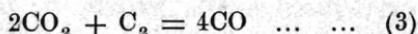


available heat from this portion of the coal will be lost. The magnitude of such a loss is thus sufficiently emphasised, but, in view of statements previously made, it should be remarked, before passing on, that it is a loss which affords no visible indication of its occurrence, and it can only be detected in practice by analysis of the flue gases.

On the face of it, the cure for a trouble of the above kind would be to provide for the admission of a larger quantity of air. Such a proceeding, however, would certainly result in an increase in the rate of heat evolution, which would doubtless not be desired, moreover, it is probable that the escape of carbon monoxide would not thus be obviated. The correct way to proceed is to consider the distribution of the air supply with regard to its admission above and below the grate.

The oxygen of the air entering through the grate will, in the first place, combine with carbon to form carbon dioxide, but if the fire be of any reasonable thickness, or if the air supply be somewhat limited, it is probable that before it escapes from the top of the fire, the carbon dioxide will be again reduced to monoxide as a result of contact with excess of incandescent carbon. This reaction differs from the preceding re-actions (3), in that it is accompanied by an absorption of heat; the re-action is symbolised by equation (3):—



It will now be evident that the desired result is to be obtained, not necessarily by a change in the total air supply; but rather, by a diminution in the quantity of air admitted below the grate, and an increase in the quantity admitted above the grate. The additional supply above the grate will oxidise the escaping carbon monoxide in accordance with equation (2), and the resulting increase in heat evolution will be counteracted by the reduction in rate of combustion brought about by cutting down the ash-pit air supply.

A distinctive feature of the fixed carbon portion of the coal, as compared with the gaseous hydro-carbons, is that the heat required to convert the molecule of fixed carbon into gaseous oxide of carbon is supplied by the combustion of the next lying molecule of fuel, and the combustion of the whole mass of carbon is therefore progressive.

Accordingly it should now be clear that true economic combustion of the fixed carbon portion of coal, and this applies also to coke, may be attained by merely paying proper attention to the distribution of the air supply, the total air supply depending on the rate of combustion desired.

The evils of the admission of air not utilised in combustion will be examined a little later in connection with the combustion of the hydro-carbons. An excessive air supply is a

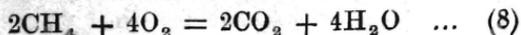
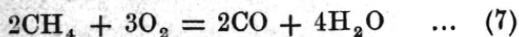
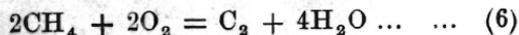
very common occurrence in practice; but, as will be seen as we proceed, even this state of affairs will by no means ensure complete combustion.

The fixed carbon portion of the coal being thus dismissed, we are now reduced to a consideration of the combustion of the gaseous hydro-carbons, but before going further it would doubtless be well to briefly indicate the difference in composition of the various grades of coal.

The various grades of coal lie between anthracite on the one hand, and bituminous coal on the other. Good anthracite coals contain comparatively a very small percentage of hydro-carbons, by far the greater part of the coal being in the form of fixed carbon. The percentage of hydro-carbons may be as low as 4 per cent. by volume of the solid coal. Bituminous coals, on the other hand, contain a relatively large proportion of hydro-carbons, amounting to as much as 40 per cent. of the whole. Lignite, peat and wood contain percentages of hydro-carbons exceeding 40 per cent., the percentage ranging from about 40 per cent. in the case of lignite to about 60 per cent. in the case of wood.

Anthracite coal needs no further consideration; it is little short of being practically pure solid carbon. It is with bituminous coals that a paper of this kind has mostly to deal, and it is these coals that are most commonly met with in practice, for they are relatively cheap and abundant, and they are also preferable in that they burn with much greater rapidity than does anthracite. The coals of New South Wales are bituminous in character, almost without exception, the percentage of hydro-carbons ranging between 20 and 40 per cent. Balmain coal lies just outside this range, containing, as it does, only about 17 per cent. of hydro-carbons. Apparently within the State there is only one known bed of coal which is of the nature of anthracite, and it is limited in extent and is quite unlikely to affect Sydney.

A discussion relating to the combustion of the hydro-carbons will probably best be opened by a brief consideration of typical chemical re-actions that are concerned in this connection. Selecting methane as an example, the following equations will serve to illustrate its behaviour under various furnace conditions:—



Equation (4) represents the simple decomposition of the hydro-carbon into its constituent elements carbon and hydrogen. Such decomposition occurs at a high temperature in the absence of air or oxygen.

Equations (5), (6) and (7) illustrate various stages in the incomplete combustion of the gas. Such incomplete combustion may be due to the supply of oxygen being insufficient, or not properly mixed with the gas, or again, it may be due to arrested combustion brought about by cooling. Cooling may be produced in a variety of ways, of which the commonest and most effective is, perhaps, that of premature contact with heating surfaces of the boiler.

