On Economy of Fuel in Ships of War

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Monday, March 18th, 1872.

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ON ECONOMY OF FUEL IN SHIPS OF WAR.

By T. SYMES PRIDEAUX, Esq., C.E.

It has always appeared to me that the question of "Economy of Fuel in Steam Ships of War" has never received that amount of attention to which the importance of the subject entitles it. All those considerations which render it so desirable to obtain steam power on land for our manufacturing and other purposes, with the smallest possible expen-

diture of fuel, are increased in force and heightened in importance when applied to the case of ships which traverse the ocean. Economy of fuel in a ship of war confers the power of selecting one or more from a list of many advantages. It is equivalent to a smaller, handier, and cheaper ship, or to thicker armour and heavier armament, or to higher speed, or lastly, but not least in value, to the capacity for remaining under steam for a longer period.

Supposing two rival powers with navies of equal force, but that the ships composing the Navy of one were able to maintain their stations at sea without resorting to a coaling depôt twice as long as those of the other, who can fail to recognise in this faculty an element of superiority that would, in the event of war, find ever-recurring opportunities of exhibiting itself?

Imagine two ironclads of the largest size and armament, costing say £300,000 each, and having stowage in their coal bunkers for 800 tons of coal, and that this quantity amounts, in the case of one, to eight days' consumption, and in that of the other to sixteen, who can fail to recognise in the latter, such a much greater capacity for doing duty as a ship of war, that almost any sum would be well expended on the former, to obtain the same economy of fuel? Were it requisite to construct her furnace bars and doors of silver to effect this object, the price should be cheerfully paid. Unfortunately, it must be confessed that our own Navy is sadly behindhand in this element of efficiency.

The comparison I have made of two sister ships, one of which burns only half as many coals as the other, is, I believe, by no means an exaggerated picture of the diminished consumption of coal per horse-power in steam vessels, which has actually taken place since my attention was first directed to this subject twenty years ago. At that period I pointed out that the consumption of coal in marine engines was excessive, and capable of being reduced one-half; but my statements on that head proved unpalatable, and found little credence amongst the engineering authorities of the day. I have lived, however, to see them verified, and also to come to the conclusion that they were so much within the mark as to be capable of being repeated, or in other words, that our consumption of coal per horse-power in marine engines may again be halved.

As long ago as 1854, at almost my first interview with Sir Baldwin Walker, who was then Comptroller of the Navy, I stated that Her Majesty's ships were burning twice the weight of coal per h.p. that would be used in a not very distant future, that all the knowledge was in existence to enable this saving to be effected, and that it ought to be applied at once. I have since had the satisfaction of sending Sir Baldwin an extract from the Naval Correspondent of the *Times*, showing that the economy predicted, had been more than attained, and I was able to append a reference, with the motto, *Litæra scripta manet*, showing that the result had been effected by the precise channel pointed out by me in my treatise on Economy of Fuel, published in 1853. In 1855, after my return from the Baltic, I was so impressed with the waste of fuel and the inordinate heat of the stoke-holes I witnessed in the fleet—the candles being melted in the Officers' cabins

in the gunboats—that I addressed a letter to the Admiralty offering to reduce the average consumption of fuel one-half, and the temperature in the stoke-holes 20° , but the offer was so distasteful to the Engineering Department, that they did not even vouchsafe a reply.

In 1857 I also offered, for the third time, to save 50 per cent. in the fuel expended per horse-power obtained, saying, “I state with confidence that this amount of saving may be effected by the channels I have indicated. In short, the question really at issue is whether a waste of 50 per cent. of fuel is to be persisted in, for the sake of the personal interests and feelings bound up with the present arrangements.”

In January, 1859, I submitted a memorandum to the Admiralty, from which I subjoin the following extract:—“For five years past I have been labouring, in season and out of season, to inculcate the importance—nay, the absolute necessity—of allowing a proper *flame-space* (large enough for the most bituminous fuel likely to be used) between the grate bars and the tubes, if anything approaching perfect combustion with its concomitant absence of smoke is to be attained. In tubular boilers as they have been, and I fear I must say still are, commonly constructed, the flame arising from the last foot or two feet of bars, is extinguished by entering the tubes before its development is complete, producing smoke instead of heat. The necessity of preserving the products of combustion from contact with metallic surfaces till after inflammation is complete, to obtain perfect combustion appears to me most obvious, yet it has been all but entirely overlooked in the construction of boilers up to the present time—the existing boilers in the Navy to wit.”

The researches of the celebrated French chemist Regnault, have given us a far more accurate knowledge of the laws governing the amount of heat in steam of different elasticities and temperatures, than was possessed in the time of Watt, so much so, that within very narrow limits of error, we may now be said to possess the necessary data for treating exhaustively the question of the steam power practically attainable by the combustion of a given weight of fuel.

The question of the economic production of steam-power naturally resolves itself into two perfectly distinct branches, viz., first, how to evaporate the greatest weight of water with a given weight of combustible, hinging on the structural arrangements and management of the furnace and boiler; and secondly, how to obtain the maximum mechanical effect from the steam raised, dependent upon the construction and management of the engine. The first branch being chiefly concerned with chemistry and physics, the second with physics and mechanics.

To evaporate the greatest weight of water from the fuel employed involves two considerations:—First, the generating from that fuel the utmost amount of heat it is capable of rendering, to be accomplished by effecting perfect combustion in the furnace. Secondly, the transference of the largest practicable proportion of this heat to the water in the boiler, to be attained by the judicious arrangement of its heating surface. The first, a question beset with complication; the second, one of comparative simplicity.

Coal is so much more extensively used than any other combustible for the production of steam power, that in so condensed an exposition of the subject as the present must necessarily be, it will be most profitable to restrict our remarks to its use.

At the outset of our enquiry we are confronted with the question, What proportion of the whole heat coal is capable of yielding, do we succeed in utilising in raising steam, or, in other words, transferring to the water in the boiler?

After carefully investigating the subject, the conclusion at which I have arrived is, that we cannot assign to carbon a smaller heating power than 9000° centigrade, which is equivalent to the capacity for evaporating fifteen times its own weight of water from 100° Fahrenheit. The average duty obtained in marine boilers at present must, I apprehend, be set down at not more than $7\frac{1}{2}$ lbs. of water evaporated by 1 lb. of coal, or, in other words, we only obtain half the duty which theory assigns to the fuel. Let us console ourselves for so humiliating a result by the reflection, that this very large margin for waste is as encouraging to our future prospects as it is discreditable to our present practice.

The heat obtained from coal is evolved by the chemical union of the hydrogen and carbon of the coal with the oxygen of the atmosphere, forming with the former substance, water, and with the latter, carbonic acid, and just in proportion to the exactitude with which we transform all the hydrogen of the combustible into water, and all its carbon into carbonic acid, without *admitting any superfluous air*, will be the temperature produced, and (other conditions being equal) the amount of water evaporated.

Different coals vary in their component parts, and in the proportion of these to each other. Carbon and hydrogen, however, are the essential constituents of all as far as their heating capacities are concerned, and I shall assume as a convenient standard that 100 parts of coal consist of 80 parts of carbon and 5 of hydrogen, leaving out of view the other elementary substances which enter into their composition (consisting of oxygen, nitrogen, sulphur, and incombustible ashes, composed principally of sand and clay), as non-essential to the subject under discussion. There is a convenience in assuming these proportions of 80 carbon and 5 hydrogen for the composition of coal, for since hydrogen furnishes, weight for weight, four times as much heat as carbon, the 5 parts of hydrogen will furnish 20 per cent. of the whole heat, and the 80 parts of carbon 80 per cent., being the same proportionate part of the heat as it forms by weight of the fuel, and thus the heating power of coal, as a whole, may be treated as equivalent to an equal weight of carbon.

The hydrogen in coal exists in chemical combination with carbon, and when heated without the access of air, passes off with the carbon, with which it is combined in the gaseous form as carburetted hydrogen, a gas consisting of 1 part by weight of hydrogen and 3 of carbon, being in fact the coal gas we use for illuminating purposes. 100 lbs., therefore, of coal containing 5 parts of hydrogen and 80 parts of carbon in the 100 lbs. would yield 20 lbs., or 525 cubic feet of this gas, and 65 lbs. of solid carbon, or coke.

