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The Combustion of Coal and the Economical Generation of Steam.

BY MR. J. R. M. FITCH (Member).

READ

Monday, February, 16, 1914.

CHAIRMAN: MR. J. CLARK (Member).

CHAIRMAN: Mr. Fitch is unavoidably absent this evening and I have pleasure in calling upon Mr. Adamson to read the paper on his behalf.

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MUCH has been written recently on the use of liquid and gaseous fuels, for the generation of steam, both in land and marine boilers, and the subject admits of no doubt that under certain conditions liquid and gaseous fuels may be employed with considerable advantage for the generation of steam. However, a large proportion of power required by the commerce of the world, is still obtained by the combustion of solid fuel, viz., coal. It therefore behoves those engineers who have control of steam plants using this class of fuel, to keep themselves thoroughly acquainted with the latest developments that have taken place in connection with its economical combustion.

The writer does not claim originality for the following paper, which is composed, partly of notes drawn from his personal experience as an engineer, and partly from recently published literature relating to the subject of combustion.

The constituents of natural fuels are: carbon, oxygen, and hydrogen, but the most important factors in the combustion process are the carbon or carbonaceous constituents of the fuel, and the oxygen of the air. Sulphur is also often present in varying quantities, but its heating effect is small. The three principal varieties of coal are: lignite, bituminous coal, and anthracite. The lignite or brown coal is the least carbonised, being more recently formed than anthracite; it shows indications of organised structure, and also contains considerable proportions of hydrogen and oxygen; whilst anthracite is the most carbonised, being earlier formed, and often contains little else than carbon and the mineral matter which forms the ash. It will therefore be seen that the percentage of carbon increases as the process of fossilization and decay advances, and it reaches its maximum in the fuels which are the oldest occurring or found in the earth's crust. The gradual conversion of woody fibre into peat, coal, and graphite is well illustrated by the following table, by Dr. Percy, in which, to show the gradual elimination of hydrogen and oxygen, the carbon is kept as a constant number:—

	Carbon.	Hydrogen.	Oxygen.
Wood	100	12·18	88·07
Peat	100	9·85	55·67
Lignite	100	8·37	42·42
Bituminous coal	100	6·12	21·23
Anthracite (Wales)	100	4·75	5·28
Anthracite (Pennsylvania)	100	2·84	1·74
Graphite	100	0·00	0·00

"The presence of oxygen is considered to detract from the value of a fuel, as the oxygen is generally regarded as being already combined with its proportion of hydrogen in the form of water (H_2O). As these gases combine in the proportion of 1:8 by weight, this virtually reduces the amount of hydrogen available for combustion by one-eighth of the weight of the oxygen present"* Knowledge regarding the composition of coal is however limited to the total amount of carbon, hydrogen, nitrogen, oxygen, and foreign substances which it contains; and although much has been written upon this subject, some doubt exists as to the way in which these bodies are combined.

* Sennett and Oram.

Combustion is a somewhat complex chemical operation, and may be described as a rapid oxidation of the carbon and hydrocarbons of the fuel, by the oxygen of the air, the result of which is heat. When burning fuel in the furnace of a boiler the main object to be effected is to obtain as much heat as possible from each pound of fuel, to conduct this heat through the heating surfaces of the boiler, and to utilize it completely for the generation of steam. To obtain the maximum amount of heat, combustion must be complete. This is the case when all the combustible constituents of the fuel are oxidised to their highest state of oxidation; thus in coal the carbon must be burnt to carbon-dioxide (CO_2); the hydrogen to water (H_2O); and the sulphur to sulphur-dioxide (SO_2). To even approach this result involves compliance with certain conditions, not always easy to procure with a boiler, and which are very often neglected in industrial applications.

Conditions of Complete Combustion.—Consider the chemical and physical changes which occur during the combustion process. To ensure combustion being complete four things are essential. The requisite quantity of air must be supplied; the air must be brought into intimate contact with the fuel to be burned; the temperature must be kept up to the ignition point until combustion is complete; and the waste products must be carried off as soon as evolved.

The elementary bodies given in the following table yield in combination with one another compounds which play an important part in the combustion process, these compounds may be either solid, liquid, or gaseous, at the ordinary temperature:—

	Chemical Symbol.	Atomic Weight.	Description.
Oxygen ..	O	16	A gaseous element, one of the constituent gases of the atmosphere. .. .. ..
Nitrogen ..	N	14	A diluting constituent of the air; will not support combustion .. .. ..
Hydrogen ..	H	1	A gaseous element, and is the lightest gas known .. ..
Carbon ..	C	12	A combustible element .. .. ..
Sulphur ..	S	32	An elementary substance, it burns in oxygen and produces a stifling gas called sulphurous acid (SO_2) .. .. ..

The air is a mixture, not a chemical combination, the average composition of which is by weight 23 per cent. oxygen, and 77 per cent. nitrogen, in the volumetric proportions denoted in round numbers, of 21 and 79. The combustible element, carbon, when burnt in oxygen or atmospheric air, produces two compound gases, known as carbon monoxide (CO); and carbon dioxide (CO_2). The first of these gases, carbon monoxide, is formed by the union of one atom of carbon with one atom of oxygen. Carbon dioxide is formed by the union of one atom of carbon, with two atoms of oxygen, thus:

$$C + O = CO$$

$$C + O_2 = CO_2$$

Substance.	Atomic Weight.	Weight of a cubic foot in lbs., at 32°F., 1 atmosphere.	Specific heat at constant pressure.	B.T.U. yielded in burning 1 lb. with O.
Air	—	·0809	·2377	—
Carbon C	12	—	·2411	14,540
Carbon Dioxide CO_2 ..	—	·1225	·2164	—
Carbon Monoxide CO	—	·0784	·2479	4,370
Hydrogen H	1	·0056	3·4064	61,260
Nitrogen N	14	·0784	·2440	—
Sulphur S	32	—	·2026	4,000

Carbon monoxide is a combustible and actively poisonous gas, and will take up another atom of oxygen and form carbon dioxide, this latter gas is non-combustible, and although it is not directly poisonous, it is not a supporter of animal life. Nitrogen is an inert gas, and is quite useless for the purposes of combustion; it simply serves as a diluting constituent of the air. Hydrogen, as already stated, is the lightest gas known, like carbon it is combustible, and when combined with oxygen in the proportion of two parts by volume of hydrogen, to one part by volume of oxygen, yields water (H_2O).

From the preceding table it is seen that oxygen is sixteen times heavier than hydrogen, so that the proportions by weight of these elements to yield water is as eight to one; the water formed by the above chemical combination generally passes off in the gaseous state, or as steam.

Sulphur burns with oxygen to sulphur dioxide or sulphurous acid:—

$$S + O_2 = SO_2$$

To a small extent the combustion proceeds further, producing sulphur trioxide : —

$$SO_2 + O = SO_3$$

Sulphur trioxide combines with water forming sulphuric acid :—

$$SO_3 + H_2O = H_2SO_4$$

These acids have a very deleterious effect upon iron and steel, and when present in large quantities cause excessive corrosion of the combustion chamber plates, tubes, etc. Economiser tubes are often corroded through this cause. The formation of these acids is greatly accelerated by the presence of moisture.

There are two separate and distinct stages through which coal passes during the process of combustion, viz.: the distillation and combustion of the gases, and the combustion of the coke or carbon which remains after the gases have been disposed of. When coal is thrown on a bright fire, it at first absorbs heat from the glowing and incandescent fuel. This liberates the various hydro-carbon gases, or in other words, the gaseous constituents of the fuel are volatilised, and much heat absorbed, being converted from sensible to latent. The more important of these hydro-carbons, with their respective heats of combustion are :—

Methane or Marsh gas	$C H_4$	— 24,017. B.T.U.
Ethylene or Olefiant gas	C_2H_4	— 21,898. B.T.U.
Acetylene	C_2H_2	— 21,856. B.T.U.

