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President—A. J. DURSTON, Esq., R.N., C.B.

Volume VII.

FIFTY-SEVENTH PAPER

(OF TRANSACTIONS)

THE COMBUSTION OF FUEL

BY

Mr. G. F. W. BAPTY

(MEMBER).

READ AT

THE INSTITUTE PREMISES, 58, ROMFORD ROAD, STRATFORD

ON MONDAY, MAY 13TH, 1895.

DISCUSSION—MONDAY, MAY 27TH, 1895.

PREFACE.

58, ROMFORD ROAD,

STRATFORD, E.,

May 27th, 1895.

A meeting of the Institute of Marine Engineers was held here this evening, when a Paper by Mr. G. F. W. BAPTY (Member), read at the meeting on Monday, May 13th, was discussed.

The meeting was presided over by Mr. F. W. SHOREY (Member of Council), as was also the meeting held when the Paper was read on Monday, 13th May.

The Paper and Discussion follow.

JAS. ADAMSON,

Hon. Secretary.

INSTITUTE OF MARINE ENGINEERS

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President:—A. J. DURSTON, ESQ., R.N., C.B.,

"COMBUSTION OF FUEL."

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INSTITUTE PREMISES, 58, ROMFORD ROAD, STRATFORD

On MONDAY, MAY 13th, 1895.

CHAIRMAN:

MR. F. W. SHOREY.

As the competition in the marine trade is yearly becoming keener, and the general cry is for the reduction of costs to enable companies to pay some dividend to the shareholders who have ventured their money in shipbuilding and its relative industries, I presume it is the duty of engineers to convey, with the means given them, cargoes from port to port with the least possible expenditure; and as the fuel question is the most important, I have chosen its combustion as the subject of this paper, hoping to gain some information, not only for myself, but for junior engineers who will have to keep pace with the times, and a discussion on the matter might give us a more practical knowledge and a clearer insight into what at present appears to be partly theory and partly practice.

With the modern triple and quadruple expansion engines, when the steam is delivered through the throttle valve, it is dealt with by them in such a manner that little more could be said as to their improvement.

I think it is generally agreed that the boiler is the largest field of scope for study of economy, and our aim is to get, as near as possible, the full calorific power of the fuel without loss. To attain this in perfection it would be necessary to convert all the carbon of the fuel into carbonic acid ($C\ O_2$), and the hydrogen into water ($H_2\ O$), and then to conduct all the heat generated by this chemical action through the metal of the boiler to the water inside to convert it into steam. This may easily be seen to be a matter of utter impossibility, but the nearer we approach it the nearer we are to perfection.

From the following it may be seen that there is a great difference between the theoretical power of heat and the power obtained by our modern machinery and boilers from the coal used.

One pound of carbon converted into carbonic acid ($C\ O_2$) gives off about 14,545 heat units Fahrenheit, or an equivalent of 11,228,740 foot pounds, or 5·67 horse power for one hour. Taking coal to be about 85 % the value of carbon, the heat from one pound of coal would give 4.82 horse power for one hour, which greatly differs from the two-thirds of a horse power, which is about what we obtain by the combustion of one pound of coal, in the most modern arrangements.

It is estimated that in the average boiler only 47 % of the theoretical heating power of the fuel is utilized.

The chief sources of loss are :—

1st. The imperfect combustion of the fuel, as carbonic oxide and soot passing unburnt through the funnel passage.

2nd. The faulty and incomplete lagging of the boiler and steam pipes or unintercepted radiation.

3rd. The latent heat taken up by the moisture in the fuel to convert it into vapour.

4th. The heat lost in the ashes drawn from the furnaces, which is considerable in the case of some inferior coals leaving sometimes about 30 °/ₒ ash.

5th. The loss of the heat of the waste gases which pass up the funnel, and whose only use is to create a draught. With this may be taken the heat imparted to the nitrogen, and other constituents of the air, which are not used in the combustion of the fuel.

The 2nd may be reduced to a minimum by lagging the boilers all round, not two-thirds covered as they generally are; also by lagging the backs, parts of fronts, steam pipes, and valves with a good non-conducting substance.

The 3rd may only be obviated by keeping the coals dry.

The 4th seems unavoidable.

The 5th. This heat might be utilized to raise the temperature of the feed water, especially in cases where forced draught is used, by having a circular tank lining the funnel, or a coil of pipe through which the feed water might pass on its way to the boiler, this would have the drawback of getting heated when raising steam; but some arrangement might be made for circulating the boiler water through it, as with the circulating check. Or another plan, which I think preferable, would be to have a heated forced draught, the air to be supplied to the furnaces to be forced or drawn through a coil inside the funnel, thereby saving a quantity of heat, which would otherwise be lost.

In blast furnaces the heat of the waste gases is used in raising the temperature of the blast, &c., in this case waste gases are of a much more intense heat than that of a steamship's funnel; but even the heat and volume of gases passing into the air, at a temperature of 600 to 700 degrees above it, is a value which ought not to despised.

The first source of loss, I think, is of the greatest importance, and that which deserves the most consideration.

It requires the oxygen of twelve pounds of air to consume one pound of coal; but the gaseous products of combustion must be diluted to a great extent to allow the air to get at the fuel, and for this reason, about a double supply of air is necessary, and as 13 cubic feet of air at 60° Fahrenheit weighs 1 lb., it would require 700,000 cubic feet of air to effect the combustion of one ton of coal. Should the air supply be deficient or injudiciously applied, some of the carbon would be only partly consumed and pass off in the form of carbonic oxide gas, in which case a large quantity of fuel is lost. For instance, one pound of carbon converted into carbonic acid ($C\ O_2$) gives off 14,545 heat units Fahrenheit, and one pound of carbon converted into carbonic oxide ($C\ O$) gives off only 4,450 heat units Fahrenheit, and the loss would consequently be 69·4 °/o

The question now arises, how is the engineer on watch to know whether he is making the best use of his coal or not? He imagines that if the ashes which are thrown overboard are free from unburnt coal, or cinder, he has obtained the full duty out of the coal consumed, and, with the means we have at present of determining the result of combustion, I do not think that he is much to blame.

From the above, it appears that we want better means of ascertaining :—

1st. Whether the gases are thoroughly consumed or not before being delivered to the funnel.

2nd. Some way of measuring the quantity of air passing into the furnace, below the bars, above the bars, and into the combustion chamber.

3rd. Some means or instrument for testing or roughly analysing the waste gases in the funnel.

The fact that there is waste is evident from the dense volumes of smoke seen issuing from the funnels of steamers, especially when using Bengal coal, and I must say that the finest liners visiting Calcutta are not exempt from this source of extravagance. This black smoke is simply fuel, and although it is so easily detected, it is not prevented. Now in the case of half-burnt carbon (carbonic oxide) we are unable to detect it, and may be losing a large percentage of our fuel without knowing it.