Equation (8) represents the complete combustion of methane; the products of combustion being carbon dioxide and water vapour.

Under the conditions productive of the reactions represented by equations (4), (5) and (6), it will be noticed that carbon is set free. This carbon is liberated in the form of five particles which go to form soot and smoke, and thus we see how these products are produced. It will also be observed that, when the supply of oxygen is limited, the hydrogen of the hydro-carbon oxidises rather than the carbon. This is due to the greater affinity that oxygen has for hydrogen, as compared with carbon, at ordinary ignition temperatures. This observation, however, should not be made without adding that at somewhat higher temperatures carbon is able to reverse this proceeding, and even rob water vapour of its oxygen to form carbon monoxide, the hydrogen being liberated. Here again, then, we see another opportunity for very incomplete, but, at the same time, smokeless combustion.

The hydro-carbons themselves are, for the most part, practically invisible; but as they are distilled from the coal they come off in the form of a brown and choking vapour, but even in this form their comparative invisibility might readily cause them to be overlooked at the mouth of the smokestack. This fact is a further indication of the almost entire inadequacy of smoke as an indicator of furnace conditions.

The importance from an economic point of view to be attached to the proper burning of the hydrocarbons may be realised by considering the amount of heat produced by this portion of an ordinary bituminous fuel. Considering a fuel of the composition, ash 10 per cent., fixed carbon 60 per cent., and volatile matter 30 per cent., the heat produced by the volatile hydro-carbons amounts to 36 per cent. of the total heat produced by the combustion of the coal.

The hydro-carbons distil off from the fresh charge of coal much more rapidly than is often thought to be the case, and this fact should certainly be borne in mind when considering the attainment of their proper combustion.

We are now in a position to consider the conditions essential for the complete economic combustion of the hydro-carbon gases as they rise from the mass of fuel on the grate. Such conditions may be summed up in the following three statements:—

1. The temperature should be sufficiently high and maintained to cause ignition of the gases, and to maintain combustion until it is complete.
2. The supply of air should be properly distributed, and sufficient for complete combustion, but should not be excessive.
3. There should be a thorough mixing of the air and hydro-carbons.

A few remarks will now be made in connection with each of the above conditions.

The temperature required for the ignition of the hydro-carbon gases is about 1240 degrees F. In the first place the temperature of the gases must be raised to this amount in order to bring about their ignition, and, in the second place, this temperature must be maintained until combustion is complete—otherwise the gases will cease to burn. Once ignition has been effected, the burning gases will, of course, supply heat to the yet unburnt portions of the gaseous mixture, but even this supply of heat is unable to fully counteract the cooling action due to contact with water-tubes or other cool surfaces. Consequently, if such contact is premature, incomplete combustion will result. It will thus be clear that an essential implied by condition (1) is that the fire-box and combustion chamber should be sufficiently extensive, and so designed as to ensure complete combustion of the hydro-carbon gases before they come into contact with the heating surfaces of the boiler. This essential is of the utmost importance, and will well repay proper attention, but in spite of this it is almost completely ignored in local practice.

An unavoidable action, which is opposed to the fulfilment of condition (1), is that the distillation of the hydro-carbons from the solid coal is accompanied by a considerable absorption of heat. On this account freshly gasified hydro-carbons are likely to be at a comparatively low temperature. Accordingly, special provision must be made to insure that they will be properly heated, and the heating should take place as rapidly as possible after distillation or the hydro-carbons will escape from the combustion chamber before their combustion is complete. The methods employed in practice to attain this end will be understood as we proceed with Part III. of this paper.

A further cooling effect is brought about by the air which has to mix with the hydro-carbons before they can burn. The air for this purpose is mostly, if not entirely, admitted above the grate. If preheated air were used, the cooling effect would be more or less obviated, and the heating of the hydro-carbons might even be assisted. However, owing no doubt to difficulty of application and attendant expense, preheated air has thus far been very little used, moreover, excellent results may be obtained without it, although, in the case of ordinary hand-firing, its use would doubtless be of no little value, but this will also be better understood later on.

With regard to condition (2), it is barely necessary to remark, that an excess of air is to be avoided, as far as possible, in the first place on account of its cooling action on the hydro-carbon mixture, and, in the second place, on account of the loss of the heat absorbed in raising the temperatures of the excess air to that of the escaping flue gases. The loss occurring in this latter way is of considerable importance, and is another case of a loss that provides no visible indication of its presence.

