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On the Economy of Fuel, Comprising Mineral Oils

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Evening Meeting.

Monday, April 1st, 1867.

VICE-ADMIRAL Sir H. J. CODRINGTON, K.C.B., in the Chair.

NAMES of MEMBERS who joined the Institution between the 18th March and 1st April, 1867.

ANNUAL.

Middleton, Francis D., Maj. 29th Reg. £1.	Moray, H. E. H. Drummond, Lieut. £1.
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ON THE ECONOMY OF FUEL, COMPRISING MINERAL OILS.

By Professor W. J. MACQUORN RANKINE, C.E., LL.D., F.R.S., &c.

This paper contains no new principle, nor any new series of experimental researches. It is an attempt to state in a compendious shape the scientific principles that regulate the economy of fuel—a shape in which they may be conveniently applied to any experimental data that now exist, or that may hereafter be obtained.

In the first place I shall have to make a few preliminary remarks on the most convenient way of expressing quantities of heat for such purposes as the present. For purely scientific purposes, the ordinary unit of heat is so much heat as raises by one degree the temperature of the unit of weight of water, whatsoever the unit of weight may be. In British measures, the ordinary unit of heat for scientific purposes is the quantity of heat which raises the temperature of one pound of water by one degree of Fahrenheit's scale—say from the temperature of 39° Fahr. to that of 40° Fahr. When we say that during a certain process—the burning, for example, of one pound of a certain sort of fuel—so many units of heat are produced, we mean that by means of that process, if there be no waste of heat, so many pounds of water have their temperature raised by one degree.

I have here made a memorandum as to the ratio of the British unit and the metrical or French unit, because the employment of French measures for scientific purposes is so common that it is important that their relation to British measures should be borne in mind, especially now that their use is permissive in this country.

One degree centigrade = 1.8 degree Fahr. ;

One kilogramme = 2.2046 lb. ;

therefore, one French unit of heat = $1.8 \times 2.2046 = 3.968$ British units.

Connected with this mode of expressing quantities of heat, is the

mode of measuring such quantities in delicate scientific experiments; and that is by the instrument called the Water Calorimeter, where there is a certain mass of water, and a process is performed, such as burning a certain quantity of a combustible substance, and the temperature of that water is raised. Then, knowing how many pounds of water there are in the calorimeter, and knowing how many degrees its temperature has been raised, we can calculate the quantity of heat which that water has received. That is a process which, simple as it may look at first sight, requires great care and delicate apparatus, to ensure accuracy. There is one circumstance that is a fruitful source of inaccuracy, or would be so but for the precautions that are used to avoid it; and that is, the temperature not being uniform throughout the different parts of the mass of water. We have a vessel containing a certain quantity of water; we have a thermometer at one point in that vessel, and that thermometer shows a certain temperature. But the temperature in other parts of the vessel may be quite different. It is necessary, therefore, that the water-calorimeter should be provided with an "agitator," like a screw propeller, for stirring or mixing all the particles of the water intimately together, and for ensuring so constant a circulation in every part of the calorimeter, that the whole of the water shall be at one temperature.

Then there are always certain causes of waste of heat at work. The water in the calorimeter loses heat by conduction, and heat is carried off by the escape of the hot gases produced by the combustion; and the losses of heat which thus occur have to be measured and to be allowed for.

The measurement of heat, then, by the calorimeter is suitable for a scientific laboratory; but on account of the minute precautions that it requires, it can scarcely be considered practicable in such a way as to be trustworthy in experiments on a great scale.

As an instance of the way in which errors may arise in that mode of measuring heat, suppose that we have a certain boiler containing water, and that we apply some heating process to that water until bubbles of steam begin to come from it under the ordinary atmospheric pressure. We should run a risk of serious error if we assumed that the whole mass of water was at the boiling point. The upper stratum of water may be at that temperature, and may be giving out bubbles of steam, but the lower strata of the water may be at lower temperatures; and we may be led to form most erroneous estimates of the quantity of heat given out during the process if we conduct the experiments in such a manner as that.

For practical purposes, connected more especially with the steam-engine, the most convenient unit of heat appears to be the *unit of evaporation*; that is, so much heat as evaporates a unit of weight of water under the mean atmospheric pressure of 14.7 lbs. on the square inch, the water being supplied to the boiler at the same temperature at which it is evaporated; that is to say, at the *standard boiling point* of 212° Fahr., or 100° cent. It is a perfectly definite unit of heat, and one that is easily measured and easily identified.

Then, in certain respects, it is identical in the measures of all

countries whatsoever. There is no question about different standards of weight or measure, when we speak of the number of units of weight of water that are evaporated at the standard boiling-point by a unit of weight of a given sort of fuel. That number is precisely the same whatsoever the system of measures we employ, whether British or French, or the system of any other nation.

The British unit of evaporation is this:—The quantity of heat that evaporates one pound avoirdupois of water at the standard boiling-point of 212° Fahrenheit, or 100° centigrade—the feed-water being supplied to the boiler at the same temperature at which it is evaporated. It is equal to 966 ordinary British units of heat: that is 966 times the quantity of heat that raises the temperature of 1lb. of water 1° Fahrenheit. The French unit of evaporation is the quantity of heat that evaporates one kilogramme of water at the same standard boiling-point, and it is 537 ordinary French units of heat.*

Now, that is a unit of heat specially convenient for purposes connected with the practical employment of fuel. For one thing, it avoids the use of large numbers. That may seem, at first sight, a trifling matter; still, it is of considerable convenience in practical calculations, that we have to deal with units and tens, instead of thousands and tens of thousands. Another advantage is, that we have the heating powers of fuel expressed in terms of the practical effect that fuel is most frequently employed to produce. A third has been already referred to; viz., independence of special systems of weights and measures in expressing the heating powers of fuel.

Connected with the expression of quantities of heat in units of evaporation, is the experimental measurement of such quantities by means of the evaporation of water; and here, too, certain precautions must be observed in order to ensure accuracy. In the first place, the condition that the water shall be "fed," or supplied to the boiler at the boiling-point, must either be exactly fulfilled, or any deviation from it must be ascertained and have its effect allowed for. In practice, the feed-water is almost always supplied at a lower temperature than the boiling-point. Then the water is not evaporated under the standard atmospheric pressure; and a further correction is necessary, depending upon the difference between the actual boiling-point and the standard or atmospheric boiling-point.

With regard to the way in which the temperature of the feed-water and the temperature of the boiling-point affect evaporation, I may refer to the following formula:—

$$E \text{ (reduced)} = E \text{ (observed)} \times \left\{ 1 + \frac{T_1 - T_f + 0.3(T_b - T_1)}{966 F. \text{ or } 537 O.} \right\}$$

* It is well known that a certain quantity of heat is equivalent to a certain quantity of mechanical work. For instance, we require to expend 772 foot-pounds of work in friction, in order to raise the temperature of 1lb. of water 1° Fahr. If we multiply 772 by 966 we get the number of foot-pounds of mechanical work that we have to expend in friction, in order to evaporate 1lb. of water: so that, to evaporate any given weight of water by mechanical work alone, we require to perform as much work as would lift the same weight up to the height expressed by the product; that is, 745,800 feet, or 227,300 metres; nearly. That is the dynamical equivalent of an unit of evaporation.

In the first place, you observe that the formula expresses this :— A certain weight of water has been actually evaporated, the feed water being supplied at some degrees lower than 212° Fahr., and possibly the boiling point being some degrees above 212° . I denote that weight by "E (observed)."