I have also seen the funnel of a steamer red hot when using a very friable quick-burning Japanese coal. I think, in the latter case, if the air which was passing up through the fire bars and decomposing the fuel could have been reduced, and a quantity of air supplied to the combustion chamber, or over the bars, the excessive heat might have been prevented, and a large saving of coal effected, without reducing the amount of steam generated in the boiler.

With deep or heavy fires, when nearly all the air supplied to the furnace passes up through the bars, the oxygen of the air combines with the carbon of the fuel and forms carbonic acid ($C\,O_2$), and this gas, passing through the upper part of the red-hot fire, takes up or combines with another part of carbon, and forms carbonic oxide (2 C O), and if this gas is not supplied with a sufficient quantity of oxygen, either in the upper part of the furnace, or in the combustion chamber, the result is a serious loss, as before shown, by the difference of heat given off in the formation of carbonic oxide and carbonic acid.

When in charge of some mill boilers of similar construction to the marine type, I arranged a system of ventilation, by which I could regulate the air supply in three directions—under and over the bars and to the combustion chamber. I found that a little careful adjustment was rewarded with a considerable reduction of the coal account.

In the vessel in which I am at present I have made the air problem a particular study, and, although I have managed to prevent the waste of fuel in the form of smoke, and have also reduced the consumption considerably, the result is hardly satisfactory, not being able to say whether I am wasting gases which might have imparted so much more heat towards the generation of steam, had they been thoroughly oxidized, or admitting too much air, and so losing the heat absorbed by the excess in being raised from the temperature of the atmosphere to that of the waste gases of the funnel.

As far as I can see, this matter will remain a mystery, until some one can devise a plan, or arrangement, by which a practical engineer may be able to account for his coal consumed, and prove that he is getting the best possible result for his expenditure. Again, engineers are often supplied with coal, which they are told is "equal to Welsh," or "good North Country," having only the supplier's word for it, and its appearance, which is often deceptive. Should the result of its use come short of the owner's expectations, engineers are blamed for not knowing how to burn it, or wasting it in the ashes, which have perhaps seemed rather in excess of what they ought to have been.

To analyse a sample of coal is a very easy operation, which can be done by any practical man, and is well worth the trouble, not only to satisfy his own mind, but to vindicate his ability, when accused of not using his coal to the best advantage.

I was supplied with bunker coals by the owners, and, as a guarantee of their quality, a certificate of analysis was sent with them, which seemed to estimate their value to be greater than I had done by inspection. After using them for some days with such unsatisfactory results as a heavy increase of consumption, and a residue of about 30 % of ash, I took two samples, representing the average quality, No 1 being the best and No. 2 the worst, and analysed them by destructive distillation, by which I found that even the best sample did not approach the standard of the certificate received from the colliery owners.

The comparison may be seen from the following figures :—

ANALYSIS SENT BY THE COAL COMPANY.

Number of Specimen	1	2	3	
Volatile Matter .. (including moisture)	31·9	37·48	38·16	38·82
Fixed Carbon ..	55·6	52·32	51·72	49·44
Ash	12·5	10·2	10·12	11·76
	100·	100·	100·	100·

ANALYSED ON BOARD.

Number of Specimen	1	2
Volatile Matter (including moisture)	38·58	28·57
Fixed Carbon	44·92	30·63
Ash	16 5	40·8
	100·	100·

The above would suggest that their samples had either been very carefully selected, or borrowed. In the latter analysis the average quantity of ash is 28·65 %, and the actual quantity thrown overboard was as nearly as possible 30 % of the coal consumption.

In the case of liquid fuel, the results have been always not only more satisfactory but more definite. Mr. Aydon, M.I.C.E., gives us an account of a trial of petroleum in an ordinary Cornish boiler. The oil was decomposed by a jet of superheated steam and "consumed in a perfect manner," causing the evaporation of 19·5 pounds of water per pound of oil; whereas, with the use of coal in the same boiler, only 6·5 pounds of water were evaporated per pound of coal. The question is: Was the coal consumed in a perfect manner?

The use of the power obtained by the combustion of petroleum direct, and without the intermediate agency of water and steam, has also been very satisfactory, as the respective quantities of oil and air can be accurately regulated and mixed before ignition.

In conclusion, I must apologise for the numerous digressions made, as the pith of the subject might have been expressed in fewer words, and summed up in the following:—

That we require a more definite knowledge of the actions taking place in the furnaces of boilers, and a means of allowing the fuel to mix with sufficient—but not too much—air; also to be able to determine when this result is attained.

DISCUSSION

AT

58, ROMFORD ROAD, STRATFORD,

MONDAY, MAY 13th, 1895.

CHAIRMAN:

MR. F. W. SHOREY *(Member of Council).*

Mr. R. DUNCAN (Member): Mr. Bapty differs in his paper from a paper which was read at Liverpool a short time since as to the mode of admitting air, and as to reducing the coal consumption by reducing smoke. In the paper read at Liverpool it was said that too much air cooled the gases, and, therefore, less heat passed to the boilers. I, however, rather agree with Mr. Bapty, provided the boilers are properly constructed, which very often they are not. The great cause of smoke is want of space, whereby the air cannot be mixed with the gases from the coal so as to cause combustion. If there is no air going in, the fire cannot possibly consume all the gases, and if there is not sufficient room for the air and gas to mix they must go through the tubes separately, and the gas will not do its work. In forced draught boilers there is a greater amount of air going through the boilers for their size, more than into the ordinary furnaces, and with the amount of coal consumed they are shown to be more economical than the ordinary furnaces. Where forced draught is used the combustion chamber should be very large to give ample space for the air and the gases of combustion to mix properly, that is to say, the fire bars should be made shorter than the furnace as compared with natural draught, to allow more space behind the bars for the combustion to become more perfect.

Mr. C. L. E. MELSOM (Member of Council): I have read an extract with reference to an instrument for measuring the supply of air, from a paper which has recently been given by Professor Unwin. In the course of his paper the author referred to the want of such an instrument. In the paper - which he read recently before the Institution of Civil Engineers, on "The Development of the Experimental Study of Heat Engines"—Professor Unwin, after referring to the want of an instrument for this purpose, which could be as easily read as a pressure gauge, gave a description of an apparatus called the dasymeter. It appears that this instrument, which was invented by Messrs. Siegert and Durr, of Munich, is a fine balance in an enclosed case, through which a current of the furnace gases is drawn. At one end of the balance is a glass globe of large displacement, at the other a brass weight. Any change of density of the medium in the chamber disturbs the balance, and will alter it immediately. A finger on the balance moving over a graduated scale gives the amount of the alteration of density. An air injector draws the furnace gas from the flues, and it is filtered before entering the balance case. An ingenious mercurial compensator counterbalances any effect due to change of temperature or barometric pressure. Here, then, is an instrument which measures the air supply, and this, I think, is what is really required.

Mr. GREER (Member): It was stated in the paper that in the average boiler 47 per cent. of the theoretical heating power of the fuel is utilized. When I was a boy I was told that only one-ninth of the whole heat was utilized; now the essayist has put it at 47 per cent. This is a very good result, considering what it was twenty years ago. Dealing with another point, Mr. Bapty said:—"The fact that there is waste is evident from the dense volumes of smoke seen issuing from the funnels of steamers, especially when using Bengal coal." Undoubtedly that is the case, and I think it would be necessary to have different constructions for the different kinds of coal.