Mayer and Münch give the ignition points of these gases as Methane 667°C, Ethylene 616°C, Acetylene 580°C. If sufficient oxygen or air be supplied, and the temperature is up to the ignition point, these gases will be consumed to carbon dioxide and water, if, however, the furnace temperature is too low, or an insufficient supply of oxygen or air be admitted, they will pass away unconsumed and will prove a loss instead of gain, as they will have carried away the latent heat of distillation.

*"At high temperature these hydro-carbons decompose, and the carbon separates as soot or graphite. If insufficient oxygen or air be present, these particles remain unconsumed, although all the hydrogen may be converted into aqueous vapour; for

* Smoke Prevention and Fuel Economy, Booth & Kershaw.

hydrogen at a certain temperature is believed to have a greater affinity than carbon, for oxygen. These particles of carbon, in the form of soot or graphite, may also remain unburnt even in presence of an excess of oxygen, should the temperature of the furnace be too low. The temperature required, in order to cause carbon to unite with oxygen to form carbon-dioxide, is known as the temperature of ignition. For amorphous carbon, this is about 700°C—for graphite it is considerably higher. The hydro-carbons have also each their own ignition temperature; and no excess of air or good admixture of the gases and air, can remedy the failure to maintain this minimum ignition temperature within the furnace."

Air required for combustion of the hydro-carbon gases.—From the combining equivalents of hydrogen, carbon, and oxygen, it is found that each volume of methane will require two volumes of oxygen for its combustion, and each volume of ethylene, three volumes of oxygen, and acetylene two and a half volumes. Therefore, between two and three volumes of oxygen will be required for the complete combustion of each volume of the gas formed in the furnace; and as the oxygen in atmospheric air only amounts to one-fifth of its bulk, between ten and fifteen volumes of air will be required for each volume of gas. It is estimated that one ton of bituminous coal will produce about 10,000 cubic feet of gas; therefore 100,000 to 150,000 cubic feet of air must actually combine with the gases produced from each ton of coal, to effect their complete combustion. But it is found in order to secure perfect combustion that from one and a half times to twice the quantity of air theoretically necessary must be supplied, to insure thorough commingling of the air with the gas; so that a minimum of 150,000 to a maximum of 300,000 cubic feet of air might be required for the combustion of the gaseous constituents alone from one ton of bituminous coal, and certainly not less than 200,000 cubic feet are necessary. If the fires are thick, all this air should be admitted above the bars, as, if it were allowed to pass through the burning fuel on the grate, it would be deprived of a great portion of its oxygen, and its value for burning the gas be depreciated.

Combustion of the Solid Carbon.—Consider now the combustion of the coke or carbon that remains after the gases have been disposed of. The combustion of this solid portion of the fuel does not really commence until all its volatile constituents have been distilled, or driven off, and up to this point the fuel remains in a comparatively cool state, and does not oxidise or become incandescent until it has attained a high temperature. The air necessary for the combustion of the carbon, must pass between the bars, and through the fuel. It is a very important point though one often neglected, that the air be properly and intimately mixed with the fuel and burning gases. This process depends to a great extent upon the thickness of the fuel on the grate, upon the size of the coal, and also upon many other conditions. If the lumps of coal be too large, the contact surface is small and combustion is hindered; if on the other hand, the fuel be too small, or in powder, the air will be unable to penetrate, and there will still only be a small surface of contact.

The carbon in the coal may be converted, first to CO, and then (with additional air) to CO_2, or it may be burned to CO_2 instantly. In the latter case, however, if the layer of coal be thick relatively to the quantity of air passing through it, much of this gas as it rises through the fire, will take up another atom of carbon, and be converted back into carbonic oxide (CO). If this process takes place, it is not a building up process, but a reducing one; and instead of yielding heat, it absorbs heat to the extent of 6688 B.T.U. Not only so, but the carbon, which would otherwise be utilised by combustion to CO_2, is used up in this process of reduction, as will be clear from the formula $CO_2 + C = 2CO$. It is necessary therefore with thick fires, to admit air above the fuel, for the complete combustion of the carbon, in addition to the air previously referred to, as necessary for the combustion of the gases.

*Herr Ernst considers that the oxidation of the carbon begins at a temperature of only 752°F., and that CO_2 is then formed as the main product, with only a small amount of CO, whether the air be admitted in large or small quantities. When the rate of combustion is increased, and the temperature rises to 1292°F, the chief product is still CO_2, even when the excess of air is such that the exhaust gases contain 20 per cent. by volume of CO_2, which is practically the theoretical maximum limit, proving that all the oxygen has been consumed. Above 1292°F., the proportion of CO to CO_2 rapidly increases, until 1823°F. is reached, when CO is exclusively produced.

Total quantity of air required.—If the composition of a fuel be known, the amount of air required for its combustion can easily be calculated. The air is a mixture, the average com-

* Engineering, April 4th, 1893.

position of which is, by weight, practically 77 parts nitrogen, and 23 parts oxygen, its volumetric proportions denoted in round numbers are 21 and 79. It will be seen that if the exact theoretical quantity of air necessary for the combustion of pure carbon were used, 21 per cent. by volume of CO_2 would be obtained in the waste gases, as the proportion of oxygen in the air is 21 per cent. by volume. This theoretical quantity, however, is not sufficient, and in order to insure thorough admixture, a certain excess of air is necessary, usually estimated at from 50 per cent. to 100 per cent. by volume.

The quantity of air necessary for the combustion of the carbonaceous portions of a ton of coal can be estimated thus:—Every six lbs. of carbon require 16 lbs. of oxygen to produce CO_2. The volume of air necessary to supply this would be about 900 cubic feet. Assuming the coal to contain 80 per cent. of carbon, about 240,000 cubic feet of air will be required theoretically, for the combustion of the solid residue of each ton of coal, after the gases have been distilled. To insure thorough commingling, this quantity of air must be increased, as in the case of the gas, from one and a half times to double the amount, viz.: 360,000 to 480,000 cubic feet, which added to the 200,000 cubic feet required for the gas, make a total of 560,000 to 680,000 cubic feet, which enormous volume of air is necessary to effect the complete combustion of each ton of coal.

The weight of air theoretically necessary for the complete combustion of each pound of fuel, can be obtained from the following formula by Rankine:—

$$A = 12 \left\{ C + 3 \left(H - \frac{O}{8} \right) \right\}$$

where A = lbs. of air required per lb. of fuel; C, H, and O, being the percentage of carbon, hydrogen, and oxygen, respectively contained in the sample of fuel. This formula is obtained from the following considerations: As previously stated, the air is composed of practically 77 parts nitrogen and 23 parts oxygen, hence to obtain 1 lb. of oxygen $\frac{100}{23}$ lb. of air are required. From the atomic weights of oxygen and carbon, which are 16 and 12 respectively, it is seen that for complete combustion 1 lb. of carbon would require $\frac{32}{12} \times \frac{100}{23} = 11{\cdot}6$. In Rankine's formula quoted, this result is replaced by the approximation 12.

The latter part of the formula is based on the assumption that the oxygen present in the fuel is not free oxygen, but is already combined with the hydrogen in the form of water, and that, therefore, the total hydrogen available for combustion is reduced by an amount equal to one-eighth the amount of oxygen present.

*Mr. W. G. Spence says, in referring to the theoretical quantity of air: "Perfect combustion with this (theoretical) quantity of air is however only possible on a very small and experimental scale, where due attention and time can be given for perfect diffusion, and the bringing of each atom of carbon and hydrogen into what may be termed actual mechanical contact with its combining equivalent of oxygen. In practical operations on a large scale, such as steam boiler furnaces, the available time is so short and the conditions, even when at their best, under which the air can be introduced to the solid carbon and coal gas are so little calculated to help diffusion, that a greater quantity than is chemically necessary should be supplied to facilitate the combinations of the atoms. For a given percentage of combustible combining with oxygen, the less of this surplus air the better; and with a given surplus this percentage of combining combustible is a measure of success in diffusion. Owing to the searching nature of air from a blast under pressure, a smaller surplus is required when using forced draught; and on the authority of Professor Rankine this surplus may in the case of ordinary well-constructed boiler furnaces, be taken at 6 and 12 lbs. per lb. coal for forced and natural draught respectively; making with the 12 lbs. chemically necessary, the total rate of air supply required for maximum efficiency = 18 and 24 lbs. per lb. of coal."