Now, in order to express this result in standard units of evaporation, we must reduce it to what the weight evaporated would have been had the feed water been supplied at 212° Fahr., and had the evaporation taken place at that same temperature; a weight denoted by "E reduced." For that purpose we must multiply the observed evaporation by $1 +$ a certain correction. And that correction is got at in this way. Let T_1 denote the boiling point, 212° Fahr. standard, and T_f the temperature of the feed water. Then $T_1 - T_f$ is the number of degrees by which the temperature of the feed water is below the standard boiling point. Let T_a stand for the actual boiling point; from that we subtract the standard boiling point T_1 , and take three-tenths of the difference, viz., $0.3 (T_a - T_1)$. Upon this quantity depends the additional expenditure of heat, owing to the actual boiling point being above the standard boiling point. And having added together those two quantities, the depth of the temperature of the feed below the standard boiling point, and three-tenths of the height of the actual boiling point above the standard boiling point, we divide by 966 if the temperatures are taken on Fahrenheit's scale, or by 537 if on the centigrade scale, and we get a certain quotient, generally a small fraction; we add that to unity, and we get a factor by which we multiply the observed evaporation, and the product is the "reduced evaporation."

If the actual boiling point has not been observed, it may still be calculated from the pressure; because there is a connection between the boiling point and the pressure, and the boiling point corresponding to a given pressure may be ascertained by means of formulæ or tables.

Besides this, great care must be taken that the true weight of water evaporated is ascertained. We must either take care that the boiler does not prime, or we must ascertain the amount of priming and allow for it. Priming is the carrying over of water in the liquid state, in the form of spray or mist, along with the steam. Supposing that in the apparatus used it is impossible to avoid priming, there is only one resource: that is, to use an apparatus which will stop all the liquid water from passing, and let nothing but the dry steam pass, and then condense the dry steam in a separate vessel and weigh it. That is scarcely practicable on a great scale, and in the rough sort of way in which many such experiments must be made; and therefore in such cases we must rely chiefly on taking care either that there is no priming, or, if that be impossible, that it is so small as to be unimportant.

Having explained the precise nature of the unit of heat which I intend to use, I will now speak in the first place of the *total* or *theoretical* evaporative power of a given sort of fuel, that is to say, the number of times its own weight of water that it would evaporate at the standard temperature, if there were absolutely no waste of heating power; and in the second place, of the *effective* or *available*

evaporative power, being what we actually get with such furnaces and boilers as we have at our command.

I may observe that the ratio which the effective evaporative power bears to the total evaporative power is a fraction which we may call *the efficiency of the furnace and boiler*. For shortness, we will call it *the efficiency of the furnace*. If the whole of the heat employed by combustion could be effectively employed at the standard temperature, without any waste whatsoever, we should have an evaporative power represented, say by E . But the actual evaporative power is a smaller quantity, say E' : then we have the ratio,

$$\text{Efficiency of furnace} = \frac{E' \text{ (available)}}{E \text{ (total)}},$$

which is a fraction less than unity; and the nearer that fraction approaches to unity, the more efficient the furnace and boiler are.

With respect to those two quantities,—total evaporative power, and available evaporative power, it may further be remarked that the total evaporative power of a given sort of fuel depends upon its chemical composition alone; while available evaporative power depends not only upon the chemical composition of the fuel, but upon the construction and mode of management of the apparatus in which it is used, upon the supply of air, and upon a great variety of different circumstances.

With regard to the total evaporative power of different sorts of fuel as distinguished from the available evaporative power, we already possess very full and accurate information. Numerous careful experiments on that subject have been made in scientific laboratories; they have consisted in completely burning small quantities of different combustible substances, and measuring the heat with scientific apparatus of a very accurate kind, and taking special care that no heat escaped measurement. For example, in such experiments it has not always been practicable to prevent hot gases, the products of combustion, from passing away at an elevated temperature. But then the volume of those gases and their temperature could always be measured, and the heat that so passed away by the chimney calculated and allowed for. It is from experiments of that sort that our knowledge of the total or theoretical evaporative power of various combustible substances is derived. Many such experiments were made by Dulong, Despretz, and other chemists and natural philosophers, from which a great deal of valuable information was obtained; but the experiments now chiefly to be relied on are those of Messrs. Favre and Silbermann, published in the *Annales de Chimie et de Physique*, for 1852-3, volumes 34, 36, and 37. Those experiments have furnished us with a body of information which, as to combustible bodies that are of any practical importance, leaves nothing to be desired: that is, as to total or theoretical evaporative power. Our knowledge of available evaporative power is still imperfect: much has been learned, but much still remains to be learned.

I will now make some remarks specially upon the total or theoretic-

cal evaporative power of certain sorts of fuel as ascertained by the experiments to which I have referred.

We may distinguish the combustible substances to which those experiments relate into two classes—elementary substances and compound substances. I have stated the theoretical or total evaporative powers of the only elementary substances that are of any practical importance in this table :—

Element.	Oxygen per unit of weight.	Air per unit of weight.	Units of evaporation.
(1) Hydrogen gas	8	36	61.2
(2) Carbon, solid	2½	12	15.0
(3) Carbon, solid, with half supply of oxy- gen	1½	6	4.5
(4) Carbon, gaseous, in 2½ parts of carbonic oxide	1½	6	10.5
(5) Carbon, pure gaseous (inferred by theory) }	2½	12	21?

} 15.0

You will observe that there are three columns of figures following the name of the elementary substance. The first expresses the weight of oxygen that is required in order to burn completely an unit of weight of that elementary substance. For example, 1 lb. of hydrogen requires 8 lb. of oxygen for its complete combustion. In order to supply that oxygen there are 36 lb. of air required; and in the second column of figures is stated the weight of air. The third column gives the total or theoretical evaporative power, which in the case of hydrogen is 61.2 times its own weight. It has the greatest evaporative power of all known substances. Then follows carbon. A pound of carbon requires 2½ lb. of oxygen to burn it completely, and to supply that oxygen 12 lb. of air are wanted; and the complete combustion of carbon produces heat enough to evaporate 15 times its own weight of water.

I may here observe that carbon exists in various states of aggregation, such as charcoal, coke, plumbago, and diamond; that the experiments of Favre and Silbermann were made upon it in those different states, and that the total heat of combustion differs according to the state of aggregation. The more hard and dense the carbon is, the less is the heat we get by the combustion—the reason evidently being that a certain quantity of that heat is expended in overcoming the attraction of the particles of carbon for each other. For example, diamond does not evaporate so much as 15 times its weight of water, because of the heat required to overcome its own cohesion. That has a bearing upon some other phenomena to which I will presently refer. But the quantity I have here set down is the result obtained from carbon in the ordinary states of charcoal and coke.

The third line in the table refers to the result produced by carbon when burned with only half the full quantity of oxygen. It is known to chemists that carbon combines in two different proportions with

oxygen. One part of carbon by weight combined with one part and one-third of oxygen produces carbonic oxide. Carbonic oxide is itself a combustible gas, and in burning it combines with just as much additional oxygen as it already contains, so as to form carbonic acid. If we have a furnace ill supplied with air, so that the carbon only gets half the quantity of oxygen that it needs in order to form carbonic acid, then we have carbonic oxide as the product. Each pound of carbon takes up $1\frac{1}{3}$ lb. of oxygen, and to supply that oxygen 6 lb. of air are required. The total evaporative power is diminished not merely to one half, but to a great deal less than one half: it is only 4.5, or three-tenths of 15, the total evaporative power with a full supply of oxygen.