Mr. MELSOM: I think that a great deal of the waste of fuel is due to the insane idea of saving a little weight. In seven cases out of every ten the engine power is greater than the boiler power, and when we are told to force the boilers to get up higher speed there is waste. If it were the other way—more boiler power than engine power—we should be able to practise economy. Danish engineers have gone into the idea of retarding the funnel draught, and I think the English should endeavour to alter their system of draught; that is to say, they should be able to retard the draught from the fires that have burnt clear, leaving the draught to those which have just been coaled. To do this we must group the furnaces, and have several funnels within the funnel, so to speak. With one funnel common to all the fires, it is impossible that we could so work it as to have all the fires clear. By means of Howden's system of forced draught we can regulate the flow of air into the different furnaces—the brighter the fire the less air.

Mr. GREER: It is generally accepted that from 18 to 20 lbs. of water are evaporated per horse-power per hour; but I find that it is 24 lbs. in a recent case which I tried, by careful observation. I made the calculation by taking the capacity of the pump, and assumed that it worked to its full capacity at each stroke.

Mr. DUNCAN: One of the speakers has spoken of the danger of economising weight in boilers, but we all know that with forced draught we get equally good results, and take 1,000 horse-power out of a boiler, whereas, with ordinary draught, we only get 500. By this means it is quite possible to economise weight, and I do not see why big boilers should be put in when smaller boilers will do. The only thing is that we do not get sufficient space for the combustion chambers. I am of opinion that the fire bars should be shorter, so as to leave more room for combustion. It is at the back of the furnace where space is required, and in my experience with three boats with the fire grates of 2 feet 6 inches, 3 feet, and 3 feet 4 inches respectively, the 3 feet 4 inch fires burnt the most coal, but they gave a far higher indicated horse-power per pound of coal. This was with ordinary draught, and with shorter bars and greater space at the back for the consumption of the gases. I question the accuracy of Mr. Greer's estimate as to the evaporation of 24 lb. of water per horse-power per hour, as it appears to me out of proportion to the general run.

Mr. GREER: That was the quantity of water supplied to the boilers by the pump. I do not say that it was all evaporated.

Mr. CRAWFORD (Member): I have always found it a good plan, when burning Japanese coal, to have small holes round the furnaces to admit air into the top, and when this is done I have never seen a hot funnel.

Mr. ATKINS (Associate Member): I would suggest that, in regard to the 47 per cent. of the theoretical heating power being utilized, that means the boilers alone; whereas Professor Unwin's calculation refers to boilers and engines as well. A boiler may give off 47 per cent. of the heat of the fuel, but it is lost in the condenser, owing to the enormous waste.

Mr. GREER: I have been engaged for nine months in calculating the waste of ashes and other matters in a new steamer, and have found that about 21 per cent. is wasted in the ashes, and the consumption of Welsh coal is 1·4 lb. per horse-power per hour.

Mr. MURPHY (Member): The steadier the steam in the boiler the better the work produced. We cannot arrive at a clear understanding, however, if we go on different conditions. We must stick to one. Almost all engine makers have their own ideas; but assuming there is a perfect boiler, then the great principle to be considered is the amount of air to be admitted to do its work for a certain quantity of coal. Even then it has to be considered what are the different evaporative qualities of coal. We have at present no instruments for measuring the actual proportionate parts of air under different conditions. It will be necessary to lay down regular tables of the different conditions and circumstances, in order to arrive at what is necessary for the combustion of fuel. There is a lot of guesswork about marine engineering, as well as other things, and this guesswork may be indulged in a little too far.

The CHAIRMAN: There should be some improvement, with the number of engineers in the country, and no doubt improvements are being made month by month, and year by year, and to this end these discussions are useful.

Mr. J. H. THOMSON (Chairman of Council): If we could get some information of a definite character we may be all right, but we cannot say that engineers shall test these things and alter furnaces to suit circumstances while on a voyage. The question the paper asks is whether some means cannot be adopted for testing the quantity of air, and that is what we must try to find out, with a means of regulating it as well. In regard to these points, I suggest that the discussion shall be adjourned, and that the members shall examine the coal-testing apparatus which we can have in operation any evening here as may be arranged. I will gladly show them the experiments.

The suggestion was agreed to, and the meeting adjourned, after the usual votes of thanks were accorded.

ADJOURNED DISCUSSION

AT

58, ROMFORD ROAD, STRATFORD,

MONDAY, MAY 27th, 1895.

CHAIRMAN:

MR. F. W. SHOREY *(Member of Council).*

The CHAIRMAN: For the benefit of those who were not at the last meeting, I may say that the subject for discussion is "The Combustion of Fuel." The paper has already been read, and as you have had time to think the matter over, I hope we shall be furnished with some new ideas to-night. It has been suggested, and I think it will be an advantage to carry out the suggestion, that the paper on the subject, by Mr. Bapty, be read again. Perhaps Mr. Ruthven will read it, as it is the wish of the meeting.

Mr. J. R. RUTHVEN (Convener, Papers Committee): Certainly, I will now read it again; it will be an advantage to the discussion.

The CHAIRMAN: While you are collecting your thoughts, I may say a word or two. I notice that all the experiments we have had up to the present have been with the usual marine type of boiler. Do you think that we are in the right direction in keeping to that particular type? Now that we are going in for higher pressures, I think the time has arrived when we should have a new type of boiler altogether. I see that some are going in for the water-tube boiler with very good results. There is a boiler now being made at Messrs. John Fraser and Son's works, at Millwall, and if any of you would like to see it, I think I could obtain permission for you to see and examine it under steam. So far as it has gone, I believe it is the best boiler extant as regards the perfect combustion, or the almost perfect combustion, of fuel. With our present high pressures we are getting such heavy strains on the different parts of our boilers, and we have never been using our coal to the best advantage. I think we must now look for a class of boiler other than the ordinary marine boiler. Perhaps some of you may have had some experience with a different kind of boiler that you may consider preferable to the present type.

Mr. ATKINS (Associate Member): I think I can speak on behalf of Messrs Fraser, in whose employ I am, and say that they will be very pleased to see any member of this Society at the works to inspect the boiler referred to, and I feel sure the inventor will be very glad to tell them all he can about it. The official figures are not known at present. I have heard what they are, but I am not at liberty to give them exactly. Very good results have been obtained. There was a six hours' full steam trial one day last week, and it went through that six hours' trial in a manner that was perfectly satisfactory. When the figures come to be known, it will be found that this boiler has done as well, if not better than any water-tube boiler that has been brought out.