Total heat of combustion.—The total heat yielded by the complete combustion of one lb. of carbon (C) to carbon dioxide (CO_2) is found by experiment to be 14,500 B.T.U. whereas the heat yielded by the combustion of carbon to carbon monoxide (CO) is only 4,400 B.T.U. which is less than one-third of the heat yielded by complete combustion. The evaporative power of hydrogen is 4·27 times as great as that of carbon, viz.: 62,000 thermal units per pound. The importance of carefully regulating the air supply in proportion to the coal fed into the furnace, so that complete combustion is obtained,

* Paper on the Combustion of Coal by William Geddes Spence.

or, in other words, so that the flue gases show on analysis a high percentage of CO_2, will at once be seen.

HEATS OF COMBUSTION.

Combustible.	Total heat units of combustion per lb.	Lbs. of water evaporated from and at 212° F.
Hydrogen	62,000	64·20
Petroleum	21,000	21·74
Carbon burned to Carbonic Oxide C O	4,400	4·55
Carbon burned to Carbonic Acid CO_2	14,500	15·00
Coal Anthracite	14,700	15·20
,, Cumberland	15,370	15·90
,, Coking Bituminous	15,837	16·00
,, Cannel	15,080	15·60
,, Lignite	11,745	12·15
Peat, dried	9,660	10·00
Wood-Oak dried	7,700	8·00

The question of air supply can be conveniently summarised in the following extracts quoted from "A.B.C. of Combustion in Boiler Settings," by J. Abady, M.I.Mech. E.:—

"(*a*) If the green gases are rapidly and immediately burned to CO_2, it must be remembered that the heat is thus evolved in the fore part of the fire before the bridge; and as they have to pass over heated carbon, there is danger of reduction to CO, with absorption of heat and loss of carbon.

(*b*) If, on the other hand, the green gases are not supplied with proper secondary air to effect their combustion the nascent flame becomes extinguished, and soot is formed and deposited in part upon the boiler plates, rendering the conduction of these bad in the extreme, and partly carried away as black smoke.

(*c*) If the carbon is rapidly and immediately burned to CO_2, there is the same danger as described in (*a*). Thus the CO_2 in passing over the hot fuel, becomes reduced to CO; and thence the gases pass through the flues up the chimney, and only produce one-third of the possible heat.

(*d*) If the carbon, on the other hand, is gradually burned to CO_2 (this process taking place as the products pass along the tubes and flues), it will be seen that there is a proper and maximum evolution of heat being absorbed by the water, because the CO ignites with the further air supply, burns with a blue flame, and gives out the full complement of heat units. Hydro-carbons have all an ignition temperature. If this is lost, then no amount of excess air will prevent splitting up with black smoke.

(*e*) If the carbon is fed with too little air it will be obvious that there will not be complete combustion at all, and that, instead of every pound yielding its full complement of heat units, the heat evolved will be very small indeed, necessitating a much greater supply of coal to convert the water in the boilers to steam.

(*f*) If the carbon is fed with too much air, then what takes place is not only a great cooling of the mass of available carbonaceous material, but a sweeping through the tubes and flues of a mass of cold air, which not only renders the transference of heat to the water sluggish, but itself absorbs a great proportion of the heat which would otherwise be available for forming steam."

The enormous volume of air necessary for the complete combustion of one ton of coal has been referred to. Much of this air in its passage through the furnace at a high velocity does not come into actual contact with the burning fuel, and gets no chance of becoming throughly commingled with the gases. These gases to a great extent pass along, in contact with the comparatively cool plate of the furnace crown, and do not obtain sufficient heat, and are in some cases even reduced in temperature, by coming in contact with the cool plates or the colder air supplied for combustion, in consequence of which they fail to ignite before passing out of the combustion chamber, this results in a considerable lowering of the furnace efficiency. From this will be seen the importance of maintaining a high temperature within the furnace, and of heating the air supplied to the furnace for combustion, which will be referred to later.

If the furnace be too small in diameter, it is obvious that its steel surface will be too close to the grate and fire, causing the gases to be chilled by contact with it; bad results will follow, and smoke and soot be produced and deposited on the heating surfaces. This cooling action also applies to some water tube boilers where there is little space for the gases to combine and ignite before reaching the tubes. In water tube boilers a fire-brick arch, built above the grate, is now often used, to deflect the gases and cause them to flow forward over the fire, instead of going directly up amongst the comparatively cool tubes.

This arch has a very important effect in forming an incandescent chamber or space, where the combustion of the gases by their union with the air can be completed, this economical arrangement is especially necessary with bituminous fuels, or coal containing a high percentage of volatile matter.

Heating value of fuel.—There are two methods by which the calorific or heating value of fuel may be ascertained. The first is by direct determination, that is, by burning a weighed quantity of dry fuel in a confined space surrounded by a known weight of water, and by noting the increase in temperature of the latter due to the combustion of the fuel. This method is the more accurate and reliable, and is generally carried out when exact knowledge is important, by means of an instrument called a fuel calorimeter. The second method is by chemically analysing a sample of the fuel, and calculating the heating value from that of its individual constituents. This method is not considered to be so reliable as the first, for the following reasons:—It is usual to assume that the constituents give out in burning the same amount of heat that they would do if they were in the free condition. This assumption is plainly incorrect, and the results given by it vary considerably, and are sometimes higher and sometimes lower than those determined by an experimental calorimeter test. No absolute knowledge exists as to how the various constituents of fuel exist in the free state, and it is probable that no two fuels have identical proximate compositions, therefore their heats of formation will vary, and any formula must of necessity be quite removed from the truth.

Dulong was the first to propose the method by calculation; and the total heat of combustion may be calculated from the following formula drawn up by him, when the chemical composition of the fuel is known:—

$$\frac{\text{Total heat}}{966} = 145\ C + 620\ (H - \tfrac{O}{8})$$

Where C, H, and O, stand for the percentage of carbon, hydrogen, and oxygen, respectively contained in the fuel. The nitrogen and sulphur are neglected, the quantity of the latter being too small to practically affect the results. The expression $(H - \frac{O}{8})$ is obtained, as previously explained, by deducting the amount of hydrogen already assumed to be combined with the oxygen.

If, for example, this formula be applied to an average sample of Newcastle coal of the following percentage composition :—

$$C = 80, H = 4{\cdot}25, O = 8{\cdot}16, N = 1{\cdot}13, S = 0{\cdot}81, Ash = 4{\cdot}25, \\ Water = 1{\cdot}4 = 100$$

it will be seen that the total heat of combustion per lb. of this fuel is 13,602 B.T.U. and its evaporative power 14·08.

Again take a sample of Welsh steam coal, of the following composition :—

$$C = 85\ {}^{\circ}/_{\circ}, \ H = 4\ {}^{\circ}/_{\circ}, \ O = 4\ {}^{\circ}/_{\circ}, \ N = 0{\cdot}5\ {}^{\circ}/_{\circ}, \ S = 0{\cdot}5\ {}^{\circ}/_{\circ}, \\ Ash = 5\ {}^{\circ}/_{\circ}, \ Water = 1\ {}^{\circ}/_{\circ} = 100$$

this yields 14,495 B.T.U. per lb. and has an evaporative power of 15.

The results expressed in B.T.U. serve for a comparison between different fuels, but to the engineer the important factor is the evaporative power or value of the coal, this is usually expressed as lbs. of water evaporated per lb. of fuel, from and at 212°F. Therefore, by dividing the total heat of combustion by 966, the latent heat of steam, the number of lbs. of water evaporated per lb. of fuel is obtained.