If we next take that carbonic oxide, the weight of which will be $2\frac{1}{3}$ lb., namely, 1 of carbon, and $1\frac{1}{3}$ of oxygen, and burn it, it takes an additional $1\frac{1}{3}$ lb. of oxygen to burn it; and we get exactly the quantity of heat necessary to make up the deficiency, namely, $10\frac{1}{2}$. The $4\frac{1}{2}$ units of evaporation during the first process and the $10\frac{1}{2}$ during the second, give 15 in all, making up the whole evaporative power of carbon with a full supply of oxygen.

A conclusion can be drawn from this, which I will now explain. It is to be observed that in both those stages of the combustion of carbon, we have the very same thing happening chemically; we have $1\frac{1}{3}$ lb. of oxygen combining with 1 lb. of carbon. But there is this difference in the two stages. In the first stage, where the carbonic oxide is produced from solid carbon, the solid carbon has to be converted from the solid state to a state of vapour or of gas. In the second stage, we have the carbon already in the state of gas. Hence it appears that the cause of difference between the $4\frac{1}{2}$ units of evaporation due to the first stage, and the $10\frac{1}{2}$ due to the second stage of the combustion, must be, that during the first stage, 6 units of evaporation disappear in transforming the carbon from the solid to the gaseous condition: in other words, the *latent heat of evaporation of carbon is six times that of water*. Thus we arrive at the conclusion, that the total evaporative power of pure gaseous carbon is 21, from which if we subtract 6, the latent heat of evaporation of carbon, there remains 15, the total evaporative power of solid carbon.

I have marked that conclusion as to the total evaporative power of gaseous carbon with a note of interrogation (?), because it is a theoretical inference which has not been directly verified by experiment, but only deduced by reasoning. Still it seems to me that there can be little doubt of its truth.

If we could get pure carbon from any natural source in the gaseous state, we should have 21 units of evaporation by burning it, because we should save the six units that are employed to transform the carbon from the solid to the gaseous state—that is, those six units would be available for the evaporation of water.

So far, then with regard to the total or theoretical evaporative power of the elements of fuel.

Now, as to that of their compounds.

It was at one time supposed, from experiments relied upon at the

time, that on order to calculate the total evaporative power of a given compound, we had only to take the separate elementary substances of which it consisted, calculate the separate evaporative powers due to those constituents, and add them together. But in the present state of knowledge we know that such a result as that is not quite accurate: that we require to subtract whatsoever heat may be necessary to separate the constituents of the compound fuel from each other. There are cases where apparently there is no sensible expenditure of heat for that purpose. But in almost every actual case that we meet with, it is evident that a certain quantity of heat disappears in overcoming the attraction of the constituents of a compound fuel for each other. So that having calculated from our data regarding elementary substances the theoretical evaporative power due to the combination of the elements of a compound fuel with oxygen, we must not stop there, but we must subtract whatsoever heat may have to be expended in order to overcome the affinity of those elementary substances in the compound fuel for each other before they can combine with oxygen.

Having premised that, I may call attention to some results of scientific experiment as to the total evaporative power of certain kinds of compound fuel.

The only compound fuels that are of any practical importance are the compounds of hydrogen and carbon. It appears from the experiments of Fayre and Silbermann, to which I have referred, that in the case of marsh-gas, which is a compound of two equivalents of carbon with four of hydrogen, or by weight, three parts of carbon to one of hydrogen, we have the following results:—

Constituents.	Equivs.	Parts by weight.	Oxygen.	Air.	Evaporative power.	
C	2	$\frac{3}{4}$	2	9	11.25	{ calculated as if solid.
H	4	$\frac{1}{4}$	2	9	16.05	
<hr/> C ₂ H ₄		<hr/> 1	<hr/> 4	<hr/> 18	<hr/> 27.3	sum
		Erap. power by experiment			24.3	
					<hr/> Difference	
					<hr/> 3.0	

Three-fourths of the weight of marsh-gas is carbon; one-fourth is hydrogen. Now if we calculate the evaporative power by taking the constituents separately, we get three-fourths of 18, or 11.25 for the carbon, if solid; one-fourth of 64.2, or 16.05, for the hydrogen; making together 27.3. But the total evaporative power is found by experiment to be 24.3; so there is a disappearance of three units of evaporation, over and above a quantity equal to that which would disappear in evaporating three-fourths of an unit of weight of carbon, viz., $6 \times \frac{3}{4} = 4\frac{1}{2}$. That is evidently due to some affinity between the carbon and the hydrogen, which has to be overcome in order to separate them from each other; and which requires, in order to overcome it, the expenditure of $4\frac{1}{2} + 3 = 7\frac{1}{2}$ units of evaporation.

Then, in the case of olefiant gas, one of the chief constituents of coal-gas, we have—

Constituents.	Equivs.	Parts by weight.	Oxygen.	Air.	Units of evaporation.	
C	4	$\frac{8}{7}$	2.29	10.30	12.9	} calculated as if solid.
H	4	$\frac{1}{2}$	1.14	5.13	9.2	
<hr/> C ₄ H ₄		<hr/> 1	<hr/> 3.43	<hr/> 15.43	<hr/> 22.1	

Here, calculating the total evaporative power from the constituents as before, we find it 22.1; and that is exactly verified by experiment. Still that very fact is itself a proof of the disappearance of some heat in separating the carbon from the hydrogen; because it has to be recollected that in coal-gas the carbon is gaseous; and if we get no more heat from the carbon in coal-gas than we get from solid carbon, it proves that as much heat disappears in separating carbon from hydrogen in coal-gas as is required to evaporate the same quantity of solid carbon.

That is a fact of much importance, and it simplifies considerably the calculation of the total evaporative power of various hydrocarbons; for the calculation for olefiant gas, which I have given by way of example, is not a solitary instance. By applying a similar method of calculation to the experiments upon various compounds of hydrogen and carbon, it would appear that the expenditure of heat in separating the carbon from the hydrogen is, at all events, to a very close approximation, the same as that required to convert the carbon from the solid to the gaseous state. Hence we get for all practical purposes a good approximation to the evaporative power of any such compound except marsh-gas, by taking the evaporative power of each unit of carbon in the compound as 15, and of each unit of hydrogen as 64, and then adding the results together. That has been verified for an immense variety of compounds. It does not hold with mathematical precision, but it holds with a degree of precision that is enough for any practical purpose.

Now as to the effect of the presence of oxygen in fuel. It was established some time ago by the researches of Dr. Joule, to whom science is immensely indebted for many discoveries of a similar kind, that a certain and definite quantity of heat is produced by the union of two chemical elements, and that precisely the same quantity of heat disappears in the separating of those elements. He verified that in a great number of cases, and established it as an universal law of nature. It holds in many other processes besides chemical combinations and decompositions, whether we are speaking of heat or of any other form of physical energy, that whatsoever quantity of energy we obtain by a given process, if we exactly reverse that process we have to expend precisely the same quantity of energy again.