Mr. J. H. THOMSON (Chairman of Council): The last paragraph of this paper sums up the whole thing. It says "We require a more definite knowledge of the actions taking place in the furnaces of boilers." I think engineers have been giving a considerable amount of attention to this subject from the earliest days, and we see from some of the old books that a number of them have gone in for experiments with different means of mixing the air with the fuel, and a considerable amount of ingenuity has been displayed in many instances. Smoke combustion has been a favourite subject for a long time, and it is a simple matter to reduce the smoke considerably, but not with economy, and that has been the trouble with smoke consuming apparatus. Mr. C. Wye Williams, who took a considerable interest in this subject, said that smoke after being made cannot be burnt, and that combustion must take place when the air mixes with the fuel gases. Then there is another point, and that is that although you may be using Welsh coal, which is smokeless, there may be just as much waste going on as when you were burning North Country coal, although it is not so visible. I have never seen any work giving instructions how to measure the quantity of air going into a furnace, but different ships have been provided with means for distributing the air under the furnace, over the furnace, inside the furnace, and at the back of the bridge in the combustion chamber. I have seen several experiments tried for supplying air at the back of the bridge in the combustion chamber, but they have always resulted in a loss, and they have never been very successful in preventing smoke. The difficulty is in getting the proper quantity of air mixed with the coal. If you use big lumps of coal you do not get the air distributed sufficiently. To overcome that difficulty, some persons have tried coal dust, and the results have been marvellous. I think they are still carrying on that system in some parts of Germany now, and that is looked upon as the best way of getting the oxygen mixed with the carbon. Engineers sometimes use the anemometer for trying the force of the draught into the tubes, but I have never yet seen it applied to a furnace. I have no knowledge of it ever being tried for testing the quantity of air going under the furnace. With the author, I think the whole gist of this paper is in the last paragraph.

Mr. G. W. NEWALL (Member of Council): The subject of this paper is of primary importance to us. No doubt we have all at various times had to weigh out and test the evaporative value of our coal, and I consider one of the first duties of a marine engineer is the earnest study of the coal side of the machinery of which he has charge; and also his business should be to enter the stokehold with the determination of learning something of the methods of firing and the several weaknesses of his firemen in regard to making and maintaining the fires. We are all aware that some firemen have their particular and pet methods of keeping steam, and no two men will feed, clean, or maintain equal furnace heats, particularly where firemen are so often changed, a fact much to be deplored, entailing as it does fresh observations on the part of engineers, and I would say further the firemen should never be left entirely to their own resources.

As nearly every fresh coaling of a vessel brings a new element into play, viz., that of the quality of the combustible, the first requirement of an engineer is to ascertain, as far as possible, the nature and fighting strength of his coal, which varies for many causes, the principal being long exposure to wind, rain, and atmospheric influences, the action of the sun being particularly bad; also the constant breaking up of the coal during transit, and the quantity of foreign material finding its way into the bunkers with coal purchased abroad, where it sometimes passes through numerous hands and storing depôts.

Many engineers treat coal, no matter where its birthplace, as one and the same material all the world over. This is a fallacy and a very expensive one, for there are scarcely two pieces of coal taken from the same seam exactly similar in quality and texture, and between the range of a thin or light to a heavy or thick fire, and between a small amount to a very huge quantity of air required for perfect combustion, opens up a wide field of constant observation, and where this is studied, economy will result, as it is the duty of all men who have control of heavy masses of machinery, developing thousands of horse-power, to wrench from their *pound* of coal the utmost energy. For if we take care of the combustion of our *pounds* of coal the *tons* will look after themselves, or, in other words, express all the work possible from our *little* of fuel, and the *much* of fuel will be a source of economy, a saving to the owners and a credit to the engineer in charge.

In discussing a question like the one before us, in my opinion, we should endeavour to leave text books on the subject alone. I am quite aware that it is exceedingly difficult to drift into a new ray of light concerning old subjects, but it will pay us better to state our own individual experiences as far as possible. There is sufficient print that would fill our library alone, as information on combustion, mostly repetition, and almost every book on the construction or working of boilers informs us in as few words as possible "that the oxygen of the air combines with the carbon of the fuel and forms carbonic acid (CO_2) and this gas passing through the upper part of the red-hot fire, takes up (unless supplied with fresh oxygen) another portion of carbon and forms carbonic oxide, $CO_2+C=2$ (CO), and when working thus a great loss of heat is the result, and so much and no more information is of little or no use to the ordinary engineer. We should not rest satisfied with a cut-and-dried statement like this. While on the matter of text books in regard to the various chemical formulæ relating to the combustion of fuel, in my opinion, the style adopted is much to be deplored. How can we be interested to know that when coal is being consumed in a furnace it requires so much of this gas or so little of that, unless we are enabled to test it and understand it ourselves, and whose symbols are represented by a few letters of the English alphabet which a chemist employs for abbreviation? When in ordering so many hundred tons of coal, we do not order so many tons or cubic feet of the different gases chemists tell us we require before we can burn up our coal, and why should engineers interest themselves in just a few symbols of chemical formulæ for the combustion of fuel, while we too readily ignore the value of many other chemical natures, quite as important, appertaining to other portions of our business? Again, few engineers are in the position to test and analyse the nature and true value of the various gases generated by the chemical change we term combustion. And are engineers supplied on board ship with the necessary instruments or apparatus for testing the value of the most important agent with which they have to deal? No, we have to call in the doctor and take the chemist's word for it that such and such a change comes about, while further he mystifies us by tacking on figures we know nothing at all about. It is time we learnt to know how to burn coal ourselves, and I think it is also time we made chemistry relating to our profession a portion of our studies, and solicit owners to provide us with the proper means for making coal and combustion tests, and until such a step as this is taken we shall still be groping in so much darkness.

Every vessel of any account is supplied by the owners with a steam indicator, for the purpose of ascertaining if there is an economical use of the steam, and it is certainly as important to supply means that shall show us if we produce economical generation of the same fluid.

Considering the many thousands of pounds worth of coal which is shot through the furnace doors of the boilers of our large steamers year after year, while the engineers in charge know little or nothing further about the combustion of the fuel than sight informs them by peering through the furnace doors, one would think that, for the sake of a few pounds, owners would supply their ships with a coal-testing plant and the apparatus necessary for the analysis of the furnace gases. Another useful adjunct would be an oil-testing plant, to show approximately the chemical properties of the various lubricating materials used on board, as these also form no insignificant item in the year's running of a large steamer. The employment of oil for lubricating purposes is as much fuel material as coal itself. The combustion of oil takes place in the thousand-and-one parts of our machinery, counteracting the heat of friction, which heat decomposes the oil in every way similar to that of the decomposition of coal, also by the application of heat, and is only a question of degree, while its study is almost as important as that of coal, both materials being the most expensive agents required for steamship propulsion, and really should come under the question of the combustion of fuel and the scientific investigation of the engineer.

Chemistry should play a most important part in the knowledge and requirements of a modern marine engineer, and except to the engineer with this knowledge and an apparatus at his disposal, symbolic chemistry to the ordinary man is a region full of mystery.