Referring to the examples given above it is seen that the Newcastle coal is theoretically capable of evaporating 14·08 lbs. of water per lb. of fuel, and the Welsh coal 15 lbs. of water per lb. of fuel. Therefore if the total heat produced by the complete combustion of the coal could be transferred to the water in the boiler, about 15 lbs. of water should generally be evaporated for each lb. of coal burned. Under practical conditions, however, this result is never attained, and the best Welsh coal burnt in ordinary furnaces under favourable conditions, seldom evaporates more than 10 lbs. of water from and at 212°F. per lb. of coal.

Sources of Waste.—Certain unavoidable heat losses occur in connection with the working of a boiler plant, the difference between the available evaporative power of the fuel, and its theoretical evaporative power may be attributed to the following causes :—

1. Waste of unburnt fuel in the solid state.
2. Waste of unburnt fuel in the smoky and gaseous states.
3. Loss of heat by high temperature of exit gases.
4. Waste caused by external radiation and conduction.

The waste of unburnt fuel in the solid state may be considered two-fold, being partly due to the heat carried away by the withdrawal of the hot ashes and clinker, and partly due to the unburnt carbon imprisoned in the same. Waste also arises from brittleness in the fuel, and considerable air spaces allowed between the fire bars, the coal disintegrating and falling between the bars into the ash pits. The waste from this source may be very considerable if due care is not exercised to ensure careful handling of the fuel, and disturbing the fires as little as possible. All small coal falling into the ashpits should be recovered and burnt. The waste from this cause may amount to from one to six per cent. The waste of unburnt fuel in the smoky and gaseous states arises from the escape of uncombined gases from the boiler flues to the chimney. This can be prevented by admitting a sufficient supply of air to the furnaces, by ensuring a thorough admixture of the air with the gases in the presence of a sufficiently high temperature for their ignition, and by careful stoking.

It is difficult to obtain perfect combustion of the gases on a minimum admission of air in any case, the fires being so close to the tubes that the gases have to be distilled, mixed with air, and consumed in the short space of time available, and the conditions necessary for this process even when at their best are little calculated to help diffusion. The absence of smoke does not necessarily imply that perfect combustion is being obtained, for this absence of smoke may be the result of introducing a large excess of air to the furnaces. If combustion be complete no smoke will be produced because carbon dioxide (CO_2) is invisible. Carbon monoxide (CO) is also invisible, but the presence of even a small percentage of this gas in the flues or chimney is a sure sign of incomplete combustion, generally due to an insufficient air supply or imperfect mixing of the gases and air. The carbon in burning to CO only produces 4,400 B.T.U. instead of 14,500 B.T.U. which would have been produced if the carbon had been completely burned to CO_2. It is necessary, therefore, to have the waste gases regularly examined, in order that the engineer may determine to what extent the conditions of perfect combustion are being maintained in the furnace or boiler. By a simple chemical analysis of the flue gases and determination of their temperature, a very good estimate of the efficiency of the boiler can be obtained. The gases may be sampled either at the end of the first flue, or at the boiler side of the damper. Without this analysis no boiler plant investigations can be considered complete, but unfortunately engineers have hitherto not sufficiently realised its value.

Complete combustion and the maximum economy of fuel can only be obtained by keeping a continuous supply on the fires and introducing a regular and adequate quantity of air for its combustion. The more continuous the supply of fuel the more certainly can it be properly consumed, but with hand stoking a continuous supply cannot be maintained, difficulty also arises as regards efficient air regulation, too much or too little being generally introduced. The furnace door is wide open for some seconds for the purpose of firing, allowing an enormous volume of cold air to rush in over the fire, cooling the furnace, flues, tubes, and brickwork. This easy entrance of air through the fire door obviously acts as a check on the air passing up through the bars, where the resistance to its passage due to the fuel on the grate is always high. The furnace is now charged with a large quantity of fuel, which is placed in front at the dead plate, or spread evenly over the incandescent surface of the fire. The generation of gas is then large and sudden; this is especially the case when the spreading system of firing has been adopted.

This volatilization of the solid fuel absorbs an enormous amount of heat, because gasification is a very cooling process, and further reduces the temperature of the fire. The fire door being now closed, there is danger that the green gases will not receive sufficient secondary air necessary for their complete combustion, and will pass away into the flues without being consumed. The fire being covered with green coal and therefore choked, insufficient air will pass through it for the combustion of the gases; further, the temperature at this point is low. It is necessary therefore to provide a secondary air supply above the fire for the combustion of the hydro-carbon gases. This is usually done by fitting suitable grids or openings in the furnace doors or frames, to allow the air to pass over the fire, air is also admitted at and above the bridge. Both these methods have a beneficial effect on the mingling of the gases. As the process of combustion proceeds, the gases are distilled or driven off, and the fire begins to assume an incandescent appearance and becomes patchy, holes forming in the thin places, allowing too much air to pass through just when it is least required. This again has a detrimental effect on combustion, and causes a lowering of the furnace temperature.

From the foregoing it will be seen how exceedingly difficult it is to properly control combustion with hand stoking, the air supply having to be carefully regulated to suit the constantly changing conditions of the furnace. With mechanical stoking however, a continuous feed of coal is ensured, either by the coking or sprinkling process, the distillation of the gases is more uniform and continuous, and the air supply can be better adjusted to suit these conditions. The loss due to the escape up the chimney of unconsumed gases is often considerable, and in some cases amounts to from 10 to 20 per cent. decrease in boiler efficiency.

Losses due to high temperature of exit gases (chimney draught). —The third and principal heat loss is that due to the gases of combustion passing up the chimney at an excessive temperature. The temperature of these gases depend to a great extent upon the amount of excess air admitted into the furnaces, also upon the cleanliness of the heating surfaces of the boiler. If a large excess of air be allowed to pass into the furnaces, the temperature of the gases will be lowered, thus resulting in a reduced heat transmission to the water in the boiler. Defective boiler settings, and leaky brickwork of flues also influence the temperature of the waste gases; if air be allowed to pass through into the flues in this manner, the gases will be considerably reduced in temperature. If the heating surfaces of the boiler are dirty or badly scaled, the conductivity of the plates will be reduced and the heat of the gases will not be transmitted so readily to the water in the boiler, the gases will therefore pass into the flues carrying away a considerable proportion of their heat.

It follows then, that the temperature of the waste gases passing out of the boiler flues, gives no direct indication as to the efficient working of the boiler, as a general rule however, given clean heating surfaces, and air-tight flues, the lower the temperature of the exit gases, the higher will be the evaporative efficiency of the boiler.

The transmission of heat through boiler-plates is proportional to the difference in temperature on each side of the plate; it follows that, to increase the output of steam from a given area of surface, it will be necessary to increase the temperature and rate of combustion, or to force the fires. It is, however, bad practice to force a boiler beyond reasonable limits, as apart from the unequal strains set up in its structure, risk of leaky tube ends, etc, this forcing must of necessity increase the temperature of the exit gases, and reduce the thermal efficiency of the boiler. In the interests of economy, it is good policy to employ boilers of ample capacity, for the duty required of them, but heating surface is too expensive to extend further than is compatible with reducing the gases to 400 or 500°F. Beyond this, the losses due to radiation and conduction counterbalance the saving effected. This will at once be realised from the fact that while heat transmission through boiler plates is directly proportional to the difference of temperature on each side of the plate, the heat losses from the boiler are also proportional to the extent of its surface. As previously stated, the transference of heat to the water diminishes with the falling temperature of the gases, and when there is only a slight difference between the gases and the water in the boiler, a limit is reached and inefficiency results. Since the draught in the chimneys of boilers working under natural or atmospheric conditions is produced by the difference in weight between the hot gases in the chimney and that of an equal column of the external atmosphere or air, it is obvious that there is a point below which heat cannot be abstracted from the flue gases without spoiling the draught, and therefore the thermal efficiency of the boiler. The economical temperature of the exit gases lies about 400°F., and it is therefore unwise to cool them below this temperature. When, however, the gases leave at the much higher temperature than this, considerable advantage is derived from the use of an economiser. These are, however, of very little use where the flue gases pass to the chimney at less than 350°F. It is readily seen then, that with boilers working under natural draught, the air supply must suffer if the temperature of the exit gases falls too low. Where artificial draught is employed, this difficulty has not to be contended with; and in such cases there is no objection to abstracting all the available heat from the flue gases, before they pass into the atmosphere. With natural draught, a certain loss of heat in the exit gases is an absolute necessity. This loss can be ascertained by the following calculations. Professor Rankine states that the weight of gases discharged by a chimney is maximum when the ratio of the absolute temperature of the air to that of the gases in the chimney is as 12 is to 25.

$$\frac{T\,2 + 461}{T\,1 + 461} = \frac{25}{12}$$

Let T 1 = temperature of the air.