If 8 lb. of oxygen combine with 1 lb. of hydrogen, they produce heat enough to evaporate 64 lb. of water. If we decompose that water by any contrivance, whether by the use of a galvanic battery, by

the superior affinity of carbon for oxygen, or by any other process, precisely the same quantity of heat disappears in overcoming the attraction of the hydrogen and oxygen for each other. Now if oxygen enters into the chemical composition of any fuel, we have this result: calculate how much hydrogen that oxygen requires in order to form water—that is to say, one-eighth part of the weight of oxygen; then the oxygen present in the fuel renders just that quantity of hydrogen unavailable for the production of heat, and takes away from the total evaporative power 64 times the weight of the hydrogen so rendered unavailable. That being known, we have the following rule in the shape of a formula:—

$$E = 15 C + 64 H - 8 O.$$

This, then, is the rule for calculating the theoretical evaporative power of any sort of fuel whose combustible materials are carbon and hydrogen from its chemical analysis. Distinguish the constituents into carbon, hydrogen, oxygen, and refuse. The refuse does harm as being a useless weight, but it does not take away from the heating power of the constituent parts that remain. For every unit of carbon that remains in the compound, we have 15 units of evaporation; and for every unit of hydrogen, in the absence of oxygen chemically combined with it, 64 units of evaporation; and if there is oxygen in the compound fuel, we have to subtract eight times the weight of that oxygen, because the oxygen renders inoperative one-eighth of its weight of hydrogen; and one-eighth of 64 is 8. The remainder gives the total evaporative power of that fuel.

The next formula shows the amount of air necessary in order to supply oxygen for the complete combustion of a compound fuel. It consists of 12 units of weight of air for each unit of carbon, and 36 for each unit of hydrogen, deducting $4\frac{1}{2}$ for each unit of oxygen in the compound; or in symbols,

$$A = 12 C + 36 H - 4\frac{1}{2} O.$$

In an actual furnace it is seldom sufficient to supply just the quantity of air that contains the oxygen required for complete combustion. It is in general necessary to supply a surplus of air in order to dilute and sweep away the *burnt gas*, as we may call it, and to ensure that every particle of fuel shall have air brought in contact with it. In furnaces with a draught produced by a chimney in the common way, the practical result is, that we have to double the quantity of air, or nearly so. But when we produce a draught by a blast pipe, by steam jets, by a fan, or by other means, which thoroughly mix the air with the gaseous fuel, we reduce the surplus air required very much. In some cases we need only half; in some cases we need no surplus at all. Hence the quantity of air actually supplied, ranges from once to twice the quantity necessary for the oxidation of the fuel.

Here follows a table of examples of the total evaporative powers

of some kinds of fuel, as calculated from their chemical composition :—

	C.	H.	O.	A.	E.	Evap. due to	
						C.	H.— $\frac{O}{8}$
Charcoal.....	·93	0	0	11·5	11·0	14·0	0
Coke	·88	0	0	10·6	13·2	13·2	0
$C_{18}H_{20}$	·84	·16	0	15·75	22·7	12·7	10·0
$C_{25}H_{28}$	·85	·15	0	15·65	22·5	12·66	9·84
Coal	·87	·05	·01	12·1	15·9	13·05	2·85
„	·85	·05	·06	11·7	15·5	12·75	2·75
„	·75	·05	·05	10·6	14·1	11·25	2·85
Peat, dry	·56	·06	·31	7·7	10·0	8·5	1·5
Wood, dry ...	·50	·05	·40	6·0	7·5	7·5	0

The first line refers to charcoal; the second to coke of average quality; the third and fourth lines give two examples of hydrocarbons, which comprise between them the chief ingredients of rock-oil. In the third, fourth, and fifth columns are stated the proportions of the chemical constituents, ranging, for the rock oils, between 84 per cent. of carbon to 16 of hydrogen, and 85 per cent. of carbon to 15 of hydrogen. The sixth column gives the net weights of air required for the oxidation of the fuel. In the sixth column the theoretical evaporative powers are set down: for rock-oils they are from 22·7 to 22·5, or, in round numbers, we may say 22½. In two additional columns are some figures to show how much evaporation is due to carbon and how much to hydrogen. In rock-oils, those quantities are 12½ due to the carbon, and 10 to the hydrogen, out of the 22½ units of evaporation. Lines 5, 6, and 7 give a few examples of coal. These might be immensely multiplied; but I have given only three specimens. They differ from the kinds of fuel previously mentioned, in having some oxygen in them, which somewhat lessens the evaporative power. Here, too, the units of evaporation due to carbon and to hydrogen are distinguished; for example, line 6 shows 12¼ units of evaporation due to carbon, and 2¼ due to hydrogen. Then follow some results for peat and for wood, on which I need not enlarge.

It is to be observed that the examples given in this table, which are only a few selections out of much more voluminous data, are all taken from good specimens. In fact, it is impossible to found experiments upon bad specimens of fuel, because people do not send bad specimens of fuel to be experimented upon. But it may be taken as the result of practical experience that the evaporative power of bad specimens of fuel from a particular district is about two-thirds that of good. This applies particularly to coal. The difference is chiefly due to refuse or ash. But it does not apply to mineral oils, because they can hardly contain anything else but combustible matter. They do not contain ash; they do not contain earthy matter. The statement then, about qualities of fuel which have only two-thirds of the total evaporative power of those set down in the table, applies to coal and peat; but it does not apply to mineral oils.

I have gone at some length into the principles of the total evaporative power of different sorts of fuel, because it is of great practical

importance to understand them. They show the theoretical limit towards which practice approaches in the course of improvement, but which practice cannot surpass nor even attain; the knowledge of those principles prevents people, on the one hand, from forming too small an estimate of the results which may be got from the economical use of fuel; and on the other hand from indulging in exaggerated estimates of those results. It shows us, indeed, what is the actual waste, when we know the result attained in practice; it enables us to judge how far that result falls short of theoretical perfection, and what room there is for further economy by means of improvements.

Now, as to the causes which make the available evaporative power fall short of the total evaporative power.

In the first place, there is imperfect combustion, all the combustible constituents not being combined with the proper quantity of oxygen. This generally arises either from want of a sufficient quantity of air, or from want of a free mixture of air; and in the case of gaseous fuel it sometimes arises from sudden cooling, through coming in contact with some cold substance, so as to lower the temperature and extinguish the flame before the combustion is complete. As to the want of a sufficient quantity of air, the remedy is obvious enough. It is to take care that there are openings enough to admit a proper quantity of air. Still we may supply a very large quantity of air, yet fail to realise complete combustion, because of the air not being thoroughly mixed with the fuel. I have already referred to what we have to do when we have a draught produced, in a quiet way, so to speak, by the ordinary action of a chimney. There is not sufficient agitation of the air to produce a thorough mixture, unless we introduce a surplus quantity of air. We may produce forcibly a thorough mixture of air with the gaseous fuel by such means as the use of the blast pipe, the steam jet, or the fan. This is one of the chief uses of the blast pipe in locomotive engines. The object of blowing steam jets into the furnace, or, at all events, one of those objects, is to produce the same effect. Although the fuel should be solid coke, a great deal of it is actually burned in the gaseous state; for it first undergoes that sort of half combustion that produces carbonic oxide. That carbonic oxide is a gaseous fuel; and in order to burn it completely we have to make sure that it is thoroughly mixed with air. Then, the complete combustion of fuel that is in the liquid state may be promoted by contrivances that blow it into spray, or convert it into vapour, and in that condition mix it with the air. We may blow it into spray by the impulse of a jet of steam; or by superheating that steam we may at the same time convert the liquid fuel into vapour, and mix that vapour with air.

As to the extinction of the flame by cooling, that is a thing which often takes place in steam-boilers, heated by coal that contains a large proportion of volatile constituents. When first set free and brought in contact with the air, these take fire; but the flame comes in contact with the heating surface of the boiler, which is at a comparatively low temperature; the combustion is checked, and instead of combustion, we have decomposition of the hydrocarbon gas. The carbon and hydrogen

are separated—the carbon in the shape of black particles, which form smoke; and both the carbon and the hydrogen go off to a great extent unburnt.