The elements of combustion for the time being may be treated as consisting of one simple agent only—air. It is our duty to ascertain how many cubic feet of air will be required to burn up a given quantity of coal. The air is there whatever it may contain - good or bad qualities—we can do nothing with it except rarify or compress it, and one important feature for the better combustion of fuel with economy is that all boilers should have a means of adjusting the funnel area and funnel natural draught, and also should be well fitted in front with good furnace doors and ash pit adjustable dampers.

We know of no other substance that is wasted to such an extent or so readily eludes our grasp as heat — one that seems to defy all restraint and yet is so important to us in our profession. One of the most prolific wastes of heat with which we are conversant is that of the sun; and when we think out the very small amount of heat the earth and planets receive from him, compared with the quantity he continually sends into space, we recognise one of Nature's profoundest mysteries, and with all our modern improvements and boasted so called knowledge of mechanics, the heat we are enabled to use, compared with what we lose during its generation, is trivial, while the work done for the effort attempted is exceedingly small.

In my opinion we should consider coal as a mechanism—pure and simple—and as much a part of the complex machinery we have to deal with on board ship, as the various elements of crank shaft, rods, levers, pumps and valves, as that of the latter goes to make up our engines. It is not a source of motion of itself—it is the medium through which change and motion is made manifest—and we get no motion out of the coal itself—neither can we out of a connecting rod or pump itself—but from external sources where motion exists, therefore, the expenditure, or combustion of fuel, represents so much, or so little expenditure of mechanism. Coal is merely a lever, by means of which we are enabled to do work. In a lump of coal is a certain quantity of what we term matter consisting of atoms of carbon bound together by cohesion, and which, under given conditions, yields up a portion of something we term heat. We know that in the days of long ago the carbon of the coal was secreted by the action of the heat and light of the sun during that important—to us, at least—coal period, when this identical mechanism was laid by for the advent of steam. It then existed as carbonic acid gas in the atmosphere, and the rays of the sun split asunder the carbon and oxygen of the gas, the carbon being stored away in the substance of huge trees to, in time, yield us coal. Now reverse the operation, and compel the coal to yield back its heat as it does when we allow these atoms of carbon and oxygen to rush together, and we have, in other words, the identical force which, thousands of ages ago, separated these elements, and in this operation, nothing is gained—

nothing is lost. Now the question of the combustion of fuel brings us face to face with some hard facts, in the above we recognise the phenomenon of heat, and while pondering on the origin of this coal matter and the forces inherent in every single atom—each, and all of which, evade the grasp of the human mind, for we have no knowledge of the creation or destruction of the least fragment—we are only acquainted with change. Our pound of coal burns in the furnace and disappears, leaving a residue of ashes. The fire has not destroyed the matter of which the coal was formed, there is only a change of form. We should extract the utmost energy —and it is with this change we have to deal. Heat, like all other forces, is invisible—no one has ever seen it—we only recognise it by sensation, by means of instruments, and by its manifestations and forms, the first and highest physical force in nature, and, unlike all other substances we know of, it ignores gravitation.

The combustion of fuel may be divided into two distinct operations; one being by mass or bulk combustion, and the other by powdered or dust combustion. I consider that to burn coal under the former method to the best advantage it should be held loosely in as open a cage-like receptacle as possible; that is to say, fire bars should have the least amount of thickness, so that the air spaces are much larger in contact with the coal than the metal of the bars, and that coal should be lightly and gently brought within the influence of the already live coal. Under the latter method, in the powered or dust condition, I think we should obtain the greatest economy and most perfect combustion. The coals should be pulverised and blown into the furnace, which would then become only a huge flame box. The existing furnace would need modification and fire bars could be dispensed with.

Some years ago it was discovered that coal dust was very inflammable, and in some cases—where the dust was sufficiently fine and in suitable proportion to the air—highly explosive, while it burns with a speed equal to that of the admixture of coal gas with air. Many coalpit explosions were attributable to the released gases and firedamp, but recent experience has taught coal miners that fine powdered dust itself is equally dangerous.

The splitting up of the volume of heat from the fires to the funnel should be rendered as complete as possible. Boiler tubes should be small and in great number, and the tube plates should present more the appearance of a surface condenser. The larger the boiler tube the more waste of heated gases pass up the centre without ever licking the metal of the tubes. Many devices are now in vogue to counteract this loss, viz: by serve tubes, either with straight or twisted ribs; by baffles placed loosely within the tubes; by internal swellings, studs and rivets.

I should advocate the use of an anemometer, under each furnace, at least once a watch, as a little practice with this instrument would soon demonstrate whether sufficient air was being devoured by each fire. Also the fixing of a pyrometer in the funnel just above the junction of the uptakes, so that temperature tests can be readily made each watch.

Air should be kept as pure as possible right up to the moment it imparts its vitality to the fuel, while air impregnated with dust, and especially that coming from heated ashes, is a most effectual damper of combustion, and another one is a too frequent spraying of water on hot ashes, which release gaseous vapours that check combustion.

As a reference for making coal tests, I should recommend that Professor Thompson's Calorimeter be described with the necessary sketches attached and included with the paper for the use of our members when at sea, or otherwise; and also, I trust the Institute will, at an early date, obtain a "Gas Analysis Plant" and appliances, so that we may periodically have practical demonstrations and test for ourselves the value of the fumes of combustion, in conjunction with the coal testing apparatus and experiments held here from time to time. I can speak with some authority of the value of such an apparatus when I tell you that a large firm in Silvertown is to-day saving between three and four hundred pounds per annum in the cost of their coal bills, through the study of this vital question. The whole cost of such apparatus may be covered by £10. The process is not difficult, and a knowledge of chemistry by an engineer is to his advantage—even if it only goes to the extent of removing the bulk of the mystery we term combustion.

It is only within the last few years that large consumers of coal have taken the trouble to investigate this feature of combustion, and of all classes of commercial concerns I consider the marine engineering one needs the most reform in this direction.

The Gas Analysis Apparatus most suitable for use on board ship is that known as the *Orsat*, which is exceedingly simple in construction, and with a little practice could soon be effectually manipulated. Its general description is as follows: It consists of a wood frame with handle at top for portability, which has on one side a long measuring tube holding 100 c.c. graduated to 40 c.c. in fifths, which is connected by means of a capillary tube with branch taps with three absorbtion bulbs. A bottle filled with mercury has a tube connected with the bottom of the measuring tube, and by raising this bottle the mercury is then free to fill the measuring tube, and expelling the air. The funnel gases to be tested are then coupled to the branch capillary tube, and on lowering the bottle containing the mercury, the furnace gases are drawn into the measuring tube and measured by the height of the mercury therein. The tap is shut, cutting off the funnel gas, and on raising the mercury again and opening one of the absorption bulb taps, the gas is forced into the absorption bulb containing a solution of caustic potash or soda, and this solution absorbs the carbonic acid (CO_2) contained in the fumes. The mercury is then allowed to run back into the bottle. The remaining gas is now measured and passed into the second absorption bulb which contains an alkaline pyrogallate solution where the oxygen (O) is absorbed; after this, the gas is again measured by the difference of height of the mercury, it is then forced into the third absorption vessel, when carbonic oxide (C O) is removed by an acid cuprous chloride solution (Cu_2 Cl_2). After the final measurement any residual gases can be discharged into the air through the spare branch of the horizontal tube, and a fresh portion of the flue gases admitted.