As the 5 parts of hydrogen in coal gas furnish 20 parts of the total heat of the coal, and the 15 parts of carbon 15 parts, the two combined contain 35 per cent. of the total heating power of the combustible. But here I must not omit to draw your attention to the important fact that if, through the defective regulation of the air supply of the furnace, you cause half this gas to pass off up the chimney unburnt, the heat wasted is more than $17\frac{1}{2}$ per cent., because the gas has robbed the furnace of the heat employed in its own volatilisation or transformation from the solid into the gaseous form. $7\frac{1}{2}$ per cent. is by no means an over-estimate of the heat subtracted from the duty of the carbon by this process, and hence we arrive at the result that, in the case of a furnace so managed as to dissipate half the carburetted hydrogen unburnt, the waste of fuel through this channel alone reaches 25 per cent. That this amount of waste does in practice often take place from this cause is unquestionable, since I have in numerous instances witnessed this percentage of saving effected by simply altering the conditions governing the air-supply of the furnace during the first five minutes after coaling, the period at which, under the ordinary system of furnace management, or rather mismanagement, this great waste of unconsumed gas takes place. In short, I have rarely seen an instance where experiment did not prove that, with bituminous or north country coal, a saving of not less than two-thirds of this amount, or from 17 to 18 per cent. was obtainable by these means, so that I feel justified in saying that in furnaces as constructed and fired at present, *i.e.*, with no provision for adapting the air supply to the changing conditions and consequent varying requirements of the fuel, this waste of a large proportion of the gaseous constituents of the coal must be regarded as the normal state of things, and inseparable from the rude, defective, and unintelligent system of furnace-management pursued.

Although, as a general rule, the combustion of the carbon of the fuel is effected without the large proportion of waste attendant upon that of its gaseous constituents, yet occasionally—in such a case, for instance, as one of which we have recently heard, where, in the Southern Pacific, the flames proceeding from the top of the funnel of one of Her Majesty's ships at night were actually mistaken for an eruption from a volcano in one of the peaks of the Andes—a great waste of carbon occurs. Such a state of things as this, however, can only exist with most defective furnace arrangements, involving a really frightful sacrifice of fuel.

I will endeavour to describe the conditions under which alone I consider such an occurrence as described to be possible. The flame emitted does not extend from the furnace through the flues to the funnel head, as many suppose, but is produced by carbonic oxide gas (generated in the furnace through deficiency of the air supply), passing off at such a high temperature as to preserve the temperature necessary for ignition, after mixing with the $2\frac{1}{2}$ volumes of atmospheric air required to furnish the oxygen needful for its transformation into carbonic acid. Now, since an atom of carbon, in combining with one atom of oxygen, and becoming carbonic oxide, only yields one-third of its heating power, the remaining two-thirds being set free upon its combining with the second equivalent of oxygen, and becoming carbonic

acid, it follows that two-thirds of the heating power of all the carbon passing off as carbonic oxide is wasted.

Even this statement does not adequately represent the frightful sacrifice of heating power, of which flames passing off at the funnel head are the sign; for small as may be the proportion of the heating power of the fuel developed in the furnace, of this small proportion, an unusually large part is wastefully dissipated into the atmosphere, as is shown by the high temperature of the gases issuing from the funnel, such high temperature being the result of the diminished subtraction of their heat by the surface of the tubes, consequent upon the latter being coated with soot. Unless there be something more than ordinarily faulty, either in the construction of the furnace, or the mode of firing pursued, the coating of the tubes with soot may be regarded as the necessary precedent to the exhibition of flame at the funnel-head, as in fact begetting the conditions under which it occurs. A deposition of soot on the interior of the tubes, simultaneously diminishes the draft, and in a still greater ratio the steam generated. Heavier firing is resorted to to keep up steam, with the effect of aggravating the previously existing evils. Flame makes its appearance at the top of the funnel, and a vicious circle of evil consequences is produced which mutually re-act upon and aggravate each other.

The waste of a large proportion of the coal gas or carburetted hydrogen contained in the fuel, during say the first third, or first five minutes of the coaling interval, which ordinarily takes place under the present system of furnace management, by no means pre-supposes such conditions in the arrangements and working of the furnace, as would subsequently lead to the dissipation of carbon as carbonic oxide. The fatal sign of flame at the funnel head, however,—announcing as it does a thick layer of ignited carbon on the bars, and an insufficient air-supply,—may be accepted as indicative of conditions being present in the furnace, which must have been productive of a more than average waste of carburetted hydrogen at an earlier period.

Great as are the evils which we have been reviewing, proceeding from a deficient air supply, they are rivalled, and, perhaps, having regard to its greater frequency (during the latter portion of the coaling interval), exceeded in amount as a whole, by the opposite fault of too much air entering the furnace. The excess of air acts prejudicially, not by interfering with the perfect combustion of the carbon, none of which under these altered conditions can escape transformation into carbonic acid, but by diluting the temperature of the furnace by the admixture of cold air, which, after receiving a large accession of temperature, passes off through the funnel, robbing the furnace of heat that should have been employed in raising steam. All good firemen are awake to the evil consequences of allowing their fire to burn through at the back, admitting a free ingress of air, or the still more fatal results of perforations in the door or bridge. Let us analyse the conditions under which these evil consequences ensue, and the causes on which they depend:—

One hundred pounds of coal require, in order to obtain the equivalent of oxygen necessary for its perfect combustion (or the transformation of all its hydrogen into water and all its carbon into carbonic acid)

15,000 cubic feet of air, and the temperature resulting may, to speak in round numbers, be set down at $4,200^{\circ}$. No such exact adjustment of the air-supply is possible in working a furnace, and there are reasons why, in practice, a better result is obtained by admitting an increased quantity, say $\frac{1}{3}$ rd more than the amount required to furnish the exact combining equivalent of oxygen. Assuming, therefore, the admission of $\frac{1}{3}$ rd more, or 20,000 cubic feet, we get a temperature of 3150° , of which, taking the temperature of the gases when they leave the heating surface of the boiler and enter the funnel at 600° , 81 per cent. is absorbed by the heating surface of the boiler, and profitably employed. If instead of 20,000 feet twice the quantity, or 40,000 feet, enter the furnace, we only get a temperature of 1575° ; and supposing the temperature of the gases entering the stack to be the same, viz. 600° , we only get 62 per cent. absorbed by the heating surface and performing the duty of raising steam. In reality, however, since twice the volume of gas traverses the flues in the same time, it must pass over the heating surface at twice the velocity. The area of the heating surface therefore becomes halved in proportion to the quantity of gas passing, and, as a consequence, the products of combustion will pass off at a higher temperature, so that in reality less than 62 per cent. will be absorbed.

Thus, paradoxical as at first sight it may appear, when a diminished temperature of the products of combustion is caused by their volume being increased by an excess of cold air entering the furnace, the lower their temperature in the furnace, the higher will be the temperature at which they will pass off through the funnel, still further magnifying the waste of fuel invariably attendant upon the existence of conditions which diminish the temperature by facilitating the entrance of superfluous air.

Our inquiries have landed us at the conclusion, that the more narrowly the conditions attendant upon the working of a furnace are investigated, and the more closely the duty performed is compared with these conditions, the more manifest does it become that the first of the two branches or divisions into which the question of the economic production of steam power naturally resolves itself, viz., "How to evaporate the greatest weight of water with a given weight of combustible?" is for all practical purposes almost synonymous with the question, "How to admit the right quantity of air to the furnace?" A competent heating surface must, as a matter of course, be provided; but it is not in respect to the absorption of heat, but in respect to its generation, that our present practice is so sadly in arrear, and that such a vast scope for improvement is visible.

How are we to realise in practice this all-important and indispensable condition to economic furnace management, the due adjustment of the air-supply, that is, the supply of such a quantity as a *whole*, and so distributed as to *period*, as to convert all the hydrogen of the fuel into water, and all the carbon into carbonic acid, with the admixture of the smallest possible quantity of surplus air? However difficult the task may be, it is nevertheless most certain that by how much we deviate from the correct quantity, either more or less, by so much do we fall short of "generating from the combustible, the utmost amount of heat it is capable of furnishing," for the

laws of chemical affinity are unchangeable and ubiquitous. In short, this danger of erring on either side, may be said to be the Scylla and Charybdis to which voyagers in search of perfection in furnace management are exposed, and safety is only to be attained by studying the landmarks and bearings so carefully as to be able to steer with confidence a middle course.