I might here enter into a calculation to show what amount of waste of fuel may arise from an imperfect or ill-managed supply of air. It would perhaps occupy too much time to go into detail; but I may refer to a fact which I have already stated in the case of carbon, that if it combines with only half of the quantity of oxygen that it requires for complete combustion, we have only $4\frac{1}{2}$ units of evaporation, instead of 15. The evaporative power is reduced to three-tenths, so that seven-tenths of it are lost.

Then in the case of fuel like bituminous coal, which consists partly of solid carbon, and partly of volatile compounds of carbon and hydrogen, we may have the hydrogen going off imperfectly consumed, either alone, or carrying away more or less unconsumed carbon along with it. From what I have stated respecting how much of the evaporative power of the bituminous coals depends on the carbon, and how much on the hydrogen, it will be understood how much may be lost in different cases: $2\frac{3}{4}$, or in some cases 3 units of evaporation if the hydrogen alone goes off without being consumed; and if it carries off a certain amount of carbon along with it, that waste may be more than doubled.

I have spoken of the remedies for the imperfect combustion of gaseous fuel, by thoroughly mixing it with the air, either by a blast pipe or by a steam jet. As to the thorough combustion of carbon in the solid state, one way to ensure that is, by keeping a thin fire, that is to say, having a very large grate in proportion to the quantity of coal to be burned, and burning only a small quantity of coal, say 10 lb. per hour, on a square foot of grate. I have known as little as 4 lb. per hour burned on a square foot of grate. Thus we may ensure that there shall be free access of air to all the burning carbon. But another plan is, to let the combustion on the grate be imperfect, by keeping a thick layer of coal on the grate, which turns into coke, and then to introduce a supply of air above the level of the fuel on the grate, for the purpose of consuming the carbonic oxide and the hydro-carbon gas that are in the gaseous state. There is a known contrivance, called the "dead plate." It is a cast-iron plate at the mouth of the furnace, on which the fresh coal is laid and exposed to a heat sufficient to distil away the volatile constituents. The coal gas so distilled passes over the layer of red-hot coke on the grate: a surplus of air passes through the red-hot coke, sufficient to burn the coal gas. Then, after the coal gas has been all distilled away and burned in that manner, the coke that remains on the dead plate is pushed on to the grate, to be burned in its turn.

In the case, then, of burning coal which is a compound of fixed carbon and volatile hydrocarbon, we have the two plans, of a large grate and a thin bed of fuel, where we have plenty of space; or, of a comparatively small grate and a thick bed of fuel, and introducing air above the fuel to burn the gas, where the space is limited.

There are numerous contrivances for the efficient combustion of coal

which cannot now be described in detail, such as the use of a separate combustion-chamber of brick, in which the burning of the whole constituents of the fuel, solid and gaseous, is completed, the chamber being built with double walls of brick, and a double arch of brick over the top, so as to prevent loss by conduction. Another plan is to make what we may call "crude gas," by the imperfect combustion of coal, so as to turn all the combustible constituents into a mixture of coal gas and carbonic oxide, and then to burn that mixed gas. There are also double furnaces, air-valves of various kinds and in various places, and an endless series of other inventions.

So much, then, as to the waste of heat through imperfect combustion, and the means of preventing it.

There is another sort of waste of heat: that is, by conduction and radiation. It was ascertained by Péclet, that about half the heat that comes from coal in a furnace radiates directly from the incandescent fuel, and is not carried by the current of flame, or the hot gas, to distant parts of the heating surface. We must be careful that none of that heat escapes from the furnace. For example, if there are openings in the furnace door to admit air, we must take care that the door at all events is double, with the openings of the inner plate not directly opposite those of the outer plate, so that radiation shall not take place through them. Or, we may have a grating of several plates placed edgewise close together, between which the entering air may pass, and so absorb the heat that has been radiated to those plates. I have already referred to fire brick casings round a combustion chamber to prevent loss by conduction. The prevention of that sort of loss is a very obvious matter.

I now come to a third mode of waste of heat, which is a highly important one: that is, the waste of heat up the chimney. The products of combustion escape by the chimney at a temperature above that of the external air. Whatsoever heat is expended in raising the temperature of those escaping gases above the temperature of the external air, is a total loss as regards evaporative power. It is useful for certain purposes. It is useful to rarefy the air in the chimney, and to make it lighter than the air outside, and so to cause the draught of the furnace; but it is not useful as regards evaporative power. The quantity of heat wasted in this way depends upon the specific heat of the burnt gas, which is about one-fourth of that of water; so that for every pound of gas that goes up the chimney, and for every degree of elevation of the temperature of that pound, we have one-fourth of an ordinary unit of heat expended: being in round numbers and for Fahrenheit's scale, about the $\frac{1}{4000}$ th part of an unit of evaporation per degree and per pound of burnt gas.

The following formula expresses in a condensed form the waste of heat up the chimney in units of evaporation:—

$$\text{Loss by Chimney} = \frac{1 + A'}{4000} \cdot T_c \text{ Fahr};$$

and the following are examples :—

$1 + A'$	13	19	25
Tc	600	600	600
Vol. gas, cubic feet ..	325	475	625
Loss of evap. power .	1·95	2·85	3·75

$1 + A'$ denotes the weight of burnt gas per unit of weight of fuel, and Tc the elevation of the temperature of the chimney, in degrees of Fahrenheit, above that of the external air.

The products of combustion, for the reasons I have already stated, are more or less diluted with additional air; so that in the case of ordinary bituminous coal, $1 + A'$ ranges from 13 to 25, and 19 is an intermediate value. In the case of hydrocarbon oils, the air that is required for oxidation is about 15·3. We have to add the weight of fuel, and we shall get about 16·3 for the net weight of burnt gas; and it is quite possible that in a well-contrived furnace, no surplus air may be necessary. We multiply the weight of burnt gas which goes up the chimney by the elevation of temperature in the chimney, and if that temperature is expressed in degrees of Fahrenheit, we divide by 4,000, and the quotient is the evaporative power lost up the chimney.

It is easy to see that in order to diminish that sort of loss, we must in the first place have the temperature of the chimney no higher than is absolutely necessary. When the chimney is the means of producing draught, it can be demonstrated that the most effective draught is produced by a temperature not much above 600° Fahr.

It is still more important to avoid an unnecessarily large supply of air to the fuel. We must supply the quantity of air that will give the oxygen necessary to consume the combustible elements, otherwise we shall have enormous loss from imperfect combustion. Every additional pound of air we supply carries to waste a certain amount of heat. I have said that when we produce the draught by means of the rarefaction of the air in the chimney alone, we require 12 lb. of air per lb. of fuel for oxidation, and 12 lb. more for dilution, making altogether double the net quantity of air. If we use the blast pipe as in a locomotive, I think it is quite certain that it is not necessary to supply more than once and a half the net quantity of air, and in some cases we need only supply a mere fraction more than the net quantity. I have very little doubt that in methods of burning mineral oils which I have seen tried, where by the help of a jet of superheated steam, the fuel is thoroughly mixed with the air immediately before the process of combustion, the net quantity of air is sufficient of itself, and we may altogether avoid that very great waste of heat which arises from the supply of an additional quantity of air.