So that our Analysis would read:

No. 1 bulb	absorbs	Carbonic Acid	CO_2	12·5
No. 2 ,,	,,	Oxygen	O	2·0
No. 3 ,,	,,	Carbonic Oxide	CO	7·2

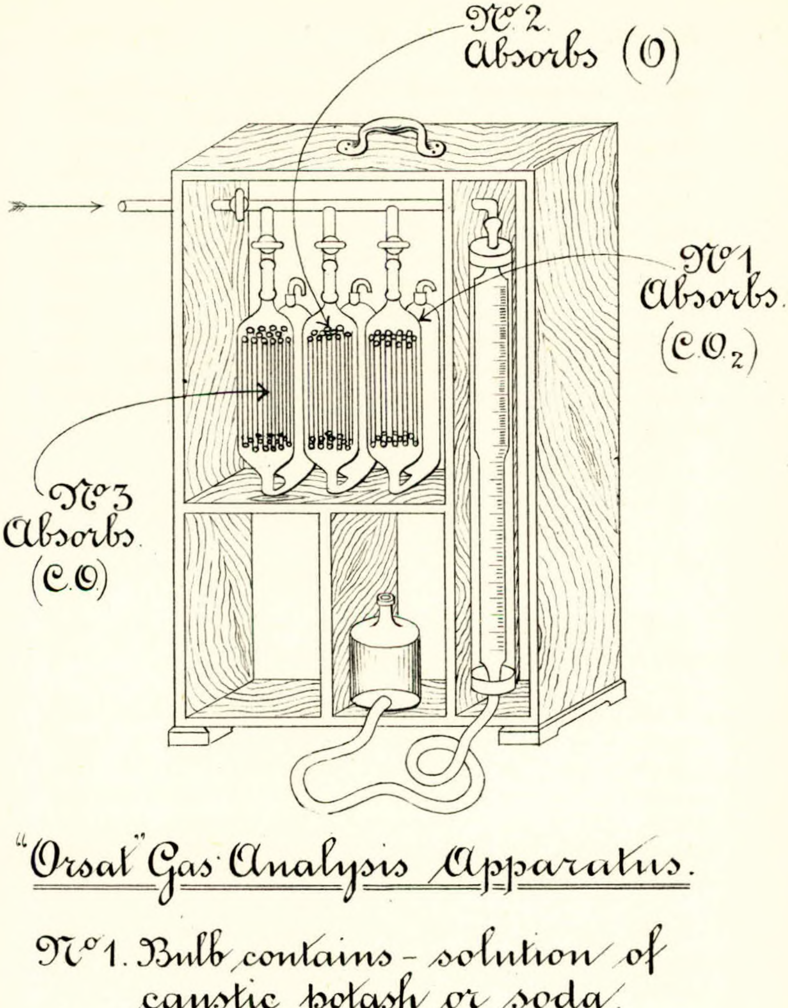
The measuring tube may be graduated with any units cubic centimeter or cubic inches.

Mr. Newall further described the construction and working of the Orsat apparatus by means of a large diagram, and in conclusion observed: That is the system of the Orsat apparatus. There is really nothing in it. It is not complicated. It requires a little manipulation, but it is certainly not more difficult than the steam indicator would be to the novice.

Mr. GREER (Member): Will the temperature of the gases make any difference in the working of the apparatus?

Mr. NEWALL: It does not, as a matter of fact, make any difference. You take such a small quantity of the gases, that by the time you have filled the apparatus the heat is normal.

Mr. ATKINS: If you have taken away carbonic acid (CO_2) and carbonic oxide (CO) the remaining gas is nitrogen.



"Orsat" Gas Analysis Apparatus.

No 1. Bulb contains - solution of caustic potash or soda.

No 2. Bulb contains - an alkaline pyrogallate solution.

No 3. Bulb contains - an acid cuprous chloride solution.

Mr. NEWALL : The bulk of it is nitrogen.

The CHAIRMAN : That settles one point the author was seeking to reach.

Mr. H. C. WILSON (Member) : There is very little doubt but that the modern boiler and the method of utilizing the fuel therewith presents great possibilities of economy, and the great losses to which the author has called special attention are worthy of careful consideration. The question of the combustion of fuel is more a question for the chemist than the engineer; but it is through chemistry that the present losses, arising from imperfect combustion, are detected and estimated Of course I quite agree with Mr. Bapty, and also with Mr. Newall, when they say that the engineer of the future must be more of a chemist than hitherto, and that any further economy in the working of the marine engine will come from the boilers, and consequently out of the fuel to a great extent I was very much interested in the explanation given by Mr. Newall of this arrangement for testing the funnel gases, but I must confess that it struck me as being rather on a par with the old tale about the cook who went to the skipper and asked him, "Is a thing lost if you know where it is?" and when the skipper replied "No" the cook said, "Well, I have just dropped the silver coffee pot overboard, but it is not lost, because I know where it is." Well, supposing we find out what these funnel gases contain; what then? No doubt there is a tremendous loss due to imperfect combustion in the furnaces, but this knowledge of loss through imperfect combustion is of little use unless means are adopted for improving or perfecting the chemical changes taking place in the furnaces. I certainly think that a good deal could be done in improving the admission of the air and in utilizing the air when admitted. I also think that the ordinary arrangement of fire bars is a most crude way of burning coal, as is proved by the fact that you get a waste of 53 per cent. all round. But while the increase or decrease in the supply of air to the furnaces has a great deal to do with the perfect combustion or otherwise of the fuel on the bars, the regulation of the supply presents considerable difficulties in practice, especially in boilers with natural draught. The admission of air directly into the combustion chamber has repeatedly been tried, but, so far as I know, with negative results. The point has struck me as to whether it is really an economy to supply more air; whether you do not so dilute your combustible gases that they become non-combustible, and whether, therefore, an excess of air is not quite as bad as a deficiency—perhaps worse. In furnaces of restricted capacity, in the interior of which the temperature is of a very high degree, there is considerable escape of dissociated elements which pass through the tubes in the boiler. These gases are unable to renew their combination in the tubes on account of their having been too highly diluted with nitrogen and carbonic acid. It is well known that combustible gases become uninflammable when diluted with too great a proportion of incombustible gases. The difficulty, then, to be overcome is to arrange that the furnace shall automatically draw in a sufficient quantity of air to complete combustion. This has been done and the device duly patented. It consists in constructing the furnaces on the Bunsen burner principle, arranging certain annular openings for the natural in-drawing of air at intervals along the furnace itself. The effect is to cause an intimate and integral mixture of air with the combustible gases as they are given off and burnt, and the result is considerably nearer to perfect combustion. This arrangement of Bunsen burner furnaces is peculiarly adapted to the use of liquid fuel, and boilers constructed on this principle are now working and giving excellent results, the combustion of the fuel being almost perfect. The furnaces of coal-fired water-tube boilers do not seem to be adapted to the perfect combustion of the fuel, and I am inclined to think that great loss takes place in them through the air not being supplied in the right place, and the high interior temperature giving rise to the phenomenon of dissociation. There is one paragraph of this paper which refers to the subject of liquid fuel, that strikes me as being very interesting. The author quotes the results given by Mr. Aydon, and I have tried to get hold of the report of that trial, but have not yet succeeded in doing so. But there are one or two terms used in this paper which rather mystify me. The author says that "the oil was decomposed by a jet of superheated steam." I do not know how you can decompose the oil. If he means atomizing it, or vapourizing it, that is another thing. Then, further on, he states that the oil was "consumed in a perfect manner." I presume he means that it was turned into carbonic acid gas. He also states that the trial was made with an ordinary Cornish boiler, and I presume with the ordinary circular furnace. But the trials that have been made with liquid fuel have given very poor results in furnaces of that kind, for reasons that I have not time to go into now. I may also add that I think it would be impossible to burn smoke by catching it after it has once been given off, for the reason that you dilute it with incombustible gases, such as nitrogen.