Let T 2 = ,, ,, ,, gases in the chimney. This formula would give, at ordinary atmospheric temperatures, about 600°F., as the temperature of chimney gases that produces the most powerful chimney draught. Should the temperature be raised beyond this point, the velocity of the gases in the chimney would increase, yet their volume would increase in a greater ratio, in consequence of which the weight of the gases discharged, and the draught, would be decreased.

It is known that 1 lb. of average fuel requires theoretically about 12 lbs. of air for its complete combustion, but in practice one and a half times to double the amount is necessary, to ensure thorough mingling. Supposing then a lb. of coal, having a calorific value of 14,500 B.T.U. is burned in a boiler furnace by the aid of 20 lbs. of air; this will produce about 21 lbs. of gaseous products. Assuming that these 21 lbs. of waste gases pass to the chimney with a final temperature of 650°F.; and the temperature of the incoming air is 60°F., and taking 0·240 as the average specific heat of the gases; the heat loss will amount to $21 \times (650-60) \times 0{\cdot}24 = 2973{\cdot}6$ B.T.U. or $2973{\cdot}6 \div 14{,}500 \times 100 = 20{\cdot}9$ per cent. of the total heat value of the coal. This then represents the heat required for creating the necessary chimney draught. Supposing that a boiler is working under artificial draught (either forced or induced) where the waste gases pass to the chimney at a temperature of 350°F.; the loss in this case amounts to only—

$$21 \times (350-60) \times 0{\cdot}24$$
$$21 \times 290 \times 0{\cdot}24 = 1461{\cdot}6$$

or $1461{\cdot}6 \div 14{,}500 \times 100 = 10$ per cent. heat loss.

In the foregoing calculations, no cognizance has been taken of the fact that air in excess of the theoretical amount results in a reduced percentage of CO_2 in the flue gases; the specific heat of these gases varies according to the percentage of CO_2 and H_2O they contain, but an average of 0·240 has been taken. These simple calculations also show the importance of carefully regulating the air supply to the boiler furnaces, and the necessity for flue gas examination and analysis as a check upon the volume of air passing through the fires. It is also seen that boilers working under accelerated draught are capable of greater economy than those working under natural draught conditions, as the air supply (both above and below the fires) can be better regulated to suit combustion, and the excess air can be reduced to a minimum. When forced draught is employed, the air can be heated before its admission into the furnaces, thus further reducing the heat losses up the chimney, as less heat will be extracted from the fire to raise the air to the temperature of the exit gases.

External Radiation and Conduction.—The further direction in which heat loss occurs, is by radiation and conduction, this loss is taken after the three preceding losses have been ascertained. The loss by radiation is largely dependent on the extent of surface for radiation per pound of fuel burnt. Most of this external surface can however be covered with a lagging of silicate cotton, or some such material, this only serves to reduce the waste, which always goes on to an appreciable extent, and if due care is not exercised the loss will rise to a considerable one. The heat losses from this cause may amount to from seven per cent. to ten per cent. of the total heat present in the fuel, but with boilers well covered with non-conducting material, the loss should not exceed seven per cent.

Efficiency of Boilers.—Evaporative efficiency means the percentage ratio between the total heat developed by the combustion of the fuel, and the heat actually transmitted to the water in the boiler. The various causes of waste mentioned above are always present to a greater or lesser extent, hence the total heat from the fuel is not available for evaporating the water in the boiler into steam. The method of calculating the working efficiency of a boiler is as follows:—

$$\frac{\text{Heat absorbed per lb. of combustible}}{\text{Heat value of 1 lb. of combustible}}$$

Heat balance, or distribution of heat under ordinary working conditions.—Total heat value of 1 lb. of combustible = 13,500 B.T.U.

	B.T.U.	Per Cent.
Converted into steam in boilers	9,045	67
Losses in chimney gases	2,700	20
Losses by unburned Carbon in ashes	810	6
Losses by radiation	945	7
Totals ..	13,500	100

The first number 67 per cent. represents the efficiency of the boiler. It must be understood that the above heat balance is only an approximate one, it not being possible to accurately determine the percentage of unconsumed hydrogen, or hydrocarbons in the flue gases, and errors are liable to occur in the sampling and analysis of same.

APPENDICES.

An interesting experiment was carried out by Dr. J. S. Owens, M.D., A.M.I.C.E., showing the actual loss in conductivity by boiler plates through being coated with varying thicknesses of soot; particulars of the experiment, and the result were given by him in a paper, read at the Smoke Abatement Conferences at the Agricultural Hall, Islington, March 26th, 27th, and 28th, 1912. The table is given below as it is interesting:—

Thickness of Soot Layer inches.	Rate of heat transfer as a percentage of that through clean plate.
·0	100
·05	86·3
·10	77·4
·15	70·0
·20	64·0
·25	59·0
·30	55·0
·35	51·8
·40	49·0
·45	46·8
·50	45·3

ANALYSIS OF SOOT (Table by Professor CORD).

Constituent.	Original Coal.	Soot from Domestic Fire Grate.	Soot from Boiler Chimney.	
			BOTTOM.	TOP.
Carbon	69·30	40·50	19·24	27·00
Hydrogen	4·89	4·37	2·71	1·68
Tar	1·64	25·91	0·09	1·14
Ash	8·48	18·16	73·37	61·80

TEMPERATURE TABLE.

Appearance of Fire.	Temp. °F.
Red, just visible	887
Dull	1022
Cherry	1157
Full Cherry	1202
Light Cherry	1562
Yellow Cherry	1833
Yellow Light	1922
White	2120

Relative value of non-conducting materials.

Silicate cotton or Slag Wool ...	100
Hair Felt	85·4
Cotton Wool	82
Sheep's Wool	73·5
Charcoal	71·4
Sawdust	61·3
Asbestos	56
Coke Breeze	43·4
Wood and Air Space	35·7

Mr. W. McLaren: I agree with some of the author's statements, but with regard to others I disagree. One in particular is about the heat of the furnaces. From my own experience I believe that the hotter you can keep the furnaces the better. He goes on to say that the heat may be obtained without converting the CO_2 into CO. I am prepared to accept that statement and I think the use of a CO_2 machine is invaluable in checking the air supply, although sometimes the recorders are not very accurate. He does not tell us how we are to gauge this supply of air in any other way. The author also recommends heated air. Where are we to get the heated air from? By heating the air we must increase the volume of air required. The heated air is certainly lighter than atmospheric air; therefore a greater volume would be required and this would have to be drawn over a heated surface. The author condemns hand stoking. There are certain conditions where hand stoking is indispensable, and any excess of air can be minimised to a great degree by closing the air inlets which are required to get a sufficiency of air on top of the fuel. With fires where the coal is banked about 6ins. on the average, it is difficult to get air through even with a good chimney draught, or $\frac{3}{4}$in. of water. Therefore air has to be admitted over the coal through the furnace door or over the bridge or in some other way, and there is some weakness with boiler furnace fronts in that the air is not deflected downwards on the coal, but is allowed to sweep over the coal along the furnace. The author mentions that the hottest part of the fire is at the bridge, and I think we have all experienced that. We always burn considerably more coal at the bridge than at the middle of the length or at the furnace fronts. Whatever means one may have of forcing the fire towards the bridge, it is fairly well spent and the heat is therefore increased at that point. The author speaks about small furnaces. I have found from experience that the narrower one can keep them the better. In a circular furnace of an internally fired boiler, it is best to keep the bars as low as possible, with a fairly efficient width of bar. For instance, if a furnace is 6ft. long, a marked difference will be found if it is shortened to 5ft. at the bridge. Instead of doing that the grate should be narrowed in proportion by being lowered, and this will be found to be an advantage.