To exemplify the waste of evaporative power that may so arise, I have annexed a few calculations to the formula. I have taken the weight of the gas going up the chimney as first 13 times, then 19 times, then 25 times the weight of the fuel burnt. I have taken the temperature of the chimney as 600° in each case, that being the best temperature when we use chimney draught. In the next line are stated the volumes of gas that go up the chimney in cubic feet per pound of fuel. That,

however, is a collateral matter. In the next line is stated the loss of evaporative power due to the escape of that gas. And observe that it is in very favourable circumstances. The temperature of the chimney is no higher than is necessary to produce the best draught, yet in the first column the loss of evaporative power is 1.95; in the second, 2.85; and in the third it is 3.75. Losses much exceeding those are very common.

If the draught is produced by artificial means, such as a steam jet, we do not need rarefaction of the air in the chimney in order to produce a draught. We may have the rarefaction as an auxiliary, but it is not indispensably necessary. In fact, it seems that if we adopt proper means for producing draught by mechanical appliances, we may use such a heating surface as to take up almost all the heat of combustion, and reduce the loss of heat by the chimney to an inappreciable quantity.

I will now say something regarding the results deduced from a comparison of experiments by many authorities upon the effect of extent of heating surface upon the economy of heat. It is through the heating surface that heat is communicated from the flame and hot gases to the water in the boiler. Upon the extent of the surface depends very much the proportion of that heat which is made available. It is not yet possible to lay down any precise theory upon this subject. But the formula I have written down gives, at all events, a good rough approximation to the results of experiment and of practice in a variety of different cases:—

$$\frac{E'}{E} = \frac{bS}{S + aF}$$

Values of a	·5	·3, &c.
„ b	1·0	·93, &c.

It is based upon principles of this kind,—that whatsoever parts of the heating surface are nearer to the fire, take proportionally the greater shares of the heat, and that each additional area more and more distant from the fire takes proportionally less and less heat. Suppose a certain area of heating surface in immediate contact with the furnace: it will absorb a certain quantity of heat. Then, the next area of equal extent beyond that will absorb a much less quantity of heat; and so on, each successive additional area absorbing a less and less quantity until at length it becomes no longer practically advantageous to increase the area of the heating surface.

By comparison of a good many experiments and a good many results of practical experience, we have this approximation to the proportions of the available to the total evaporative power of fuel, as depending upon heating surface. Let S denote the number of square feet area of heating surface, and let F denote the number of pounds of fuel burned per hour; let a and b be co-efficients to be deduced from experience. We multiply the area of heating surface by the co-efficient b , and we divide by the area of heating surface, plus the number of pounds of fuel burned per hour, multiplied by another co-efficient a .

From the practical results to which I have referred, it would seem that the value of the co-efficient α , upon which the waste of heat mainly depends, ranges between 0.5 and 0.3. It is 0.5 for a chimney draught, and it is 0.3 for the draught produced by a blast pipe or jet of steam. This 0.3 is found as the result of the use of the blast pipe in locomotives. And it would seem that the co-efficient a is very nearly proportional to the square of the ratio of the total weight of burnt gas to the weight of fuel; so that if we double the quantity of burnt gas, per pound of fuel, we shall quadruple this co-efficient a ; if we can reduce the quantity of gas, per pound of fuel, to one-half, we shall reduce the co-efficient a to one-fourth. As to the value of b , it comes very near to unity in some cases, in which care has been taken to make the motion of the water in the boiler take place in the most advantageous direction, relatively to the motion of the products of combustion, that is to say, in the reverse direction—to introduce the feed water in contact with the coolest part of the heating surface, and let it advance gradually to the hottest part, where it is finally converted into steam. That principle was carefully attended to in the boiler invented by Lord Dundonald. If that precaution is neglected, we may lose from 8 per cent. to 10 per cent. of efficiency. But the diminution of efficiency depends mainly upon the waste of heat up the chimney, which is brought into the formula and provided for by the co-efficient marked α .

Here is an example of a particular case:—

$$\text{Let } \frac{S}{F} = 1; a = .5; b = .9; \text{ then } \frac{E'}{E} = .6.$$

We will suppose that we have one foot of heating surface for each pound of fuel burned per hour: then S divided by F is equal to 1; that we use a well managed chimney draught, so as to have a equal to 0.5; that we do not pay particular attention to the place where we introduce the feed water, and do not use a feed water heater; so that we get b equal to 0.9. Then, by introducing those values into the formula we get for the efficiency, or proportion of the total evaporative power to the available evaporative power, 0.6. This is a very common case in practice, and when it is realized it is considered a very good result. If we have a specimen of coal whose total or theoretical evaporative power is 15, and we get 6 per cent. of that, and its actual or available evaporative power is 9, that is regarded as a good performance. You see how that arises,—how step by step such a result is arrived at upon scientific principles.

I may observe that the actual efficiency of furnaces—the proportions of the available to the total evaporative power of fuel, go through a very wide range. We find cases in which there is only 45 or 50 per cent. of the total evaporative power actually realized, or made available, and yet these are not considered very bad. From 55 to 60 per cent. are ordinary results, in good marine boilers. When we get above those we get to results that are rather uncommon, and when we get to 80 or 90 per cent. being realized, it is considered very extraordinary.

In conclusion, I may make the following observations on what we may look forward to as the probable result of the introduction of such classes of fuel as mineral oil as substitutes for coal. Coal is a very complex kind of fuel. To ensure the best possible economy in the use of it requires the fulfilment of many different conditions, some of which conflict with each other. We have to burn fixed carbon, and we have to burn the gas that is disengaged from the coal. We may burn one very efficiently, and not burn the other. It is extremely difficult to manage the introduction of air, so that there shall at once be no risk of a deficiency of air, which causes imperfect combustion, and gives bad economy in one way; or a surplus of air, which carries heat to waste up the chimney, and causes bad economy in another way. On the one hand we are exposed to the risk, from any little fault of construction or management of the furnaces, of the hydrogen going off unburned, and of its carrying off a large portion of the carbon unburned also. On the other hand we are exposed to the risk of solid carbon being imperfectly burned, and going off as carbonic oxide. The contrivances for diminishing the causes of waste are somewhat difficult and complex to apply in practice; and above all, too much depends upon the skill of the fireman or stoker. We may say almost everything depends upon the way the furnace is managed. The very best furnaces, the very best boilers that were ever contrived, may be made extremely wasteful by a careless stoker. On the other hand, in using mineral oils, we are somewhat in the position of the chemist who has got a good burner for burning coal gas. We have to contrive a suitable apparatus for introducing that oil into the furnace in such a way that it shall be thoroughly mixed with air—whether in the state of vapour, or in the state of fine spray, with or without the assistance of some porous substance to act as a wick. A steam jet seems to be the most efficient apparatus for that purpose. Then if our apparatus is properly contrived and properly constructed, and works in the right manner and produces complete combustion at first, there is no reason to suppose that it will ever act badly if treated with ordinary care.

It would seem to be no difficult matter with fuel of that sort to diminish the waste of heat through imperfect combustion to nothing, and the waste of heat through hot gases going up the chimney to something very small indeed. In fact, such an efficiency as 90 per cent. of the total evaporative power being realised, instead of being a very extraordinary thing, may be looked for as a very ordinary thing; so that, taking the theoretical evaporative power of some hydrocarbon compounds at $22\frac{1}{2}$, we ought not to be surprised that even with rude apparatus, in a merely experimental state, we get an evaporation of 19 or 20 times the weight of the fuel—say 19, at all events. I believe that has been realised in experiments that have been made, and that are now being continued.