The supply of air which enters a furnace depends upon the ratio existing between the *pull* exerted by its chimney or stack and the *obstruction* caused by the layer of fuel on the grate-bars, and a more or less confined ashpit. The force of the pull, or suction, exerted by the stack, is the difference in weight between the column of heated gas it contains and a similar column of air at the temperature of the atmosphere. The higher the temperature and the taller the stack, the greater the force of the draft, and *vice versa*. The great practical difficulty which stands in the way of obtaining the regular flow of the right quantity of air into the furnace, is the fact that the demand is not a *constant*, but a *varying*, quantity. Were the same conditions always present in the interior of the furnace, that is to say, the same thickness of fuel on the grate bars, and the various layers of this fuel at similar stages of combustion, so as to cause the supply of air demanded by the wants of the fuel to be uniform, then, the average rarefaction or draft in the stack being once attained, a steady supply would enter the furnace, proportionate to the thickness and closeness of the layer of fuel, the area of the grate-bar openings, and the free ingress of air to the ashpit, which, once adjusted, the equable and economic working of the furnace would be secured. Unfortunately however, for the cause of economy of fuel, the reverse is the case; not only are the requirements of the furnace not uniform, but they fluctuate within very wide limits, whilst the evil results in waste of fuel which ensue, are aggravated by the fact that the furnace's unassisted power of supplying itself, *varies in an inverse ratio* to its requirements, being least when these are greatest.

Assume a coaling interval of 15 minutes, and that towards its end the carburetted hydrogen having passed off, a layer of ignited carbon alone is left on the bars through which the current of air has gradually worn for itself a series of channels or perforations, till their united area is more than sufficient to admit the right quantity of air under the existing amount of draft. Let us then examine the condition of the same furnace a few minutes later, after the act of coaling has taken place, and we shall find a thicker layer of fuel on the bars, the channels for the passage of air which previously existed in the thinner layer, obliterated, and the temperature of the furnace greatly lowered by the abstraction of heat consequent upon the introduction of the charge of cold fuel, and the volatilization of its gas going forward. Thus the diminished temperature in the stack diminishes the draft at the period when the resistance offered by the fuel to the passage of air is greatest, and the demands of the furnace for air is at its highest point, in consequence of the large quantity of oxygen required for the ignition of the carburetted hydrogen gas now in course of rapid evolution. As the necessary sequel to these conditions, the gas generated passes

off unburnt, worse than simply wasted, because it has abstracted a portion of heat from the ignited carbon in undergoing transformation into the gaseous form. We here get an explanation of the fact that more heat is practically obtained in some kinds of furnaces from coke, or, in other words, coal deprived of $\frac{1}{3}$ rd part by weight of that portion of its combustible matter which is richest in heating material, than from coal in its pure state. From the same cause also, viz., defective furnace management, the commercial value of coal is often in an inverse ratio to the quantity of its bituminous constituents and heat-giving power, were proper means employed to make them practically available.

In short, under the present system of furnace management, the function of the furnace as an agent for raising steam may be said to be almost entirely suspended after each coaling interval, and only gradually regained, the furnace virtually assuming the office of a retort for the manufacture of gas, but with this difference in the result, that the gas which in the latter case is carefully preserved as a valuable commodity, is here despatched unconsumed up the chimney, carrying off at the same time the heat stolen from the carbon in effecting its volatilization.

Can a doubt be entertained of the wisdom and desirability of burning this gas instead of wasting it—of filling the furnace with flame instead of smoke—of causing the generation of steam to proceed with additional rapidity immediately after coaling, instead of being all but suspended?

Now all that is required to evoke this transformation is to supply the gas with ten times its own measure of atmospheric air, and (except in a few exceptional cases of badly constructed furnaces) it will require no further solicitation to burst into flame. Why is this not universally done? A curious chapter of human error is unfolded by the answer. When apertures of the necessary size to admit the requisite supply of air were arranged to open into the furnace above the fuel, notwithstanding the smoke and gases were converted into flame, it was found that the production of steam was diminished from 25 to 30 per cent., and only when there was sufficiently ample boiler power to allow of heavier firing, and burning from 25 to 30 per cent. more coal, could the previous supply of steam be obtained. The most extensive experience, and the most exact experiments, alike concur in establishing the accuracy of these figures.

The analysis we have made of the varying conditions of the furnace at different periods of the coaling interval, and of the sequence of chemical changes of which these varying conditions are productive, not only enables us to explain how, and why, this great diminution in the generation of steam occurs, but places us on a vantage ground of knowledge from which the necessity of such a result is foreseen. So dark, however, has been the pall of ignorance that has rested on the subject, in such mystery have the chemical operations of our furnaces been shrouded, that for half a century each year has seen the advent of some new scheme, identical with its predecessors in the folly of allowing a constant supply of air to enter the furnace above the fuel, but vainly pretending to elude the evil consequences inseparable from such a practice, by trivial alterations in non-essential details. Strange to say, the persistence of these evil results, after the *shape* of the orifices

for the admission of air had been changed from round to square, and from square to oblong; the *material* from firebrick to cast-iron, and from cast-iron to wrought; the *position* from the door to the bridge, and from the bridge to the flues; instead of opening the eyes of the experimenters to the common ground of failure inherent in all their attempts, caused them to adopt as an indisputable maxim the dogma "that smoke can only be burnt at the cost of fuel," a doctrine most correctly describing the result of the faulty expedients they resorted to for obtaining this object, but widely the reverse of truth when enunciated as a general law.

When a continuous stream of air is allowed to pass into the furnace above the fuel, about six times the required quantity of air enters and mingles with the products of combustion, and the great resulting waste of fuel, amounting to from 25 to 30 per cent., will be seen to be a necessary consequence, by all who have followed the exposition I have given of the great reduction in temperature inseparably attendant upon the entrance of a large surplus body of air into the furnace.

The fact is, the policy of admitting air above the fire, is governed by the very simple law that no more should be admitted than is required to furnish the quota of oxygen necessary for the perfect oxydation of the gases rising from the fuel at the moment. The quantity required is greatest after coaling, gradually diminishes in amount throughout the space of about five or six minutes, and then ceases altogether, the increasing draft in the stack having become sufficient to supply through the grate bars the diminished and diminishing wants of the fuel.

To secure the entrance of the required amount of air and no more, to ensure that this supply shall vary in quantity *pari passu* with the wants of the fuel, that is to say be greatest after coaling, gradually diminish in amount throughout a space of about five or six minutes, and then cease altogether, it is indispensable that the regulation of the feed of air be placed under the control of automatic mechanism, which not only far surpasses in regularity as to time, and equability as to motion, the limits attainable by the utmost watchfulness of man, but is free from the liability to the omissions from negligence, inseparable from human superintendence, especially where, as in the present instance, that superintendence would be of an exceptionally monotonous and wearisome character, and carried on in an atmosphere most oppressive and exhausting.

The front of every furnace should be supplied with air passages of an area equal to the admission of the largest required amount of air, and opening into the furnace by small perforations or grating for finely dividing and heating the air, but communicating exteriorly with one common mouth fitted with a valve closing automatically in any desired period of time. This valve is to be thrown wide open upon closing the door after coaling, when it immediately begins to close gradually, supplying the furnace with the great desideratum, a gradually diminishing feed of air throughout the five or six minutes' interval for which it is adjusted.

To illustrate my views on the subject in a practical form, I have placed before you on the table an apparatus which I consider fulfils the required conditions. Without admitting any superfluous air it converts

into flame the carburetted hydrogen rapidly evolved after coaling (and wasted under the present unintelligent system of furnace management, apparently as a matter of course). The economy resulting is from 8 to 10 per cent. with best Welsh, and from 16 to 24 per cent. with bituminous coal, and since the apparatus presents no objectionable feature to counterbalance these advantages, but on the contrary increases the steam supply, diminishes the temperature of the stoke-hole, prevents smoke, and increases the durability of the sails, I venture to predict that, when the incredulity of ignorance as to possible saving of fuel, which now flourishes, becomes replaced by an intelligent insight into furnace operations, its use will become universal, and it will be regarded as being as indispensable an adjunct to the furnace, as the governor now is to the engine.

PRIDEAUX'S FUEL ECONOMISER, OR AUTOMATIC APPARATUS FOR
REGULATING THE AIR-SUPPLY OF FURNACES.

Front View.

Back View, opening on interior of Furnace.

DIFFERENT SYSTEMS OF FURNACE MANAGEMENT COMPARED.