With regard to the temperature of the gases, Mr. Fitch certainly mentions a temperature of 600° towards the end of the paper, but I could not agree with his references to temperatures of 400° to 500°. I think 600° is a good average temperature, and there is some defect if it is lower. It is a fair temperature to aim at if there is nothing between the boiler and the chimney to absorb the heat. I should not care to lower it down to 400° even at the expense of a great number of tubes. Then the author does not deal very much with the question of mechanical stoking, although he does mention that there is an advantage in using it either by the coking or the sprinkling processes. I have not had much experience of the coking stoker, but the sprinkler system seems to me to be the most desirable. I should be glad if the author could give us some particulars of these two systems. The author has a complaint to make about small coal being used. It is only in case of accident, or trying to drive through to make things better that we hear of small coal going through the furnace bars, because we can now use the finest dust at the expense of the heaviest clinker, by induced draught underneath the grate.

Mr. G. W. Newall: This question is a very vital one to engineers; but I think it is all wrapped up in the remark that: "The importance of carefully regulating the air supply in proportion to the coal fed into the furnace, so that complete combustion is obtained, or, in other words, so that the flue gases show on analysis a high percentage of CO_2, will at once be seen." I think that is the whole story in this paper, and the whole story to engineers who have to burn the coal. As Mr. McLaren has remarked, it is a very difficult matter to know how to deal with the air admitted into the furnace. There is very little round the furnace to tell one when the coal needs more air. The furnace door has to be opened at times to replenish the fire, and of course great volumes of air go in and upset the working conditions. This is the great difficulty even with CO_2

recorders and other recorders to automatically register the amount of CO_2, CO and oxygen passing over or through the furnace, fixed on the boiler. We read on the recording chart what is happening owing to the conditions under which boilers are fed, and there are many varying conditions throughout the day in stoking, owing to the different classes of coal used, local troubles, opening of furnace doors and trying to regulate sliding gratings, either on the door or furnace fronts. It is very difficult to know how to ascertain the best amount of air for the condition at the moment, and even the best instruments; although they may give a good analysis of the condition of the gas, are powerless to alter those conditions. The question of how to burn coal to the best advantage is a very difficult one, and I suppose that ever since engineers have had control of boilers the "rule of thumb" has been the method most adopted. Some day we may be able to know and to regulate, and to measure the quantity of air admitted into the furnace either above or below the coal to the best advantage, but as things are now, either on board ship or on land, we are left more or less to the firemen. Of course, as the author states, CO_2 and CO are invisible gases, and this is another reason why they do not lend themselves easily to treatment. Towards the end of the paper the author says: "These simple calculations also show the importance of carefully regulating the air supply to the boiler furnaces, and the necessity for flue gas examination and analysis as a check upon the volume of air passing through the fires." In this great question of combustion I think that is the main item: how are we going to put on board ship an appliance that would meet this case, that is, an apparatus to ascertain the volume of air required for the varying conditions?

Mr. F. O. Beckett: I wish to add my testimony to the value of this paper and my thanks to the author. I think he is to be congratulated upon the way in which he has advocated mechanical stokers. In the course of his remarks upon acids, he says: "These acids have a very deleterious effect upon iron and steel, and when present in large quantities cause excessive corrosion of the combustion chamber plates, tubes, etc. Economiser tubes are often corroded through the cause." I have come across the same thing, the acid taking effect especially on cast iron. I cannot quite agree that it has the same effect upon economiser tubes; but I think there is another agency acting upon economiser tubes, the shrinking effect of the varying temperatures, although I have come across sulphurous effects there. In speaking of the temperature required in order to cause carbon to unite with oxygen to form carbon-dioxide the author quotes Booth and Earnshaw as follows: "For amorphous carbon this is about 700°C—for graphite it is considerably higher." I should very much like to know the temperature higher than this which is necessary for graphite. Following this he refers to Abady as stating: "If the carbon, on the other hand, is gradually burned to CO_2 (this process taking place as the products pass along the tubes and flues), it will be seen that there is a proper and maximum evolution of heat being absorbed by the water, because the CO ignites with the further air supply, burns with a blue flame, and gives out the full complement of heat units. Hydro-carbons have all an ignition temperature. If this is lost then no amount of excess air will prevent splitting up with black smoke." In my opinion that, undoubtedly, is due to faulty design of the combustion chamber. The author also says: "The enormous volume of air necessary for the complete combustion of one ton of coal has been referred to." As engineers on board ship we have a lot to do with firemen and are very much in the firemen's hands in this matter, and I believe that stoking, both at sea and on shore, is a calling. It is not fair to put a clodhopper in the stokehold and expect him to fire efficiently. The author speaks about not forcing the boilers. I cannot agree with him there as you have to force them at times and they are designed with that in view. He also refers to a brick arch for water-tube boilers. That is all very well with chain grate stoking, but I cannot see the utility where the boilers are hand fired. He says later on: "The absence of smoke does not necessarily imply that perfect combustion is being obtained, for this absence of smoke may be the result of introducing a large excess of air to the furnaces." In making a long voyage one is bound to get changes of fuel. With some kinds you get a fire at the top of your funnel and no smoke whatever, and we know it is a waste of heat, but one cannot avoid it on a long voyage owing to bird-nesting in the tubes, choking up the combustion chambers and spaces for getting the combustion. The author advocates the chemical analysis of the flue gases and says: "Without this analysis no boiler plant investigations can be considered complete, but unfortunately engineers have hitherto not sufficiently realised its value." Allow me to say that they have realised this very much, but we cannot help it because of the accumulation on a long voyage, causing all this fouling up. With regard to the author's remarks about having small coal in preference to large, I quite disagree. If you want good results from the boiler you must have good coal. He says: "From the foregoing it will be seen how exceedingly difficult it is to properly control combustion with hand stoking, the air supply having to be carefully regulated to suit the constantly changing conditions of the furnace." That is entirely wrong. If the engineer knows his work he knows how to fire. In the paragraph beginning "Losses due to high temperature of exit gases (chimney draught)" he says: "Defective boiler settings and leaky brickwork of flues also influence the temperature of the waste gases, if air be allowed to pass through into the flues in this manner, the gases will be considerably reduced in temperature." Yes, but I think there is a bit of the defective design in the boilers. I think he is not quite right there. In the last paragraph he gives a list of materials for covering boilers externally to prevent radiation. Might I point out that he has omitted to mention asbestos, which is a most important covering.*

Mr. JAS. SHANKS: The paper we have had to-night contains very little that is new, practically all the information could be obtained from text books or from the Transactions of the Institute; but the author deserves our thanks for "rubbing us up" in the subject. I agree with Mr. Newall that the principal thing for us to discuss is the regulation of the supply of air admitted to the fires. There are many things in the paper upon which one could raise a discussion, but that is the most important. The value of CO_2 recorders is well-known to engineers, but as Mr. Newall said, with all the recorders fitted to the boiler how are you going to regulate the supply to each furnace? They are stoked with different classes of coal, and the conditions are continually varying every day on board ship. The author advocates mechanical stoking, but with mechanical stoking it is necessary to have coal of uniform size and quality. A ship goes all over the world and takes in coal at various ports. They have to take the coal given to them. I do not agree with Mr. Beckett that it is want of data that prevents the supply of air from being regulated. The engineer cannot do it, that is my experience, because of the varying conditions. Mr. Speedyman, who is with us to-night, has had long experience of burning coal on long voyages, and he knows what the furnaces and combustion chambers are like at the end of such voyages. With some coals the distilled gases dissolve, which means hard firing to get the ship along, with

* Added p. 75.

the result that there is a very much increased temperature of the escaping gases. The whole question turns on how we are to regulate the quantity of air in the furnace. The author does not enlighten us; he tells us the importance of it, but does not show how to do it.