There is another phenomenon as to which I may say something—the mode of operation of steam jets in cases of this kind. There can be no doubt that one use of the steam jet is the mechanical action to which I have frequently referred—the thorough mixing of the gaseous

fuel with the oxygen required for the purpose of combustion—the churning of the particles all together, so that they shall be brought thoroughly into contact. There may be another mode of operation of steam—a chemical action whose effect is to prevent the deposition of unconsumed carbon from gaseous fuel. All hydrocarbons have a tendency when raised to a high temperature to deposit the carbon, unless it be instantly burned. We see that in the smoke that a flame tends to give out, if there is anything to prevent immediate and free access of oxygen to the carbon. Now it is possible that besides its mechanical action, the steam jet may also have a chemical action of the following kind:—The oxygen of the steam combines with the carbon of the hydrocarbon fuel, and the hydrogen of both is set free; there is a mixture thus produced of carbonic oxide and of hydrogen, which is sure to be completely burnt as soon as a sufficient quantity of air gets access to it, and thus the deposit of unconsumed carbon is entirely prevented.

I have now gone as far as I think I can venture to occupy the time of this meeting. It would be out of place for me to enter upon the consideration of nautical questions, such as the comparative weight and bulk of different sorts of fuel; therefore I have now only to thank you for the kind attention with which I have been heard.

The CHAIRMAN: Does any gentleman wish to make any remarks upon the paper?

Captain JASPER SELWYN, R.N.: This is a subject which has engaged my attention for the past two years. I had the pleasure of bringing it to the notice of this Institution, persuaded as I was of the enormous value of the whole question, more particularly to the Navy of this country. I knew that if the economy which Professor Rankine has put before us, and the use of materials better adapted for such combustion as we require, were once brought into play, that a very great proportion of the unjust fears, which existed two years ago very strongly indeed, as to the consumption of our whole coal supply, would be met by an economy which was the truest method of supplementing any possible failure; though I scarcely believe such to exist. I am sure that had the members of this Institution been more generally aware, particularly my naval brethren, of the very complete way in which the whole question of the economy of fuel would have been brought before them to-night, we should have seen a very much larger attendance than we now see. However, it matters the less, because this is a paper which will be read with the greatest attention in the Journal. It will, I am persuaded, command a very wide class of readers, not alone in the Navy, but among all those who are interested in this great question; among foreigners as well as our own countrymen. Professor Rankine has followed up, most beautifully, I think, the composition of fuel, the value of each proportionate part of it in accomplishing the effect we desire, the causes of loss, and the possibility of economy. The points to which he has drawn your attention are those which belong to the science which he has cultivated with so much success. The points to which I had the honour of drawing your attention were principally those which affect our own profession, inasmuch as this was a fuel which alone could be burned with greater economy, would require fewer attendants, economising their wages and victuals, would be attended with more certainty even by inexperienced persons, and would give us a power of stowing and taking it on board conveniently in places where we could not have so stowed it formerly, and with none of those wretched residuary products which we find so much difficulty and so much nuisance in getting rid of. The Professor has adverted to the causes of loss in the deposit of carbon. I think I may ask him whether he is not of opinion that that has another and most important effect, which is that the heating surfaces, becoming covered with such a

deposit, lose very materially their efficiency; and that wherever an entire absence of such deposit can be obtained, it not alone indicates economy of the unconsumed carbon which is now burned, but it indicates also the increased efficiency of the heating surfaces, which are left in their integrity, as the maker intended them to exist. The question also of blasts has been brought very strongly before you, showing you the economy of the artificial blast, and where this blast is supplied, at such a point of the furnace as to be itself a contributor to the total heat of combustion, and in this way it becomes clearly very much more valuable. I think I gathered from what Professor Rankine said, that he considered it quite probable that a double decomposition took place, and that the oxygen and hydrogen of the steam contributed to the total heat of combustion; therefore, although it was necessary for the purpose of the blast to sacrifice a certain portion of the steam generated in the boiler, yet that steam, having done a certain portion of mechanical duty in creating blast, also restored to the boiler a certain proportion of the duty of combustion, and was not, therefore, so great a loss as some persons would be led to believe. I put this more in the shape of a question, which I hope Professor Rankine will remember in his reply, in order that my naval brethren may be thoroughly aware of what the bearings of the question are upon points which are perhaps a little obscure. The question of burning mineral oils is also very materially a question of price. Now, if we were to bring to this Institution a proposition to burn something which cost £10, £15, £20 a ton, you would probably meet the person who brought forward such a proposition by saying, "We are aware that such great results may be obtained by such expensive fuel, but we think the expense too great to be justified." But we do not do that here. The term "mineral oil" is applied to a wide range of products, many of them refuse products, such products as arise from the distillation of illuminating oils, and from the refuse of gas manufactories, which are known by the name of "dead earth oils," and which are sold entirely as refuse at prices not very materially above that of coke. From a halfpenny to three-halfpence a gallon, I think, is the price at which they are being actually burned at this moment, and doing duty rather in excess, I think, of what Professor Rankine has claimed for them as yet; not in excess of the theoretical evaporative power, but in excess of the power which Professor Rankine claims in his last words—the theoretical evaporative power very largely secured with very little waste; and an economy in all other points, such as he has spoken of being pretty fairly carried out in these early experiments, has resulted in the duty, done by 30 lb. or three gallons of this dead earth oil at from one halfpenny to three-halfpence a gallon, being precisely the same as had been previously done in the same boiler, with very little change in it, by 60 lbs. of coal. Now, I hope that this subject will not be allowed to drop; that it will be made the subject of very close study indeed by those who are responsible for the cheap and efficient conduct of our naval affairs. I, for one, have to lament the knowledge which I have recently acquired, viz., that one of our most recently built iron-clads can only carry four days' coal to sea. I say distinctly, and I am sure my naval brethren will say with me, that it is utterly impossible we can go on in that way; that to encounter a great European war with such means of locomotive power, even though we should have carried out the views of seamen, and not of those who advocate fighting machines without masts or sails, although we should have carried into effect good sailing ships as well as good steam-ships; yet if they can only steam four days, we shall lose the empire of the ocean for want of being able to go to sea under steam, or, I should say, to keep at sea under steam. I hope, then, that some other person will kick the ball again; that this will not be a subject with respect to which it will be said, "There has been a splendid paper read upon it; we will now consider the subject as closed." Let us rather consider it as only now opened—most ably opened by Professor Rankine. I am sure he has given those who are inclined to study the subject at all the materials with which they may do so successfully.

Mr. J. RICHARDSON, C.E.: As regards fuel, I think we may safely say that that fuel is the most valuable which can be burned with the least waste. We all know that the best coal when carefully burned will evaporate 10 lbs. of water to 1 lb. of coal. Laboratory practice is hardly a test of the result in real practice. In this, evaporation is seldom obtained of more than 7 lbs. of water to 1 lb. of coal. There

is a cause which considerably accounts for this difference. It is necessary in large furnaces, every seven or eight hours, to remove the clinkers from the fire bars; and in doing so, the stokers seldom stop at two-thirds of the contents of the grate, but they rake out nearly all the contents, clinkers and ashes, and the whole go over the side into the sea. This is not enough: every three or four hours all the ashes are raked out, and they go over the side. Besides the waste of coal in raking out the fires; there is also deterioration of coal in hot climates. I have had the opportunity, when at Woolwich, of speaking to engineers there, and they all confess that the amount of evaporation obtained from coke and coal in a long voyage is never more than 6 lb. of water to a pound of coal. Liquid hydrocarbon can be burned nearly without any waste. A ship starting from Southampton, and going to Calcutta, has only got to get her steam up before she leaves the harbour. She may have her furnace doors locked, and she may keep them locked till she gets to Calcutta; and there may be an evaporation obtained of 16 lb. to 18 lb. of water from one pound of fuel, without the slightest change, the whole distance. Evaporation can be obtained without the least trouble to the stokers; they have only to attend to the fire, and see that it does not make too much head, or get on too fast. The fact is that 200 lb. of this liquid hydrocarbon will produce as much heat as 600 lb. of coal. I think this is a most important result in favour of these fuels. There is one fuel that has not yet been tried. This is a solid fuel—naphthaline—and I believe is stronger than creosote. I believe it would produce 24 lb. of evaporation. The Admiralty have given a common service boiler, which is going to be tried, first with coal, and then with the liquid hydrocarbon fuels.