Systems.	Results.	Coal burnt.	
		Bituminous.	Welsh.
<i>Old, and still prevailing.</i> No air admitted above fire.	SMOKE. Hot furnace door.	100	90
<i>Annually tried under a new alias for fifty years past, but always abandoned.</i> Constant admission of air above fire.	NO SMOKE. Diminished steam supply.	130	110
<i>Plan of the future.</i> Air admitted and cut off by Automatic Air Regulator.	NO SMOKE. Increased steam supply. Cold furnace door.	80	80

To discard the use of self-acting mechanism for closing the apertures for the admission of air, and elect to effect this object by hand in preference, is a step as retrograde as going back in the construction of the steam-engine to the era of Humphrey Potter, and stationing a boy to open and shut the valve between the cylinder and the condenser. Adequately to appreciate the obtuseness and stolidity involved in the adoption of this oft-tried and abandoned system of shutting by hand, when self-acting mechanism invented specially for the purpose is in existence, so perfect in its action as to leave nothing to be desired, we have only to consider that, even supposing a man were detailed for the purpose, whose sole duty would be to stand with a watch in his hand to shut off the air supply at the right moment, twice the proper quantity of air would enter the furnace; whilst how hopeless of attainment is even an approximation to such a result, except in an experiment, all having any practical knowledge of stokers, stoking, and stoke-holes, can decide for themselves.

I will now draw your attention for a few moments to a subject by no means inoperative in relation to consumption of fuel, I allude to the temperature of the stoke-hole. However perfect we may make our furnace arrangements, we cannot withdraw ourselves from a certain amount of dependence upon the intelligence and attentiveness of our firemen. And very sure I am that the less exhausting we render their occupation, and the more comfortable we make the place in which they perform their duties, the greater will be the amount of attention the furnaces will be likely to receive. Indeed I think it would be to be regretted were it otherwise, so very little regard, according to my experience, does the humanitarian side of the question command. There cannot be two opinions but that far greater strain is made on the

physical energies of a fireman by working in a temperature of 120° than would be occasioned by performing the same duties in an atmosphere of 100° . In fact, the depression of the vital powers that ensues in tropical climates, where the heat of the stoke-hole often mounts up to 135° , is a fertile source of disease, and loss of life. Now experience authorises my saying that there is hardly a ship in Her Majesty's Navy in which the temperature of the stoke-hole might not easily be reduced from 20° to 30° .

The same apparatus which regulates the air-feed forms a most efficient agent for preventing the radiation of heat into the stoke-hole, from the fire door and front of the furnace, never becoming so hot but that you can place the back of your hand against it. As to the other great source of heat, the smoke-box doors, they should be fitted with what I have designated "non-conducting shields." These are made of tin, are light, easily applied, and productive of no inconvenience of any kind, and, at the same time, are so effective in resisting the passage of heat, that, in conjunction with the air-feeding apparatus, they cause the stoke-hole to be on the average at least 24° cooler.

As an advocate of the comfort of the fireman, I am glad to be able to adduce in support of my own opinion that of Staff Commander Balliston, of the "Elfin," who, in his official report, says, "I cannot speak too highly of the smoke-box doors supplied for trial. They are simple, and easily applied to all steam vessels, neither do I consider them the least in the way, as they are fastened on to the present doors, and can be taken down or put up at pleasure.

"I consider their merits are even better than the enclosed report of the temperatures taken with the doors on now, and the corresponding account of the temperature taken last year when they were not supplied. My reason for saying so is, that, from the confined space of the stoke-hole, the thermometer is obliged to be placed in a corner out of the way of the stokers, where the heat must necessarily accumulate. The patent doors are so cool that you may place your hand upon them without feeling the least warmth; the same may also be said of the front of the patent fire-door.

"The thermometer, when placed on the patent smoke-door, showed 92° ; and when the door was taken down, and it was hung on the flue-door, it immediately went up to 116° , thereby showing a difference in the temperature of 24° , and that in a place where the stokers have to work."

My attention was first called to the great heat firemen are often subjected to in stoke-holes in the following manner:—My first experiment was made by permission of the Admiralty, at my own expense, in Portsmouth Dockyard. A thermometer with its bulb in contact with the face of my fire-door never marked more than 64° , whilst the adjoining door of the same marine boiler was sometimes red with heat. The contrast seemed to strike the Naval Officers who witnessed it as something marvellous. The first lieutenant of a steamer just returned from the West Indies observed to me, "Mr. Prideaux, your apparatus will lead to a considerable saving of fuel. I don't mean by producing more perfect combustion, which it *may* or *may not* do, for I have not

"tried it; but it will save fuel by enabling the men to tend the fires with more comfort. My experience is, that a high temperature in the furnace-room always tells its tale in the consumption of fuel; for whatever people may think, careful stoking does not take place in an atmosphere of 140° , and it is not in human nature that it should."

He also informed me that when commanding the "Bull Dog" in the Channel the summer before, he had had several instances of stokers fainting, and being obliged to be hoisted up on deck by tackle, to be revived by the fresh air. The thermometer in the stoke-hole indicated 140° , and the firemen could not handle their implements without binding cloths round the handles. It seemed to me monstrous that men should be tortured in this way if it could be prevented, and so I devised these non-conducting shields; and it should not be overlooked that, in addition to keeping down the heat of the stoke-hole, they prevent a waste of draft power. I determined from the first never to make an article of profit of them, and I have always offered to supply owners of steam vessels with them at cost price.

In treating of so important a question as the economic production of steam power within limits so inadequate to do justice to so extensive a subject, that some departments must necessarily be left comparatively in shadow, I have felt I should best consult your wishes to acquire, and mine to impart, useful information, by endeavouring to emphasize those points at present least understood and most neglected. In endeavouring to fulfil this intention, I find I have already occupied so much of your time on the right management of the furnace, that it will be impossible for me to advert in more than general terms to the structural details of the boiler and the engine. It must suffice to say, that in the past, attention has in the former, been directed too exclusively to the amount of grate, bar, and heating surface, to the comparative neglect of securing the due circulation of the water, and an adequate amount of what I have designated *flame space*, that is, a sufficient distance between the end of the bars, and the beginning of the tubes, to admit of the completion of the formation of flame before the products of combustion enter the latter.

If you take a piece of wire gauze, and insert it across the middle of the flame from a gas burner, or candle, you will find that the portion of the flame above the gauze becomes immediately extinguished. We have flame *below* the gauze but smoke *above*. The inflammable mixture of air and gas, which would otherwise form the upper portion of the flame, is cooled down by contact with the wire net work below the point of ignition. What the wire gauze does in the experiment with the flame of a gaslight, viz., prevent combustion by cooling the mixture of air and gas below the point of ignition, the surface of the boiler tubes (kept comparatively cool by contact with water) effect with the gases rising from the furnace, and hence waste of fuel takes place as a matter of necessity, where the distance from the end of the furnace bars to the beginning of the tubes, is not sufficient to admit of the completion of the development of the flame; the gases which otherwise would have formed flame, passing off as smoke, or being deposited as soot.

Fig. 1.
Scale $\frac{1}{8}$ " to foot.

A few days ago, sorting over some papers, I came on a tracing (Fig. 1) endorsed "order declined," which forcibly illustrates how little the necessity for a flame-space has been understood up to a comparatively recent period. It was sent to me by a firm on the Thames as a guide for making a set of my furnace doors for a steamer in process of building. I wrote back suggesting that 6 inches should be taken off the bars, and 6 inches added to the flue, and the crown of the furnace raised at the back, and stated that, notwithstanding the tubes would be shortened 6 inches, I would guarantee the furnace should make more steam, and burn a very much smaller quantity of coal. I was told in reply that they had been obliged to make the most of the limited space at their disposal, and requested to proceed with making the doors. This, however, I declined to do, assigning as a reason that the proportions of the boiler were so radically bad, that nothing but disappointment and discredit to all concerned could attend on its construction as designed.

Now in this case the prevalent faults in boiler construction are carried to such an extreme of badness that I doubt if any of you ever saw such a boiler at work, for it would fail so utterly in generating steam that I imagine, after a short trial, it would be thrown aside as worthless. You will observe there is absolutely no provision for a flame-space, and, as a necessary consequence, the heated gas coming at once in contact with the cold tubes, is cooled down below the point of ignition, and instead of forming flame to raise steam, produces soot to coat the tubes. The prevention of smoke in such a furnace is a physical impossibility and the waste of fuel enormous.

Fig. 2.