Mr. MELSOM (Member of Council): I do not quite agree with the last speaker as to the value of this instrument described by Mr. Newall. I think it would be a very valuable apparatus on board ship. It is to test the gases that are wasted in order to know what we are wasting. It is not a question of burning the smoke in the funnel. It is to find out what we are losing through the funnel, and by testing the funnel gases we shall then know what to do with our fires. I think it will be a most valuable thing to have on board ship.

Mr. J. H. THOMSON: This apparatus described by Mr. Newall is very interesting as affording a means of finding out what the funnel gases are composed of; but, after all, the position of an engineer on board ship is a very difficult one. When you have found out the composition of the funnel gases, it is impossible with natural draught to make any extensive alterations while still at sea. You cannot make any alteration in the funnel or furnaces. With forced draught you may be able to do something, but with an ordinary furnace you have no means of regulating the quantity of air that goes in on the top. These experiments might very well be conducted on shore, but I do not see what use it is going to be at sea, when you have found out all about these gases. When you have ascertained what the gases consist of, what can you do? Tests of the kind might be carried out at sea with a view to alterations on the arrival of the ship in port, but in ordinary circumstances I am afraid it will not be possible to do much at sea. So that after all, engineers are to a great extent very helpless when at sea.

The CHAIRMAN: You are referring more especially to natural draught?

Mr. THOMSON: Yes.

The CHAIRMAN: By knowing what your funnel gases are you can make an alteration by shutting your dampers. You can make an alteration even with natural draught.

Mr. THOMSON: What I mean is, that when you are at sea you cannot make any very extensive alterations. You have a damper in the ashpit and the ventilator slide in the furnace front, but I do not see how with these doing all that is possible, you can do much better.

Mr. NEWALL: You have not assumed that you may be getting too much air by natural draught. You have put it on the side that you are not getting enough air. But suppose you are getting too much? Then comes in your adjustable dampers. If you are getting too much air this machine would tell you that you are letting in too much air, and so killing your combustion. At any rate it is worth the experiment.

Mr. MELSOM: When this paper was read, I suggested that we should be able to retard the draught from the fires that have burnt clear by grouping the furnaces, and leaving the greater draught to those which have just been coaled. When you have just coaled a fire you want all the draught, but when a fire has burnt clear you want to retard the draught, and you can reduce the temperature of the funnel gases by that means. The ordinary system of a damper in the funnel is no use at all, because if you damp one fire you damp the lot. I suggested an arrangement by which you should group the furnaces in sets of three.

The CHAIRMAN: Supposing you have a boiler with three furnaces and a combustion chamber common to all three, if you want to check the draught in one, it checks the draught in the other two as well.

Mr. NEWALL: They should be separate.

Mr. MELSOM: And it is an easy thing to make them separate. I am sure that this is a means by which we can effect a great saving.

Mr. J. R. RUTHVEN (Member of Council): As I have read this paper for Mr. Bapty, I think I may say that he will be very pleased to read the remarks of Mr. Newall. I think that he has added greatly to the paper. In fact he has brought the whole subject into a practical form, and I believe that when we get over the novelty of the apparatus it will be largely used, and lead to a great improvement in our knowledge of the combustion of fuel. It seems to me to be just as important to take a diagram of the combustion of the coal as of the action of the steam in the cylinders. I hope that Mr Newall's paper will be printed in its entirety, and that it will lead to a better understanding of the subject. I also hope that a set of this apparatus will be supplied to some ship, and after one engineer has experimented to his heart's content it might be shifted to another vessel, and let everybody have a trial in turn. The cost of the apparatus is comparatively trifling—£20 or even £10 might be sufficient. I think it would be well worth the trouble and would be most interesting. Possibly, in the course of a few months, we may have some trials with this machine recorded, and I should think that some of our big steamship companies would do well to furnish their staff with such a machine.

Mr. J. H. Thomson: With reference to Mr. Ruthven's remark on what I said, I may explain that what I meant was that you were helpless at sea. You could, of course, remedy your defect when you got into harbour.

Mr. Atkins: We have all listened very attentively to the very interesting description given by Mr. Newall of this apparatus, which comes under the third of the three headings or wants mentioned by Mr. Bapty, viz. "some means or instrument for testing, or roughly analysing the waste gases in the funnel." But I should like to say a word about the second want mentioned by the author—"some way of measuring the quantity of air passing into the furnace." It so happened that, in the course of business, I recently called at the offices of Messrs. W. & A. Martin & Co., where I saw Mr. Martin, senior, one of the introducers of induced draught. He told me he had found that the anemometer was not a reliable instrument for measuring the gases passing into the ashpit, and that he had made an instrument for the purpose which he hoped to put upon the market very shortly. He described his invention to me, and so far as I can, from his description, I will draw a sketch of it.

Mr. Atkins drew a sketch of the apparatus on the blackboard, and proceeding to describe it said:—It is simply a light frame of metal with a hinged flap capable of opening and closing the orifice. The frame has a means of measuring the angle formed by the opening of the flap, and the indicator is so calculated as to enable anybody to read off directly the velocity of the air passing through the opening. The apparatus is thrust into the furnace by means of a handle—it is pushed well in—and while in that position this flap opens to a certain angle, which can be read off from this angle scale, and it is possible to obtain a direct reading of the velocity. That velocity calculated into the known area of the ashpit gives the quantity of air passing into the ash pit.

Mr. GREER : That would only indicate the amount of air passing at a particular time?

Mr. ATKINS : Yes, but I only gathered what I have described from what Mr. Martin told me verbally. Taking it from Mr. Martin, who is a most experienced man, I certainly thought that there was somethng in it. You put the machine in the entrance to the ashpit.

Mr. MELSOM : I should be very glad to hear any observations on water-tube boilers *versus* the ordinary type. One gentleman said that it is the form of boiler, not the gases, that we are considering. So far as I can find out by reading, there is no gain at all in water-tube boilers so far as combustion is concerned. I have not had any practical experience myself on the point.