Captain BURGESS: What is the price of the naphthaline?

Mr. RICHARDSON: About 18s. a ton.

The CHAIRMAN: What effect has oxygen when chemically combined with fuel?

Professor RANKINE: With respect to the question you have just put, we know from the results of experiment, when oxygen does exist in a state of chemical combination with fuel, that it actually forms water with part of the hydrogen. Its operation is this: it annuls the heating effect of a certain portion of the hydrogen. Suppose in 100 lb. of a certain sort of fuel there are, we will say, 5 lb. of hydrogen, and 4 lb. of oxygen, the 4 lb. of oxygen render $\frac{1}{2}$ lb. of hydrogen inoperative. It does not burn, because it has combined with the oxygen, and it cannot combine with any more. So, while the total hydrogen in the fuel forms 5 per cent. of its weight, the effective hydrogen is only $4\frac{1}{2}$, the remaining portion being rendered inoperative, owing to the presence of the oxygen with which it is able to combine. That seems to be the explanation of the effect of the presence of oxygen in coal. It is well known that it deteriorates the coal. It is further certain that this is one of the causes why coal exposed to the atmosphere becomes deteriorated, and loses heating power. It is equivalent to a partial combustion, leaving so much the less to be burned. Then, with regard to the previous remarks, there is no doubt that all that has been said about the stirring of the fire to remove the clinkers is perfectly sound and perfectly applicable. It is a cause of great waste of heat; and it is important, as regards one objection to the use of coal to which I have already referred, that it leaves so much dependent upon the skill and care of the stoker. There is no doubt that, with very careful firing, the waste from this cause may be reduced perhaps to only about $2\frac{1}{2}$ per cent. of the total evaporative power; but with bad and careless firing, there is no saying how much it may amount to. With mineral oils you are free from dependence upon uncertain matters of that sort. Captain Selwyn put a question regarding the chemical action of a steam jet. There can be no question at all about the advantage of its mechanical action, mixing the air and the fuel together, and bringing the oxygen into thorough contact with the inflammable matter. As to chemical action, as far as chemical action upon steam itself is concerned, it would just amount to this—that the steam is first decomposed into oxygen and hydrogen; and that then the hydrogen is combined with the oxygen again. The result of that, as regards heating power, would be simply nothing. A certain quantity of heat disappears in decomposing water; precisely the same quantity of heat is reproduced by the oxygen combining with the hydrogen again. It is indirectly conducive to a very important saving: all that oxygen which is separated from the

hydrogen during the decomposition of the steam serving to hold in solution the carbon of the inflammable gas or oil, and to prevent its being deposited in a solid form. I quite agree with Captain Selwyn. It was an omission on my part not to refer to the prejudicial effect of such a deposit of carbon upon the heating surface, in reducing its conducting power. It is no doubt from a cause like that—from the carbon encrusting the heating surface that cases of this sort have arisen:—a steamer would make her trial trip burning only 4 lb. of coal, per indicated horse-power, per hour. She would start upon her voyage burning the same quantity. The consumption would gradually rise to $4\frac{1}{2}$ lb., 5 lb., and so on, and at the end of the trip she would be burning 6 lb. of coal, per indicated horse-power, per hour, without any deterioration in the working or in the management of her engines, but solely from the loss of conducting power, owing to the deposition of the carbon upon the surface of the tubes.

Captain SELWYN: May I say that I particularly wish to have an opinion from you with regard to the difference between the action, chemically and mechanically, of the blast in the chimney and the blast in front of the furnace?

Professor RANKINE: I think there is one difference with respect to the mechanical action—that a blast directly into the furnace is much more efficient. It produces a more thorough mixture of the inflammable gases with air than the chimney blast does. A chimney blast in a locomotive is a very convenient thing; but I do believe that you can produce an equally thorough mixture, or a more thorough mixture by direct blast into the furnace with less expenditure of air. Then, as to the indirect chemical process to which reference has already been made. Of course, if you blow steam into the chimney it does not take place at all. That chemical process that tends in an indirect way to economy of fuel can only take place if you introduce steam in contact with the inflammable gases. I am glad that Captain Selwyn has referred to this matter, because I ought to say something as to the temperature at which steam is introduced. Captain Selwyn has referred to this fact, that it may be said a certain quantity of heat is wasted in generating this steam, but that heat is made available again. Now, that depends, I may say, almost entirely upon the temperature at which the steam is used. You expend a certain quantity of heat in evaporating water, and you send the steam in at a comparatively low temperature. In the ordinary state of saturated steam, the temperature of 212° as compared with burning fuel, is cold. It may be very hot as compared with the ordinary temperature of the atmosphere; but as compared with the temperature of fuel in the furnace, it is a very low temperature indeed. A body cannot give out heat to a body that is hotter than itself, so that the heat spent in producing steam at a comparatively low temperature will be wasted; but if you use superheated steam, in the first place a much less quantity of steam will serve the purpose. The mechanical effect depends upon pressure and volume. In order to get a great pressure and a great volume with small weight of material you must employ a high temperature; you must, in short, use superheated steam. As a great part of the expenditure of heat in producing the steam depends on its weight, the use of superheated steam tends to lessen the expenditure of heat for a given mechanical effect. Then, if you raise the steam to a temperature approximating to that of the flame itself, you get back nearly the whole of the heat again; because the superheated steam, being at a higher temperature than the heating surface of the boiler, gives out a great part of its heat to that surface just as the flame does.

The CHAIRMAN: I am sure that the meeting will join with me in offering our thanks to Professor Rankine for this lecture—I may say for this lesson. As an old Naval Officer myself, I feel that during the time when I was captain of a line-of-battle ship I should have been very glad of such a lesson as we have had to-night. I may also add that I hope it will be of great use, not only to us who are going out of the profession, but to those who are rising up in it. I must also make another remark—that the small number who are here present is no measure of the value of a lecture such as this, or of the good that it will effect. There are many others who, thanks to our Journal, will have the opportunity of studying this lesson, Naval Officers especially. There is a great deal in the professional part of the question which Professor Rankine

has thought it right to leave out. But points have been touched upon very ably by Captain Selwyn in almost every one of which I cordially join, because I think those points are of great importance. The efficiency of our Navy will very much depend upon the fuel we shall use in the future, and upon the way in which we shall be able to economise the use of it, or economise the space for it in stowage. Every pound of fuel we shall be able to save hereafter will be so much space gained; not merely space gained for air and so on, but space for efficiency, for the life of the ship, because her efficiency depends upon the quantity of fuel she can stow. She is no man-of-war if she goes to sea devoid of fuel, and is met by an enemy with a good supply. There would be an end of her. We must also remember that all we can gain in the way of space and efficiency will enable us to carry a better armament, and to devote the space saved to other purposes, even if we do not devote it to the life of the ship, viz., the fuel she carries; for fuel to a ship is as the air we breathe. I must again ask you to join with me in thanking the Professor for the very able lecture which he has given us.