Fig. 2 is a sketch of the furnaces of H.M.S. "Princess Royal." This is a great advance upon the preceding, for this is a workable furnace. Nevertheless the prevalent faults above alluded to, are only diminished, not removed. The bars are too long, and the flame-space much too short and narrow, to obtain the best results even with Welsh coal, whilst were bituminous coal used, smoke, with its attendant great waste of fuel, would ensue, especially when steaming at full speed. Since a boiler with a flame-space of sufficient dimensions to allow of the inflammation of all the gas from bituminous coal, is perfectly well adapted to burn

Welsh coal, I think it is obvious that all the boilers for the Navy should be so constructed. In this case, even when supplied with all

Fig. 2.
1" to foot.

bituminous coal, which must occasionally happen in time of war, smoke could always be prevented. I hardly know a subject on which so great and wide-spread a misapprehension exists, as that entertained with regard to furnaces making smoke. If the flame-space of a furnace be not sufficiently roomy to admit of the full development of the flame, the prevention of smoke is a physical impossibility, but if the flame-space be sufficient, nothing can be easier. A few holes in the door or bridge, or the furnace-door left ajar, are sufficient to prevent smoke. But such, or any mode of preventing smoke by the admission of a continuous supply of air above the fire, necessitates 30 per cent. more coal being burnt to obtain the same supply of steam. This it is which has imparted to the nuisance its vitality, and not the existence of any difficulty in the attainment of the object itself.

Fig. 3.

Fig. 3 embodies my views of what the proportions of the existing type of a naval boiler should be. You will observe it affords ample space for the full development of the flame of the most bituminous coal before the products of combustion reach the tubes, and it might be fed entirely with bituminous coal without an atom of smoke being visible, whilst it would give better results in regard to economy than any naval boiler of the kind it has been my lot to meet with. It possesses a novelty in a bridge (a) of firebrick which spans the flue,

with its under side level with the crown of the furnace. By preventing the current of heated gases taking so short a curve as would otherwise be the case, it materially contributes to their more equable diffusion through the tubes, remedying the fault at present complained

Fig. 3.
 $\frac{1}{4}$ " to foot.

of, that the major portion passes through the lower tubes, leaving but little to find its way through the higher, which is in reality tantamount to a diminution of the heating surface.*

Before quitting the first branch of our enquiry, viz., "How to evaporate the greatest weight of water with a given weight of fuel hanging on the structural arrangements and management of the furnace and boiler," I am desirous of bringing prominently under your notice the fact, that since the office of the boiler (including the furnace) begins and ends with the evaporation of water, the proper way to test the work it performs, is *to measure the quantity of water it evaporates*, by fitting every boiler with a water meter, instead of estimating its duty in the very vague and unsatisfactory mode in use at present, viz., by the performance of the ship it serves to propel, thus subjecting the

* In 1857 I made an offer to the Admiralty to improve the furnaces of H.M.S. "Impérieuse," saying I could do so very inexpensively, whilst they could be restored to their previous form if thought desirable; that this would not likely be the case, as the alterations I should make would not be *experiments*, but founded on a knowledge of the subject, acquired by having for seven years past made the specialities of furnaces almost exclusively the object of my study, in addition to which, during the last two years I had had the experience of adopting my automatic furnace-door to 600 furnaces of the most varied character, adding, "whenever an opportunity is afforded me, I shall be happy to give the country the benefit of my long study and experience on this subject; and I unhesitatingly affirm, that boilers may be constructed greatly in advance of those at present used in the Navy."—T. S. P.

results to all the uncertainty inseparable from a variety of contingences such as defects in packing of pistons, in valves, in bearings, in condenser, or other portions of the engine, and the vicissitudes of winds, tides, currents, and sea, and the state of the ship's bottom, propeller, &c., &c., the effects being to import such an amount of uncertainty into the results, that the formation of positive conclusions and comparisons is rendered impossible.

In carrying out scientific experiments, the first thing considered is, how best to eliminate sources of error by securing as far as possible the existence of similar conditions during each experiment of a series, for thus only can reliable results be obtained. In their experiments on "Baxter's mixture," the Admiralty had put to sea in search of variable conditions, and after being at work in the "Lucifer" and "Urgent" for three years, had apparently failed to arrive at any useful or decisive conclusion. In fact, I do not suppose they have added one grain of positive knowledge to our previous stock. Now had they put to me in a definite form the question they wanted solved, I would have undertaken to have given them an answer in three weeks instead of three years, and one which no subsequent amount of experimenting would ever have invalidated. The probability, however, is, that I could have given them an answer without experimenting at all. As Naval Officers, what would you think of sending a gun to sea to test the accuracy of a new mode of rifling, and determine the target figure? Now to a chemist, testing the value of a fuel by the locomotive performance of a ship, which means measuring the results at the tail-end of a set of variable conditions, was equally absurd. It was lamentable to see such a want of intelligence exhibited in the conduct of public affairs, for it not only caused a great waste of money, but discredited the nation in the eyes of foreign states.

The first step to progress, or rather an indispensable preliminary to taking the first step, is an accurate knowledge of our existing position, and it always has been my opinion that what I cannot but regard as the present highly unsatisfactory amount of coal burnt, to power obtained, is greatly to be attributed to our habitually neglecting to determine by exact measurement, the actual work performed by the fuel in water evaporated. Many years ago I took considerable trouble to induce the Admiralty to fit the boilers of all Her Majesty's ships with "water-meters," and keep a record of the duty performed in weight of water evaporated, for coal expended, believing the adoption of such a system could not fail to be ultimately productive of a greatly increased economy of fuel, but my efforts were not successful.

In reviewing the present state of the question of economy of fuel as a whole, I confess the point which presents itself most forcibly to my mind, both from the waste it entails, and the degree in which its existence is overlooked, is the circumstance that in the management of our furnaces we make no provision for the widely different conditions as to air supply, which ought to prevail, as more or less time has elapsed after coaling, involving the more or less rapid evolution of gas, or coke alone remaining to undergo combustion.

The SECOND BRANCH of our subject, "How to obtain the maximum

mechanical effect from a given quantity of steam," dependent upon the construction and management of the engine, is, no doubt, a far more attractive subject for enquiry than furnace-management, and one which commands a far greater amount of attention, and on some future occasion I may perhaps have the pleasure of presenting you with some analysis of its details. For the present I must content myself with saying in general terms that a very general agreement now exists as to the channel through which increased economy is to be sought, viz., by increasing the extent to which the steam is used expansively, through employing steam of higher pressure, and applying heat to the surface of the cylinder. A great increase in economy has been effected by travelling on this road, and I cannot doubt but that it may be pursued still further with advantage. In my treatise on "Economy of Fuel," published in February, 1853, I gave an estimate of the theoretic capabilities of a steam-engine working at 90 lbs. pressure, and cutting off at one-sixth, with the exterior of the cylinder preserved at the same temperature as the boiler, observing "the time will come when it will be quite an exceptional case for an engine to be worked at a lower pressure, or at a lower grade of expansion than this, for the simple reason that there is nothing to prevent this degree being generally used, and, therefore, to employ less will be considered as sacrificing economy without an object." At this period the general pressure employed in the Navy was 10 lbs., whilst there was not a single steamer afloat provided with any appliance for applying heat to the cylinder.

Shortly after a consultation was held by desire of the Admiralty, at which it was decided that a considerable increase, I think to 26 lbs., should take place, and I was informed by a gentleman present that my book, which had then just appeared, was quoted in support of the opinion that a much higher pressure might be adopted with perfect safety and great advantage.

From that period to this the pressure has gradually crept up till from 45 to 50, and even 60 lbs. pressure is now not unfrequently used in marine boilers, and I am quite satisfied this progressive advance will continue till the pressure of 90 lbs. is reached, for the simple reason as I then stated, "that there is nothing to prevent this pressure being generally used, and, therefore, to employ less will be looked upon as sacrificing economy without an object."

I do not believe, however, that we shall rest at 90 lbs. Other conditions being equal, the higher the pressure the greater the economy, but as we mount upwards in pressure, certain impediments, certain drawbacks present themselves. Now locomotive engineers being shut out from the advantages of condensation, have had every inducement to increase their pressure till some barrier was encountered which rendered further advance no longer advantageous, and I find they have settled down to working with from 120 lbs. to 140 lbs. on the guage, or, in other words, using steam of from 9 to $10\frac{1}{2}$ atmospheres, and I have no doubt but that in marine engines we shall ultimately come to much the same practice. Could I afford the luxury of a steam yacht, I should certainly arrange to work with steam of 9 atmospheres, and cut off at $\frac{1}{6}$, and by combining with this degree of pressure and expansion in-

creased economy of fuel by the use of my automatic apparatus for regulating the air supply, I should expect to attain an economy of about 1 lb. of coal per indicated horse-power per hour. If I live a few years longer, I believe I shall see this degree of economy realised, and I do not hesitate to give the opinion that when we have arrived at this point, we shall have nearly reached the utmost limits which the nature of the subject renders practically attainable.

Lightness and simplicity of working parts powerfully contribute to economy of fuel, and I think we are justified in expecting to see great advances made in the future in these directions.

