is very simple. The pipe L is connected to the supply of gas to be analysed and, as the end

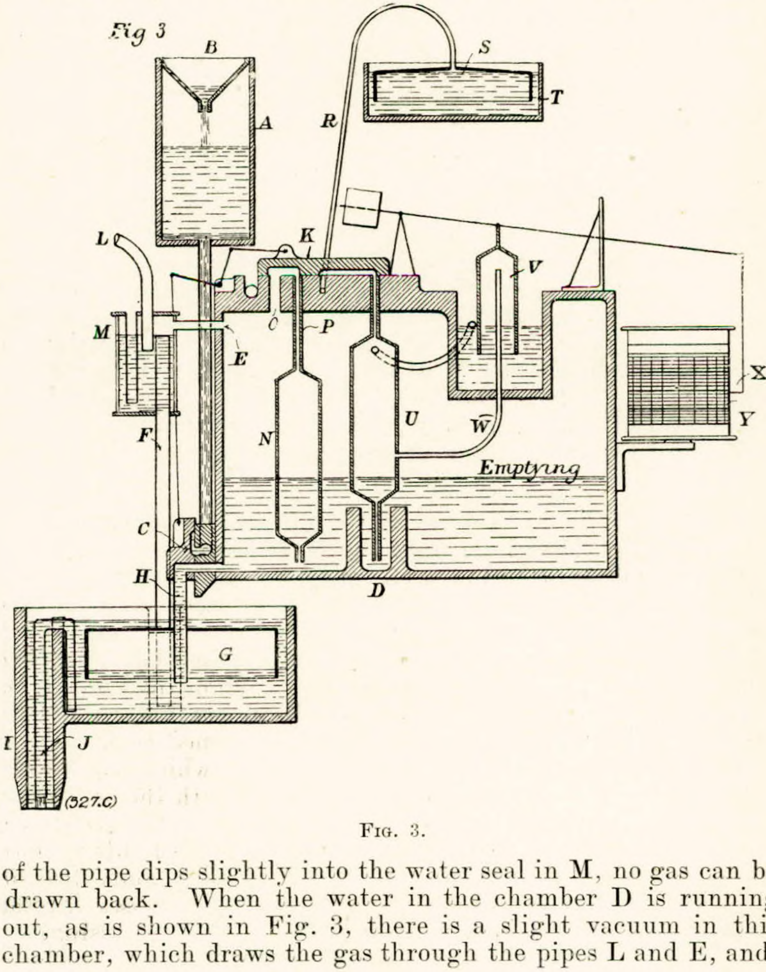


FIG. 3.

of the pipe dips slightly into the water seal in M, no gas can be drawn back. When the water in the chamber D is running out, as is shown in Fig. 3, there is a slight vacuum in this chamber, which draws the gas through the pipes L and E, and, as the first measuring vessel N is in communication with the chamber D through the passages O and P and the valve K (see Fig. 3), it is entirely filled with flue gas. Much more gas is drawn in than is analysed, in order that the sample may be as fresh as possible. When the water reverses and begins to run into D, as shown in Fig. 2, the valve K having moved, the gas enclosed in the vessel N is sent through the pipes P and R, under the dome S, in the caustic-potash vessel T. This dome is of large area, and the gas is in a thin layer between the wet dome and the top of the solution, so that the absorption of the CO_2 is rapid. After the water has risen and expelled all the gas from the vessel N into the absorber, and has again begun to run out, the valve K having once more moved into the position shown in Fig. 3, the water, as it descends in the second measuring vessel U, draws in from the absorber S the gas which has not been absorbed. As the measurer U is of the same capacity as the measurer N, it follows that, if there is not sufficient gas received from the absorber S to fill it, it will, after emptying the absorber, draw the remainder from under the bell V through the pipe W, and cause the bell to descend; the greater the amount of CO_2 absorbed, the lower the bell V will be pulled down. As the bell is suspended from a balanced lever, which has a pen X attached to it, the pen marks the chart Y, which is placed round a clockwork drum, the lines made by the pen being of varying lengths, according to the amount of CO_2 which was in the quantity of gas in the first measurer N.

It has been found that one of the greatest troubles with recorders of this kind is to keep the pipes from the flue to the instrument clean. In the recorder we are now noticing, however, particular attention appears to have been paid to this point, and the filter shown in Fig. 4 is the result. It is placed horizontally as near to the flue as possible, so that when the top of the filter is removed the short pipe from the flue can be cleaned with an iron rod. The gases from the flue are drawn up the vertical pipe, and meet the cool inclined cover, which condenses the larger portion of the moisture, which can trickle back into the flue. The gases after contact with the top of the casing pass to the underside of the perforated dish *a*, as shown by the arrows, and then up through some rough filter cloth which takes out the coarse dust. As this cloth only lies on the dish, as soon as one part becomes dirty the gases lift the cloth slightly and expose a fresh surface. After passing the cloth the gases travel down through ordinary chemical filter-paper, which thoroughly cleans them before they pass into the pipe to the recorder. The operation of cleaning this filter is said to occupy only about five minutes, and it is necessary to perform the operation every two days, although these filters