Mr. E. Shackleton: I am sure we are all very much indebted to the author for this paper. I am not so much interested in this matter of consuming coal in boilers, but the last speaker reminded me of something which might be worth mentioning. It is possible to regulate the air, but we would have to revolutionize the methods—I am talking quite within the field of practice—by first producing gas in a generator. You may accept a very common coal and fire your boilers efficiently. I do not suppose it will be possible in the marine world with the latest type of steamers to do it as cheaply as firing direct with coal; but you could also recover sulphate of ammonia. In certain conditions direct producer gas firing has not had that attention it might have had. That would be the only way in which it would be possible to regulate the amount of air for the boilers and sooner or later we shall come to a consideration of that even for fairly high powers. I notice the author referred to acid being formed in connection with certain fuels or gases. I may say that is quite true. The products of combustion in other generators have given quite marked effects in that direction. In one case I know of a large exhaust boiler which was attached to a 400 h.p. engine operated from the exhaust gases, gave a considerable amount of trouble and set up excessive corrosion unless the boiler was kept warm when the gas engine was at work. It was found that when the boiler maintained steam this excessive corrosion did not take place. In all forms of combustion you get this acid re-action.

The Chairman: I am sorry the author of the paper is not with us to-night, especially as I am sure he would not agree with some of the statements made. The question of the supply of air has been mentioned. A good fireman, who knows his business, knows very well when the fires are working at their best and making steam. It seems to me that Mr. Fitch's paper is a highly useful contribution to the Transactions of the Institute. It goes thoroughly into the chemistry of combustion, and here and there throws new light on this somewhat familiar subject. Table II. is hardly complete as it stands, and it does appear to be necessary to state the temperature at which the weight of a cubic feet in lbs. of the various gases is taken. Perhaps Mr. Fitch will add this when he revises his paper. We are all aware that carbonic acid gas is the product of combustion and is, therefore, non-combustible, but in addition to it not being a supporter of animal life it also will not support combustion, this being fully dealt with in papers recently read at our Institute on the subject of fires on board ship and their subjugation. Mr. Fitch mentions the deleterious effect upon iron and steel which sulphurous and sulphuric acid gases have, but this action is only severe in the presence of dampness or sweating. Economiser tubes will last for years provided there is no sweating. I am no believer in the theory so often stated and mentioned by Mr. Fitch that gases can be cooled down in the furnace to such an extent that smoke will be produced. Some theories have long lives and the curious thing is that no facts are ever brought forth to substantiate them. Smoke obviously is caused by want of sufficient air supply where necessary, and the proof is that the opening of the furnace door is sufficient to kill black smoke almost instantaneously: now if the cooling theory is correct, by opening the door and letting in a huge supply of air the gases should be cooled down still more and produce more smoke, but it has just the opposite effect. The theory may be quite correct under certain conditions, but I will be very much surprised to find that these conditions can be found inside a boiler furnace. Mr. Fitch's paper is particularly interesting on the subject of testing fuel. No doubt most present know that we carry out fuel tests from time to time, but useful as these are, perhaps the real test is to be found in the boiler furnace, so many factors affect economy in burning fuel—its size, the percentage of ash and the rate of burning as well as the rate of evaporation, because, after all, economy in burning fuel is directly based upon evaporation. Every paper on this subject insists upon analysing the flue gases if we are to attain the highest efficiency, but not one has anything, or at least anything of importance, to say regarding keeping the apparatus in order. I am speaking now about the pipes. As a rule they frequently get choked, or are too long for the strength of suction, and I venture to say more than half the failures are due to the pipes and their want of arrangement. Mr. Fitch mentions that the transmission of heat through boiler plates is directly proportioned to the difference of temperature on each side. So it is, and inversely as the plate thickens, but this is in its simplest form where the two sides are kept at different constant temperatures. A reference to the laws of heat transmission is incomplete unless it takes the work of Osborne Reynolds into consideration and his law that the heat transferred is nearly proportional to the speed of flow. Professor Perry and the late Dr. Nicholson have emphasised the importance of this law. I am afraid Mr. Fitch's results of natural and forced or induced draught are not very convincing. Seemingly, natural draught absorbs 20 per cent. of the heating value of the fuel while forced or induced only require half this amount. I observe the cost of producing forced or induced draught has not been included and nowadays power or its equivalent is not got for nothing. This must be borne in mind when comparing one with the other.

The HON. SECRETARY: In connection with a remark by Mr. Beckett there is an experiment being made by the Liverpool Education Board, which seems to be founded on very good lines. They are opening classes for young messenger boys and others who are not in training for any particular calling sufficiently remunerative to keep them, to train them as sailors. As an offshoot of this, if we had some of the same class trained as firemen and coached up in the different details it would be very useful. With regard to Mr. Shackleton's remarks I might mention that, shortly after the Institute was founded we had a demonstration from one who was particularly interested in using gas for getting up steam in boilers, and his idea was to have a big gasometer on board a steamer crossing the Atlantic and to fire the boilers with the gas generated on board. We had one or two demonstrations using the gas which was obtained from Beckton, so that this seems to be an old idea revived in a somewhat different form.

The meeting concluded with a vote of thanks to the Author and to the Chairman.

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MR. FITCH's reply to discussion :—

I much regret not having been present to read the paper and to reply personally to those members who took part in the discussion; I hope, however, to make amends to some extent for my absence by replying somewhat fully to the questions.

I wish to express my thanks to the Hon. Secretary for so kindly reading the paper on my behalf.

In reply to Mr. McLaren, I agree with him that the use of a CO_2 machine is invaluable in checking the air supply to the furnaces; my experience, however, has been that they are of more utility in land installations, and when making boiler tests, than for marine use; as a subsequent speaker remarks, "difficulty is experienced in keeping the pipe arrangement clean and free from deposit," and the engineer, even if he had time, would be unable to keep the pipes clean when at sea, more especially so on ships making long voyages. In the case of land boilers, these are opened up more frequently for cleaning, and a better opportunity would be afforded for keeping the apparatus clean and in working order. These machines require a lot of attention, and if not kept clean are practically useless. No other reliable method exists which will gauge accurately the supply of air fed to the furnaces, and we must, to a certain extent, rely upon the fireman for this, who, if he is a capable man, can tell by observation when the fires are receiving the necessary air supply. As regards the employment of heated air, great advantage is to be derived from heating the air supplied for combustion; this is often done in the case of forced draught by causing the air to pass round a series of thin vertical tubes placed in a chamber immediately over the smoke box, and through which tubes the escaping hot gases pass on their way to the funnel. In order to insure the air being fed to the furnaces at a high temperature, especially having regard to the difficulty experienced of imparting sufficient heat to air, it is necessary to keep the heating surface of these tubes as large as possible. It must be remembered that the higher the temperature of the air supplied, the higher will be the efficiency of the furnace.

Mr. McLaren says I condemn hand stoking; I am well aware of the fact that under sea-going conditions, hand stoking cannot be dispensed with. The varying quality of the coal obtained at different ports makes it impossible to lay down hard and fast rules as to the manner in which it should be consumed; however, the fact remains that, where mechanical stokers can be employed, they show a distinct advantage over average hand firing. I see no reason why some form of mechanical stoking should not be employed in ships making short voyages between the same ports, where a uniform quality and size of coal could be obtained; better opportunity would be afforded for opening out and keeping them in repair than on ships making long voyages.