Here is a small model of an engine of novel construction which I have recently met with, which appears to me to offer peculiar advantages in many points for marine use, and which, if I am not greatly mistaken, has a future before it. Half the cases of steam ships breaking down arise from either the crank or the connecting-rod breaking. This engine dispenses with both. The speciality which first attracted my attention as marking it as peculiarly adapted for marine use, is its economy of space. It requires only five-eighths the space of the shortest connecting-rod engine, whilst in regard to friction I think it will compare advantageously with the trunk engine.

I am also assured, on testimony on which I can rely, that its average weight and average cost will not exceed five-eighths of that of marine engines of the ordinary form. An engine of the kind, of 20 horse-power, has now been in constant work night and day for two years pumping the water for a paper mill in the vicinity of London without once requiring repair.

Besides lending the model for exhibition this evening, the proprietor has kindly given me permission to invite any gentleman interested in the subject to see the pumping engine at work.

There is one phase of the question of economy of fuel on which I have not touched, viz., that concerned with husbanding the resources of the steam-power at command; on what occasions slow speed should be used, and on what the use of steam-power dispensed with altogether. But these are questions of seamanship on which it would be presumptuous in me to offer you advice, and if not presumptuous, superfluous, since the subject has been most ably handled by a gallant Officer whom I have the pleasure of seeing here to-night, Admiral Ryder, in a book well deserving of being more widely known.

THE CHAIRMAN: Is yours a self-acting apparatus to admit the air?

MR. PRIDEAUX: I daresay the Members of this Institution are aware that I have been at work at this subject for a very long period. This drawing represents the first apparatus that I had for self-closing. This is a water cylinder which is fitted with a vulcanised cap of india-rubber. This piston is the same kind of piston as is used in the hydraulic press. You may move it up rapidly, because the india-rubber side collapses and allows the water to pass. When it is up, the india-rubber expands by the pressure, and it can only pass down as the water below travels through this small aperture (the size of which is regulated by a screw), and comes over the top. The only defect in this apparatus was, that it wanted to be filled with water every day. When it was filled every day the india-rubber piston lasted, on an average, nine months. In fact, it just amounted to this, that when the engineer took an interest in the thing, it was easily kept in working order. In the "Argus," under Captain Grandy, it worked exceedingly well. Sulphur is used in

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Captain HOSEASON: What is the royalty to an engineer?

Mr. PRIDEAUX: That includes royalty and everything,—the entire cost.*

The CHAIRMAN: I think you will all agree with me that this is a most important subject that Mr. Prideaux has lectured upon. I think no engineer or naval man can differ as to the great importance of some apparatus for consuming smoke. The only question, it appears to me, is what is the best plan for accomplishing the object. Mr. Prideaux has explained very clearly, both in his lecture and by his diagrams, that there would be a very great saving in the consumption of fuel according to his plan; and I have not the slightest doubt about it, as long as this apparatus works properly, and the door is kept clear of dust and dirt. The only thing that puzzles me is, that the plan has been before the Admiralty so very long, and they have not adopted it. But that does not at all imply that it is not the right plan. We all know that the Admiralty very often take up plans which, in my opinion, they ought not to take up, and cast aside plans which they ought to take up. According to what I understand, the plan for consuming smoke that they have adopted is the plan of Mr. Murdoch, a naval engineer. It acts upon a different principle from that of Mr. Prideaux; instead of a current of air over the top of the fire, it admits the current of air at the back of the bridge; and it equally consumes the smoke. But this (Mr. Prideaux's) apparatus does not interfere with the size or proportions of the furnace at all. I suppose every engineer when he makes his engine calculates the size of his fireplace, and that everything is most correctly proportioned. If you take his (Mr. Murdoch's) furnace, and cut off one-fifth from the end of it, supposing it is calculated to burn a certain quantity of coal, you diminish his power of producing steam. Therefore, if all the fireplaces in the Navy are to be altered on Mr. Murdoch's plan, and this plan of Mr. Prideaux's would answer equally well, without the necessity of making any alteration in the furnaces, I think it would be preferable to adopt it. I hope some gentleman will give us his opinion on the subject.

Admiral WELLESLEY, C.B.: If I am not trespassing too soon, there is one point with regard to this subject which Mr. Prideaux might explain. It is with reference to these self-acting doors. If I understand rightly, when that door is open the quicksilver is pumped up, or whatever the process may be, and as long as the door is open, nothing takes place. But the moment the door is shut, the valve begins to act, and then five minutes must elapse before it has gone down again. Supposing the engineer to walk along his stokehole, and that he wants to have a look at his fires as he goes along, in order to see that his people are doing their work properly, he throws all his doors open each time, and consequently the moment he opens the fire door the quicksilver is pumped up again, the valve is raised, and the process is all gone through again needlessly. Then, again, it is no novelty admitting the air over the top of the fire-place. It has been done by our engineers for themselves; they have been in the habit of perforating the front door; but the difficulty they had was that the holes were always there. As I understand it, the merit of this plan is that it is a self-acting apparatus. It would be so if you were always to fill your furnace by means of it, and let the fire remain thirteen or fourteen minutes. But that will not do for a naval engineer, who wants to be going along, constantly, looking at his fires and having his doors open. As I understand, every time that door is open, the valve is raised again, and it requires five or six minutes to close the valve. I only want to know whether the engineer can disconnect it in any way.

* With regard to the question of price, I am desirous of observing—

1st. That the dimensions of the air-passages in each furnace-door and front are a matter of calculation, each having to be constructed with reference to the furnace for which the door and front is designed.

2nd. That the workmanship requires to be of the best character, and great solidity, to maintain the apparatus in working order, amidst the dirt and heat of the stoke-hole from one year's end to another, without requiring even cleaning, a desideratum attained for the first time, in the present apparatus.

3rd. That, on an average, the price charged, is repayed by the saving of fuel in three months.

4th. That I have always offered to accept six months' saving of fuel, as payment for the apparatus.

Mr. PRIDEAUX: You need not make the air valve self-opening. It is perfectly easy to make it the duty of the fireman to open the valve after coaling. Then of course it would not open of itself with the opening of the door. But if the engineer opens the door to look at the fire, when he shuts the door he has only got to close the valve down at once. You cannot have it both ways. Holes that are always open admit about six times as large an air supply as this apparatus.

Admiral WELLESLEY: Supposing the engineer should wish to look at his fires before it is time to coal, then by opening the door he opens the air-feed.

Mr. PRIDEAUX: At first I did not make it self-opening, but only self-closing, maintaining that you ought to have firemen sufficiently intelligent to understand and remember that when they shut the door after coaling they had to lift this air valve up, and then it would shut itself. But we find that our customers generally prefer to have them self-opening as well as self-closing; but you can shut the air valve down close at any moment if desired.*

Admiral WELLESLEY: Exactly; that meets my question.

Admiral RYDER: You spoke of the tin shields.

Mr. PRIDEAUX: What I call a non-conducting shield. They are closed air chambers of tin. Air is an exceedingly bad conductor of heat. These shields are screwed on to the flue doors. They are very slight and easily taken off.

Rear-Admiral RYDER: Mr. Prideaux has kindly alluded to a work of mine on "Economy of Fuel," long out of print, published some twenty years ago, which touched upon various parts of this subject that he has not alluded to. The subject is a very wide one. I am sure it could not be discussed properly to-night; I doubt if it could be discussed in less than two or three nights. "Economy of fuel" includes many branches; I will run over a few of them, very shortly, to show what a large subject it is, and what a great deal there is in it. The particular branch of the subject dwelt upon by the Lecturer, viz., the introduction of air into the furnace, is very important, and his doors appear to meet the difficulty. After considering the title of the paper in all its width, one may fairly say that the question each naval Officer would naturally have asked himself before coming here to-night was, what part of this very large subject, "How can the economy of coal be best promoted in the Navy," is to be considered by Mr. Prideaux to-night. We now know, thanks to the most interesting and instructive paper read by Mr. Prideaux. Well, but let us take the broadest part of this very wide subject first, viz., the question as it must be considered at head quarters. At once we find ourselves face to face with that moot question, What is the most *suitable* and most *economical* kind of fuel to be supplied to ships of war, and are the terms convertible? This is a very large subject with which naval Officers in command of ships have practically nothing to do, for we must take what coal is given to us, and make the best we can of it. Another very important question relates to depôts of coal abroad. This bears also, like the preceding, upon economy in the *gross* sum expended upon coal yearly. The necessity of our having numerous fortified depôts for coal, the coal being covered and not kept too long, was touched upon in a very interesting paper read last year by Captain Hoscason, R.N. This, again, is a very large subject, and a most important one, which would take a long time to discuss. We have all heard a great deal lately of the question of the "mixed coal" which is now supplied to the Navy. I hope we shall soon have some facts from the Admiralty detailing the experiments which have been tried across the Mediterranean, and comparing the economical merits of Welsh coal with those of the Admiralty mixture, and of north country coal by itself. I believe, from what I have heard, it will be shown that Welsh coal is very much more economical in all respects, even to the extent of 20 per cent., than the "mixture." At the same time there is this to be said on the other side, and it must not be forgotten, viz., that the Welsh coal, if stowed in the tropics, is said to deteriorate sooner, owing to its friability (not to any chemical change) than all other kinds of coal. It is well, therefore, that our furnaces should be fitted, if possible, so as to

* In point of fact, however, opening the door a little to look at the fire hardly opens the valve at all; only when the door is thrown wide open, as for firing, is the valve widely opened.

burn Welsh coal well and economically, and also to burn well and economically other kinds of coal, if, indeed, we can have furnaces so fitted. If we cannot, then I agree with Lord Lauderdale we had better have our furnaces fitted to burn, at all events, well and economically the Welsh coal that we shall endeavour to supply our ships with in war. Experiments on the relative merits of different descriptions of coal under all circumstances should be commenced at once.