The CHAIRMAN : In a short time you will be enlightened.

Mr. P. SCARTH (Member) : Have they not been condemned in the Navy?

Mr. MELSOM : No, they are fitting them in now.

Mr. H. C. WILSON : I do not want to have it thought that I wanted to run this apparatus down. The point I wanted to go for was, that although you might know by means of that apparatus that you were deficient of air in the funnel, or had too much, the question really is, how can you alter that in the furnace? This is the question which Mr. Bapty is asking. Simply to alter the air supply is not the whole and sole means by which you can get the full value out of your coal.

The CHAIRMAN: Combustion is regulated by the air supply.

Mr. WILSON: Undoubtedly; but after you have got your gases into the combustion chamber, if you raise the temperature in there above a certain heat, I believe I am right in saying that a process of dissociation takes place. You split up the combustible elements in your gases. If you have an excess of air coming in you are diluting those gases in such a way that you cannot burn them in the tubes, and the instrument in the funnel tells you that you are getting too much air. It is clear that the temperature in your combustion chamber is too high. You have split the whole thing up, and you cannot re-unite them; and this has been particularly the case with liquid fuel.

The CHAIRMAN: The idea now is to have a large combustion chamber, and to admit plenty of air into the combustion chamber, but to have retarders so as to prevent the air rushing through the tubes, and secure it being used with the gases in the combustion chamber.

Mr. WILSON: If you took a sample of the gases by that instrument from the funnel of a forced draught boiler, you would find any amount of carbonic oxide in it, and the reason is, that in spite of the retarders, the carbon in the fuel is not burnt, you are wasting it.

The CHAIRMAN: If nobody else desires to make any remarks I now declare this meeting closed, and this is the last meeting of the present session for the reading and discussion of papers. We shall adjourn from to-night until the month of September. The Recreation Committee have under consideration the usual annual dinner, which will doubtless take place in September, before the next paper is read.

Mr. MELSOM: I rise to propose a hearty vote of thanks to Mr. Newall for his interesting contribution and drawing.

Mr. Ruthven: I have very great pleasure in seconding that, and I think it one of the most valuable contributions we have had, although it is only part of the discussion.

Mr. Newall: It is very kind of you, but I hope the time will come when the Institute will provide us with an apparatus and let us try and work it. The machine as it stands costs about £3, and it will require about four pounds of mercury at 5s. a pound, and another sovereign will clear it. So that for £5 we can have a few experiments and test this question, and see how we like it. We have got to commence. It is no good saying it is outside the question. This question of coal combustion is really a serious matter. A man who is getting rid of a great quantity of pounds, shillings, and pence, and taking no interest in how he is getting rid of it, and not doing his level best to try and save as much as possible, is only half doing his duty. This question is not a political one, and it is really very simple. This firm that I speak of at Silvertown have only commenced the study of the subject within the last year or so, and they are really saving some £400 per annum on their coal bills. They test their gases and also their coal, and from their tests they know what quantity of air is required to burn it up economically. Some remarks were made just now that engineers cannot help themselves. The steam indicator is to indicate to the engineer when he cuts his steam off, when he compresses it, and other information. This apparatus is to tell the engineer whether the funnel is too large or too long, whether he has too much draught in it, or no draught in it at all. If he has induced draught he can regulate it, but the instrument that I have tried to describe to-night is a means of pointing out the difficulties or defects in combustion, in much the same way as the indicator does of your slide valve. There are many points in a furnace that may be at fault. You may not be getting sufficient air at your fire bars. I think that this instrument, if it is studied in a fair spirit may do us some good, and I consider the Council of the Institute should obtain one for us.

The CHAIRMAN: On behalf of the Council, I may perhaps say that they are always ready and willing to take up anything new that the funds will allow of, if it is for the benefit of the members. Mr. Newall has asked us about getting one of these instruments; but where is the funnel to try it with here? If we are going to have any practical tests we must have some boiler funnel.

Mr. NEWALL: It is not necessary to have a boiler funnel. Wherever there is a flue we can test the gases that are in it.

MR BAPTY'S REPLY.

In replying to the discussion on the "Combustion of Fuel," I will endeavour to touch on the different points of argument.

I am sorry to say that I have not seen the paper on the same subject which was read at Liverpool, though I must to a certain extent agree with the ideas of its author. Too much air admitted is most certainly detrimental to the efficiency of the boiler, as I pointed out myself in my paper; but the loss is not so great as it would be if too little air were admitted, being only the quantity of heat necessary to raise the temperature of the excess air from its original temperature to that of the waste gases. The idea of the gases being passed through the tubes too cold is rather absurd, as the temperature of the uptakes is generally about 700° Fah., and the internal temperature of the boiler (carrying 160 lbs. pressure) is only about 370°.

I agree with Mr. Duncan as regards the large space required in which to mix the air and gases so as to thoroughly consume them, as well as the free particles of carbon, which would form smoke; but I think that in boilers where the space is limited the same result may be attained by a careful arrangement of the ventilators, letting in the air in small quantities through several different places.

A jet from the forced draught stirs up the gases and mixes them thoroughly, whereas the natural draught carries them in almost their same relative positions from the furnace to the funnel, and their mixing is only caused by interruptions, such as striking against the bridges and tube plates.

The instrument mentioned for measuring the speed or quantity of air supply might be used to advantage by the manufacturers of the forced draught arrangements, to test and graduate their apparatus for the future use of the marine engineer, who would then be able to regulate the quantities of air admitted to the furnaces by following the instructions sent with each arrangement. An engineer burns a certain quantity of coal, and after finding out its properties, he knows almost exactly how much air is required, and if he has been using too much, he would reduce the quantity injected into the combustion chamber or over the bars. On the other hand, if he has not been using enough air, it would be evident that the combustion was not complete, and less air admitted under the bars would reduce the consumption.

In saying that about 47 per cent. of the theoretical heating power of the coal was utilized, I of course meant 47 per cent. of the heating or evaporative power, and not the mechanical equivalent of the heat, though I did make use of the mechanical equivalent to show the difference between it and the power obtained by modern boilers and machinery. The 47 per cent. is not my own estimation, and I think that it is only in boilers of very inferior type that such a low percentage is obtained.

Mr. Newall's description of the "Orsat" gas analysing apparatus has cleared up one of the important questions asked, and I am very much surprised to think that if such a useful and accurate instrument has been known for some time, it has not been more extensively used, as it supplies the greatest want of the coal user. As to the use of powdered coal, I think it would be more difficult to manage, and far less effective than petroleum.

From the discussion it appears to me that we have come to a very satisfactory solution of several of the difficulties. If we had the results from a system of forced draught which has previously been tested and fitted with adjustable graduated air injectors, and the "Orsat" instrument for analysing the waste gases, the information would prove of great value. With the "Orsat" an engineer would be able to find out whether the air was properly applied or not, and with a careful regulation of the draught I think he might obtain almost a perfect combustion of fuel.

I must thank the members who have so kindly taken an interest in the paper and thrown so much light on a subject which is of vital importance.