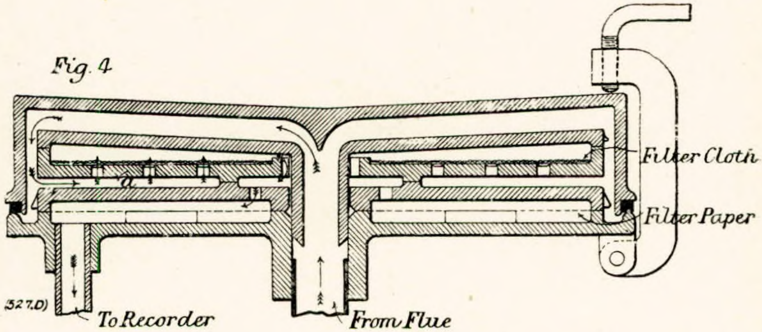


FIG. 4.

have been known to run for a week without attention, when used with gases from the end of a furnace tube in a boiler using coal so fine that over 60 per cent. would pass through a $\frac{1}{4}$in. screen. The joint between the upper and lower portions of the casing is made with a rubber ring.

Two diagrams taken in actual work are shown in Figs. 5 and 6, page 332, from which it will be seen what a great difference careful firing can make in the amount of CO_2 found in the flue gases from the same furnace on two consecutive days. On the second day, when the CO_2 was about 15 per cent., 10 per cent. more water was evaporated for the same weight of coal than when the CO_2 recorded was only about 8 per cent. The coal was accurately weighed, and the water passed through a positive test-meter.

A feature of this recorder, to which the makers attach particular importance, is the fewness and the simplicity of its parts. The "Auto" recorder, when once started, fills itself, keeps itself at correct level, and automatically adjusts itself, so that no further attention is required on this head.

As an instance of the amount of attendance required by these recorders, we understand that one of them was locked up and run under test conditions for a fortnight, and it was found that the average time from unlocking to locking it again was less than four minutes per day, and the record on the last day was as accurate as at the start, without any attention whatever. The instrument required about twenty minutes' work to change

Fig. 5.

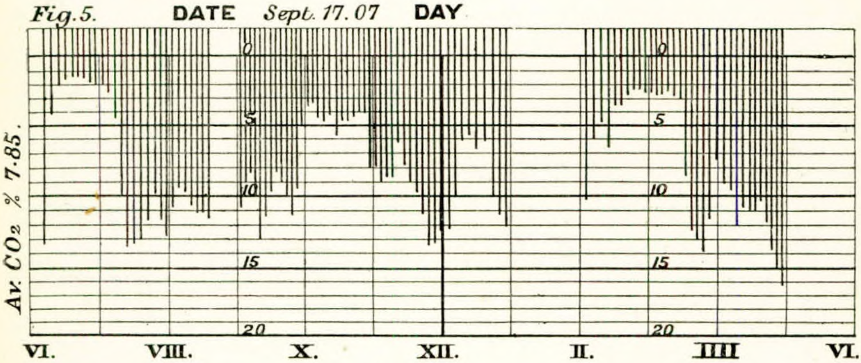
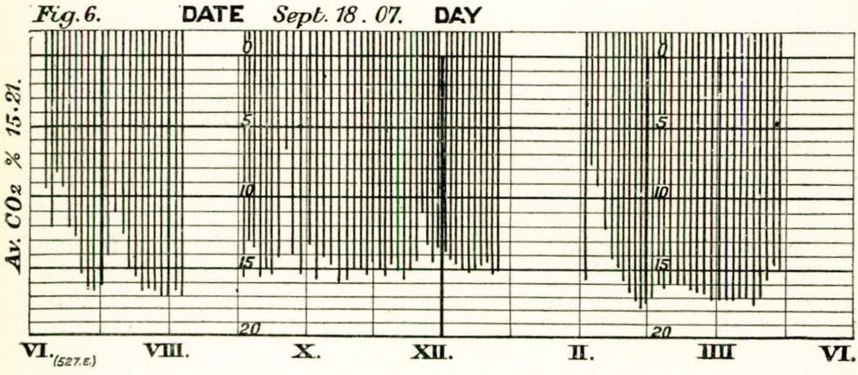


Fig. 6.



FIGS. 5 AND 6.

the caustic soda and clean down for a similar run, and the cost for water and caustic soda is less than 1d. per day. The makers tell us that they manufacture another machine of this type to work with chimney draught.

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Essay Competition Awards.

The following awards have been made in connection with the various essay competitions, held during the session, on the recommendation of the Awards Committee, confirmed by the Council:—

Associate Members.—In the competition for Associate Members, Mr. Walter Smith was awarded the prize to the value of £2 (two pounds) for his essay on "The Economic Use of Coal on Board the Modern Steamship."

Graduates.—In the competition open to Graduates of the Institute, Mr. Jas. Marsden was awarded the prize of £2 (two pounds) for his paper on "The Safety Devices required in a Modern Marine Boiler and Machinery Installation."

Open Competition.—In the open competition for the best essay on the subject, "The Welding of Iron and Steel, Past and Present Methods," the following awards were given:—

Prize of £2 to Mr. Thomas E. Dodds (Graduate).

Prize of £2 to Mr. Robt. J. Walker (Graduate).

Prize of £1 to Mr. G. A. Murray Brown (Graduate).

Prize of £1 to Mr. Wm. Auchinloss.

The Essays for which awards of £2 were given, are now published in the following pages for the special benefit of the Junior Section of the membership.

Messrs. The Darlington Forge Co., Ltd., very kindly gave a donation of £3 towards the prize fund in connection with the above.—J.A.