The CHAIRMAN: We must first be satisfied that the north country coal does keep better in a hot climate than the Welsh. I entirely dispute that.

Admiral RYDER: Perhaps you may be right, but I only say it has been stated so. The person who gave me the information was Rear-Admiral Sir William Mends, who has had a great deal to do with coal depôts for troop-ships. The information he gave me was in print, and professed to be a report on the deterioration of coal *abroad*. These are two of the points which occur to me as forming the broadest part of the subject.

When we are treating of the economy of fuel in the Navy, we at once see the importance of our having the most economical engines and boilers in the ships, economical as regards the consumption of fuel, as well as of wear and tear. The Committee of Designs, of which I was a member, received much evidence on this point a few months since, and satisfied themselves that the compound engine is by far the most economical engine that we can have, and that the pressure on the boiler is being increased year by year. The compound engine will burn a less quantity of coal per indicated horse-power than any other, approaching to 1 lb. per indicated horse-power per hour. The expansion gear should cut off as early as one-twentieth of the stroke, and the ports should be much increased in size. Having got our engine and boiler on board, and the ship in our hands, the question, of course, presents itself, what is the most economical way of managing the fuel when you have got it on board? There is no doubt about it that the more you can use sail, and the less you rely upon coal, simply *quâ* economy, the better. It is then a very important question to what extent should our ships be masted, and to what extent should they have engines? This is a large question, indeed, and it would take a very long time to discuss. I am of opinion that no ship-of-war, except vessels for harbour defence only, should be without a sail equipment sufficient at least to make them manageable in a gale of wind, and aid them in making passages, and that the majority of our men-of-war should be fully rigged, and so constructed that they should be able to beat to windward under all plain sail in smooth water more than one mile an hour.

In the next place there is the most important question of working steam *expansively*, which I am sure Captain Hoseason will allude to presently, as he can speak on it with more weight than I can. It is a question which ought to interest all naval Officers, and which I am afraid is often overlooked by those of them before whom it has not been properly brought. I have, when taking passages in ships-of-war, been startled to see how little the expansion valves of the engines were considered or used with judgment, and how often ships were burning a great deal more coal than they ought, simply because the steam was not used as expansively as it ought to be. This, also, is a very large question which would take a long time to discuss. There is another matter germane to it which has often occurred to me, and especially when I was last afloat. I communicated with the Admiralty upon the subject, and they desired me to draw up a draft circular on Economy of Fuel. A part of this circular was adopted.* The point I raised was this:—I think it will be admitted by everybody, when they consider the subject, that always in ships without masts, and frequently in masted ships, with foul wind or calms, steam must be used, but that if there is no particular object in reaching your port on a particular day, the most economical speed for the *voyage* will be, *ceteris paribus*, that which will cause the

* Since this paper was read, another Circular has been issued, dated April 26th, 1872, adopting the recommendations made by me to their Lordships three years since, viz., that the speed which was the most economical *per mile* should be ascertained at the earliest opportunity in every ship, in calm weather, should be reported to their Lordships, and be always maintained under ordinary circumstances.

least consumption of fuel "per mile" (you must always carefully distinguish between "per mile" and "per hour"), and which will be either under sail alone, if there is no urgency whatever in the orders, or else some definite speed to be ascertained by experiment. Now the most economical speed under steam "per voyage" and per mile, is probably to go as *slowly* as possible. Of course it is, I hear some one say. But though everybody says "of course it is," they don't practice it. You will rarely find when you are cruising that the vessel is going as *slow as possible*, and if you suggest that she should only go three and a-half or four knots, you would probably not be believed, and it would often be considered an absurdity by the Captain that he should be expected to reduce speed to three and a-half knots in a ship that can go fifteen. I do not say this is the universal feeling, but I know there is such a feeling. Officers have thought that no one has any right to hint even at their going less than seven or eight knots under steam alone, but lately, I believe, some ironclads have reduced their speed to two and a-half knots—so I have been told, and have seen in reports. When there is no object in going any quicker, the slowest speed is, as a rule, in light winds, or calms, and smooth water, the most economical speed per mile, on account of the resistance varying as the square of the speed, or nearly so. Of course we must look at both sides of the question. There is a speed in some engines which racks the engine, and causes backlash, to which the engines must not be reduced, and which although it might be the most economical speed, might injure the engine; this you have to guard against. But Officers in command should not speculate as to what is the most economical speed per mile when the breeze has freshened, or a sea got up, they should always ascertain it. If they take a little pains they can do so, and it will vary with the conditions of sea and wind which are happening at the time. Having determined what is the most economical speed per mile, they should maintain it. Of course they can proceed more quickly at any time, if there is reason for it. This is a very important point connected with "economy of fuel." Captains should always be asking themselves day by day, and hour by hour, whether they are steaming at the most economical speed *per mile*, and if not why not? One of the questions which came on the other day before the Committee on Designs (the report is on the table of the House of Commons, and no longer confidential) was this—In our large ships we have enormous engines of 1,200 horses nominal, working up to 7,000 indicated horse-power. If, as I maintain is true, the slowest possible speed is, under ordinary circumstances, the most economical per mile, and therefore per voyage, or when cruising, then we are led up to this consideration, viz., that we have enormous engines with great friction, requiring constant supply of lubricating material, which must, somehow or other, be always driven along, even when we only want to maintain a speed of say three or four knots. Just as if a man, when driving his one horse coal cart, insisted on fastening all his stud to it, and dragging them after it. It is evident that there will be considerable loss in driving this monster, while we only want to maintain this speed of say 3 knots, and for which 200 or 300 indicated horse-power might be sufficient. Therefore, a suggestion was made, that in designing the engines for these large ships a small portion of (probably the after part of) the engine, say one eighth, or 150 nominal horse power, should be capable of being disconnected from the rest of the engine, and be used for all ordinary occasions, viz., when you want the ship to go as slow as possible, and, therefore, as economically as possible. The Chief Engineer of the Admiralty, Mr. Wright, admitted that this would be an economical proceeding. Economy of fuel in war time will be everything, it will tend to ensure success.

THE CHAIRMAN: I should say with two and a-half knots you will never get to the end of the voyage. Give us a half speed of ten knots.