Broadly speaking, mechanical stokers may be divided into two classes, viz., the coking type and the sprinkling type.

In the former, of which the "Vicar's" stoker is a good example, the fuel is fed from a hopper into the front of the furnace and gradually carried forward by a reciprocating motion of the bars, being gradually converted into coke as it advances. For boilers that are often forced, or where there is a fluctuating demand for steam, the sprinkling type is considered more suitable. The fuel in this case is thrown directly on to the grate by means of small fans, shovels, or pushers. The grate bars sometimes move forward, or they may be stationary. As a rule the bars are kept much more evenly covered with mechanical stokers than they are by hand firing.

There are certain advantages derived from the use of the coking stoker which are not obtained by the sprinkling process, viz., in regard to a more perfect combustion of the gases and hydro-carbons. In the coking process the charges of coal are forced on to the grate and gradually worked forward along the furnace by the reciprocating motion of the bars. It is obvious that the hottest and brightest part of the fire is nearest the bridge, as combustion there is in a more advanced stage. The green gases distilled from the coal which is being heated up, have to pass over this hot area, and get a chance of being properly consumed. In the case of the sprinkling process, the distillation of the gas takes place over the whole surface of the fire, and the conditions are not so favourable for their combustion.

Mr. McLaren seems to prefer small furnaces, and believes the narrower one can keep them the better. He gives an instance of a furnace 6ft. long, and says: "A marked difference will be found if it is shortened to 5ft. at the bridge." My experience has been that if the furnaces are too small in diameter, insufficient space is allowed above the bars for proper diffusion and combustion of the gases, also the flames are too close to the furnace crowns; this, of course, can be obviated to a certain extent by placing the bars low down, but then there is danger of cramping the ash-pits, which, when partly filled with ashes, may not allow sufficient air to pass along and up through the bars; another objection to long narrow furnaces is that the fireman cannot properly control combustion at the back part of the furnace in front of the bridge. I have invaribly found that a hollow is formed in the fire at this place through which too much air passes, and with a rake on the bars, it is difficult to see from the front properly when the back part is well covered.

An interesting experiment was carried out on a boiler at Devonport, by shortening the tubes one foot and adding this amount to the width of the combustion chamber. It was found that the efficiency of the boiler remained exactly as before the alteration, the increase in combustion chamber area making up for the loss of a much greater area of tube surface. Of course, this shortening of the furnace could not be carried out beyond certain limits.

With reference to Mr. McLaren's remarks as to temperature of the gases, the 400° to 500°F which I state in the paper apply to boilers in which economisers are fitted, and I should perhaps have expressed myself somewhat more clearly as to this. I quite agree that 600°F is a good average temperature when they are not fitted.

As regards the waste caused by small coal falling through the furnace bars, of course this does not occur to any extent with forced draught underneath the grate, but with natural draught this is a very common source of waste if due care is not exercised, and the fireman made to rake this small coal out and burn it.

I note Mr. G. W. Newall's remarks, to which I agree, and do not think they call for any comment. I see he has grasped my object in presenting the paper.

In reply to Mr. F. O. Beckett's query as to the ignition point of graphite, I am unable to state this definitely, but it is supposed to be nearly as hard to ignite as diamond (which is pure carbon), no doubt because of its compact form. Of course, all these ignition points are approximate figures, varying considerably with the mechanical state of the substance in question.

I agree with his remarks about firemen, and consider that they should be compelled to receive some sort of training, and pass a practical examination before being allowed to ship as efficient men.

As regards the forcing of boilers, I stated in my paper that boilers should not be forced beyond reasonable limits; I am aware that on occasions it is necessary to do so, but if carried to excess inefficiency will result.

Mr. Beckett later on refers to my remarks on chemical analysis of the flue gases; I wish to explain that I do not advocate the use of CO_2 recorders for marine use; on long voyages they are practically useless owing to the fouling up of the pipes, but on boiler trials and investigations, it is absolutely necessary to chemically analyse the flue gases if it be desired to ascertain whether proper combustion is being obtained.

Mr. Beckett disagrees with my remarks about the advantage of small coal over large, and says: "If you want good results from the boiler you must have good coal." With this I agree, but it does not necessarily follow that because coal is large in size, it is of good quality; what I meant was, that by using coal of a moderately small size, the contact surface is larger than it would be with coal in large lumps; that is to say, with moderately small coal the lumps present a larger surface for contact with the air than does coal in large lumps, but on the other hand coal in the form of dust or powder, lies too close and does not allow sufficient air to penetrate.

Mr. Beckett takes exception to my remarks on hand stoking; he says: "If the engineer knows his work he knows how to fire." I would point out that, however competent the engineer is, he has not sufficient time to spare to be continually in the stokehold, and to a certain extent he is in the hands of the fireman, on whom he must rely for proper air regulation to the furnaces.

With reference to Mr. Beckett's remarks on my table of non-conducting materials, I may say that asbestos is not such a good insulator as is usually supposed. Its non-combustibility is, of course, a great advantage. I have now added this to the table.

I have to thank Mr. Shanks for his remarks. I do not think they call for any comment from me.

In reply to Mr. Shackleton; I note his suggestion as to the possibility of generating gas in a producer, and then burning same under the boilers. I think the whole apparatus would be too cumbersome to recommend it for marine use.

I have to thank the Chairman for his contribution to the discussion. As regards Table II. being incomplete, I have now added the temperature at which the weight of a cubic ft. in lbs. of the various gases is taken, this is 32°F.

With reference to Mr. Clark's remarks as to the cooling of the gases of combustion, his theory appears to be that smoke is caused by want of sufficient air supply where necessary, and I think this, in the main, is correct, but it is also true that if the temperature of the fire falls too low, no amount of air will prevent the formation of black smoke. I would suggest that what happens when the furnace door is thrown wide open, is that a huge quantity of air is admitted which so thins down the smoke as to make it almost invisible; of course, if the temperature is sufficiently high, no doubt some of the hydro-carbons will be consumed, but air is far in excess of the requirements for proper diffusion and combustion.

Mr. Clark goes on to state that this cooling theory may be quite correct under certain conditions, but he would be very much surprised to find that these conditions could be found inside a boiler furnace. In reply to this I would ask Mr. Clark to consider the conditions that prevail when lighting up fires in a cold boiler; how is it that smoke is always produced then? I suggest that the temperature of the furnace being very low, the gases do not obtain sufficient heat for their combustion, and therefore pass away in the form of smoke.

Regarding Mr. Clark's remarks in reference to natural and forced draught, of course, some allowance must be made in the case of the latter for the power required for creating it, but it is somewhat difficult to obtain reliable information respecting the cost of this.

I think the suggestion made by the Hon. Secretary regarding the training of messenger boys and other lads as firemen is a very good one; great difficulty appears to exist in obtaining reliable firemen who thoroughly understand their work, and great advantage should be derived from the employment of thoroughly trained men.

ELECTION OF MEMBERS.

The following were elected at a meeting of Council held Wednesday, June 17th :—

As Members.

John Anderson, Marine Engineers' Institute, Shanghai.

William A. Driver, 16, St. Vincent Street, South Shields.

Duncan J. Finlayson, 34, Boone Road, Shanghai.

Henry M. Hall, 13, Fletton Road, Bowes Park, London.

Mark Hull, Indo-China S.N. Co., Hong-Kong.

John E. Kode, 425, Longmarket Street, Pietermaritzburg, South Africa.

Bernard May, 5, Marlborough Road, Tue Brook, Liverpool.

Peter Weir, c/o E. I. Lines, Karachi, Sind., India.

Thomas A. Seaward, 11, Inglefield Avenue, Cardiff.

Transferred from Graduate to Associate Member.

James R. Thomson, B.Sc., 30, St. Georges Road, Golders Green, London, N.W.