Admiral RYDER: Ten knots is, I admit, a very *comfortable* speed, so is that of the express train; but it may be a ruinously extravagant speed, even in a fifteen knot steamer. Of course, if coal were not an object, it is the speed one would prefer to any slower. I have crossed the Atlantic in a steam line-of-battle-ship (the "*Hero*") at a speed purposely reduced throughout the voyage to from three to four knots, in light head winds and calms, when had I attempted to go faster, I should not have reached my port (Bermuda) for weeks. There is another question with regard to "economy of fuel," which came before us, very prominently, which is alluded to in the Com-

mittee's Report, and is also advanced I see in the Annual just published by the Professors and others of the School of Naval Architecture, Kensington, viz., that the "turbine" promises, when thoroughly developed, to be a very economical propeller, perhaps the most economical. It is much to be hoped that the Admiralty will now take steps to carry out most thorough experiments with regard to the turbine. This is the unanimous recommendation of the Committee on Designs, one of the few important points on which they were unanimous. There is an impression abroad that the turbine must be a less economical propeller than the screw: but the writer of the article referred to speaks of it, as at all events theoretically, the most economical of the two. Its numerous other advantages are manifest, and have often been pointed out here. I have suggested to the Admiralty that to promote "economy of fuel" at sea, when under steam, an entry should be made every day by the Captain in the log at noon, and oftener if necessary, replying to the following questions: 1. What speed are you maintaining? 2. What fuel are you spending per mile? 3. What speed would be most economical in fuel per mile at this particular time, either as estimated or ascertained, by diagram? 4. If you are not proceeding at the speed which is the most economical per mile, why not? If this were ordered to be done, and Commanding Officers had every day to make that little confession, as it were, to their Commander-in-Chief and the Admiralty, I am sure that a very remarkable reduction in the total consumption of fuel throughout the Service would take place: because when a man had to answer these questions daily, it would often puzzle him to find and to give any sufficient reason why he was not steaming as economically per mile, which is per voyage, as he might. He would thus be led gently, but by an irresistibly persuasive power, to practise the utmost economy, not a senseless economy, imperilling the ship, but a wise and judicious economy. An order to the above effect would also tell upon the senior Officers, commanding fleets and squadrons; and they would certainly adopt the plan of more fully explaining than at present to the Captain in their sailing orders, either the urgency or non-urgency of the orders, or state the day beyond which it was not desirable their voyage should be extended.

The indicator diagram, that invaluable aid to the Captain, as well as to the engineer, tells us by the "terminal pressure" what is the relative "consumption of fuel" per "revolution," and therefore per mile, when the speeds compared are not widely different. Suppose that the speed has been maintained in a calm at the slowest speed possible, without backlash or racking, say 2·5 knots, and that that speed has been ascertained by aid of the diagram to be, in a calm and smooth water, the most economical per mile. The wind freshens to a steady breeze ahead, and the revolutions (say 20) which drove the ship 2·5 knots in the calm cease to drive her ahead more than 1 knot. The 20 revolutions must evidently be increased, but by how much? The experiment should be conducted in this way:—Increase the revolutions by say two or three at a time, using the expansion gear of course, ascertaining the speed, and taking a diagram at each increase of revolutions. Then the

$$\frac{\text{No. of revolutions} \times \text{terminal pressure in tenths of inches}}{\text{Knots of speed}}$$

will give a comparative measure of the consumption of coal per mile at each speed, and the fraction which yields the smallest quotient will have as the speed involved in it the most economical speed per mile for those circumstances of wind and sea.*

* *Example.*—The breeze having freshened ahead, the number of revolutions (20) which had previously driven the ship 2·5 knots now only drives her 1 knot, increase the revolutions successively to say 23, 26, 29, 32, 35, and let the mean terminal pressures on both sides of the piston be 10, 11, 12, 13, 14, 15, and the speeds 1, 2, 2·8, 3·4, 3·8, 4·1, then as—

$$(1) \frac{20 \times 10}{1} = 200.$$

$$(2) \frac{23 \times 11}{2} = 126.$$

Steaming against a current, the most economical speed is approximately half as fast again as the current. If current 4 knots, speed through the water should be 6 knots, over the bottom, 2 knots. As I said at the commencement of my remarks, the title of the paper is so *wide* that I have been seduced into greater discursiveness than I intended. I wish Mr. Prideaux all success.

Captain HOSKASON, R.N.: As my friend, Admiral Ryder, has alluded to me in his observations, especially as to that economy of fuel that is derived from the expansive action of steam, I hope I may be able to say a few words which will, I trust, be a course of consolation to the lecturer. He has told us how many years he has treated upon this all important subject, the economy of fuel, and for what a lengthened period he has been engaged in endeavouring to push forward his invention, and that he has encountered little more than a passive resistance at the hands of the Lords of the Admiralty. Yet we all agree that the abatement of the smoke nuisance is one of vital importance both as regards efficiency and economy in steamers. There is no want of lucidity in the lecturer, therefore if those at the fountain head do not see their way clearly, it cannot be from want of having the facts placed clearly before them.

I also have been a labourer in the same vineyard with himself. It was in the year 1842, I first brought my views of the economy of fuel to be derived from a still further development of the expansion of steam before the Admiralty, and in the year 1872 I find the subject but little understood and still less cared for.

The Lords of the Admiralty caused the following letter to be written to me, dated 19th July, 1842:—"I am commanded by my Lords Commissioners of the Admiralty to return you their thanks for your communication on the subject of using steam expansively, and to send you the accompanying copy of a memorandum they are about to issue on the subject to the Commanding Officers of all Her Majesty's steamers."

They sent me the memorandum in question without ever having consulted me as to its composition, and when I came to peruse it, I found it drawn up in such English, and so unscientific, that I felt myself in duty bound in respect for my own reputation, to fully analyse their Lordships' Circular, which will be found contained in the pamphlet I hold in my hand, and which I here present to the Institution.

The lecturer in introducing this paper has, as Admiral Ryder states, opened up a very large and important question, which is daily growing in importance, seeing that our Naval and mercantile steam fleets are now nearly entirely composed of vessels whose primary power is steam. And I have only to regret that we should be called upon to discuss off hand so large and difficult a subject, and with our time, after having the paper read, so much restricted.

The CHAIRMAN: I think you will all agree with me that we ought to thank Mr. Prideaux for the very interesting lecture he has given us. I only wish we had more time to work out the subject, and that he would expand it to greater length. There would be more questions put upon the subject, because when a subject is

$$(3) \frac{26 \times 12}{2.8} = 112.$$

$$(4) \frac{29 \times 13}{3.4} = 111 \text{ (the minimum quotient).}$$

$$(5) \frac{32 \times 14}{3.8} = 118.$$

$$(6) \frac{35 \times 15}{4.1} = 128.$$

No. 4, viz., 29 revolutions, giving a speed of 3.4 knots, appears to be the most economical speed per mile, as 111 is the minimum quotient. This case is given merely in illustration, and does not profess to be a *bonâ fide* experiment. If time admits, the actual expenditure of fuel per mile should of course be ascertained.

brought before a meeting of this sort, and only partially discussed, very little good results. There is no doubt of the necessity for consuming smoke, but the question is whether or not the smoke can be consumed. Mr. Prideaux contends that by his plan there is a gain of fuel; many engineers contend that the smoke cannot be consumed without a loss of fuel. There is a wonderful difference between the two. It would be of great importance if the question could be worked out and discussed. Perhaps Mr. Prideaux would answer any observations that have been made.

Mr. PRIDEAUX: I think that what fell from Admiral Ryder and Captain Hoseason hardly related to the particular department of economy of fuel which I have treated on to-night. With regard to what your Lordship said, I would just observe that the distinctive difference between Mr. Murdoch's plan and this plan is, not so much the part of the furnace in which the air is admitted, though that is a considerable point. There is no doubt that it is more injurious to admit a continual supply of air above the fuel at the bridge than it is at the door. But the distinctive difference between the two plans is this, that Mr. Murdoch's, if it is to be called Mr. Murdoch's, is one of the old plans in which the shutting off is left to human agency. I maintain that that is never to be relied upon, and that it is impossible by this means to regulate the air-feed correctly, because if you had a man to stand with a watch in his hand, to shut it off at the expiration of five or six minutes, which you would never get a man to do, even then twice the right quantity of air would enter the furnace. It has been tried over and over again, and it has always been abandoned. When I heard the Admiralty were trying to burn "Baxter's mixture" on such a system, I predicted from the first that they would never accomplish it. But if they had had this automatic apparatus, they might have burned the coal very well. I have proved it in vessels that were burning all Newcastle coal. I tried it in the "Elfin." For two hours Admiral Denman and myself steamed through the fleet at Spithead at full speed. So copious was the steam supply, that we had only three fires lighted out of four, and I do not think at 100 yards' distance anybody could have told from the top of the funnel that there was a fire on board the ship. It was all Newcastle coal. On the deck of the ship, as each shovel full was thrown on, you could see a trace of dust; but the moment the door was shut, it was all clear. No alteration was made to the furnace bars; the only alteration made was the substitution of my door for the common door. It certainly proved that Newcastle coal could be burned without smoke, in the ordinary marine boiler of the "Elfin."

Admiral RYDER: Do you say that the burning on that occasion was more economical than if you had Welsh coal with your door?

Mr. PRIDEAUX: I believe Newcastle coal with this door will answer as well as Welsh coal.

Admiral RYDER: The door in use in both cases?

Mr. PRIDEAUX: I think the result is about the same. Certainly, with a mixture of half Newcastle and half Welsh, if the furnace was fitted with one of these doors, you would not see any smoke from one month's end to another, and you would have a great economy of fuel; and, certainly, an increased quantity of steam.