Air contains approximately 21 per cent. of oxygen by volume. When oxygen combines with carbon to form carbon dioxide, the volume of the carbon dioxide so formed is equal to the original volume of the oxygen, temperature conditions, of course, being assumed to be the same. It will thus be seen that with complete combustion of carbon and air, the whole of the oxygen in the air being utilised to form carbon dioxide, a gas will be obtained containing 21 per cent. by volume of carbon dioxide. When bituminous coal is burned the hydrogen of the hydro-carbons carries off some of the oxygen to form water; as a result of this, the maximum percentage of carbon dioxide that can be obtained with such fuel is about 19 per cent. The highest figure obtainable in actual practice with bituminous fuel is about 16 per cent.

The determination and the magnitude of the loss of heat that may occur in the form of heat carried away by excessive air supply may be illustrated by the following example.

The assumption of an atmospheric temperature of 60 degrees F., a chimney gas temperature of 350 degrees F. and 8 per cent. of carbon dioxide in the flue gases will provide an example, which will come well within possibility in some of the best present-day practice. To make the example still more practical, it will also be assumed that 16 per cent. of carbon dioxide is the maximum percentage theoretically obtainable in the flue gases.

One pound of coal requires theoretically about 12 pounds of air for complete combustion. Since, however, we are assuming that 16 per cent., in place of 19 per cent., is the maximum

obtainable percentage of carbon dioxide, the amount of air required per pound of coal will be increased to 14.25 pounds.

With 16 per cent. of carbon dioxide as basis, 8 per cent. indicates that the excess air amounts to 100 per cent. of the amount of air actually utilised in combustion, that is to say, there are 14.25 pounds of excess air per pound of coal. The specific heat of air under constant pressure is 0.237, so that the heat carried away by the excess air per pound of coal amounts to:—

$$14.25 \times 0.237 \times (350 - 60) \\ = 980 \text{ B.Th.V.}$$

Assuming that the heat value of one pound of fuel is 13,500 B.Th.V., the loss of heat is thus seen to be approximately 7.25 per cent.

A chimney gas temperature of 400 degrees F. is about the maximum temperature that should be allowed in practice, but it is generally exceeded, often by a large amount. Accordingly, 350 degrees F., the figure used in the above example, is certainly on the low side. Owing to bad furnace design, 8 per cent. of carbon dioxide is a figure that is often not exceeded, even where special attention is paid to combustion.

If the flue gases contain 4 per cent. of carbon dioxide, and have a temperature of 400 degrees F., figures which are certainly not out of the way in ordinary practice, then the loss works out at no less than 27 per cent. of the total heat value of the fuel.

With regard to the question of insufficient air supply comment is hardly necessary, for its evils should by this time be sufficiently apparent. The hydro-carbons will not be properly burnt, smoke is inevitable, large volumes of carbon monoxide, and also quantities of hydrogen and unburnt hydro-carbons are likely to escape up the flue. Within reasonable limits an excess of air is certainly preferable to a deficiency in that respect.

The third condition deals with the admixture of the air and hydro-carbons. If such admixture is not efficiently brought about, it is equivalent, of course, to admitting excess of air to portions of the hydro-carbons, and insufficient air to other portions. The uneconomic results of these two proceedings have already been discussed so that further comment in this connection is barely necessary. It should be borne in mind, however, that the mixing must be very thorough, for it is necessary for each molecule of hydro-carbon to come into close proximity with the molecules of oxygen necessary to its combustion, and such admixture must be attained as rapidly as possible after distillation of the hydro-carbons, otherwise they will escape from the combustion chamber before combustion is complete.

In view of the importance, in connection with economic combustion, of obtaining proper draught conditions, it will probably not be out of place to provide a little information at this point with regard to the determination of chimney height and size of flues. The following data may be used for this purpose, and the method of applying it will be demonstrated by running through an example of its practical application.

The volume of a given mass of gas is proportional to its absolute temperature (absolute temperature equals temperature in degrees F. plus 461). In making this statement it is assumed that the pressure is constant, which is a fair assumption under the conditions existing in ordinary practice.

The density, or weight per unit volume, of a gas is inversely proportional to its absolute temperature. This observation really follows directly from the preceding statement.

The weight of a cubic foot of air at 60 degrees F. (and with barometer at 30 inches), may be taken as 0.076 pounds. The weight of a cubic foot of flue gas, under the same conditions as to temperature and pressure, may be taken as 0.08 pounds.

The height of chimney required to obtain a draught of, say, one inch of water with a chimney gas temperature of, say, 400 degrees F., may be found as follows:—A pressure of one inch of water represents a pressure of 5.2 pounds per square foot, and this must be the difference in pressure between the outside and the inside of the chimney at the grate level. The weight of a column of air at 60 degrees F. (assumed to be the atmospheric temperature for the present example), and of height H , and also of one square foot section is .076 H pounds. The weight of a similar column of flue gas at 400 degrees F. will be

$$0.08H \times \left\{ \frac{461 + 60}{461 + 400} \right\} \text{ that is } 0.048H$$

pounds. Accordingly to determine the height of chimney for a difference of pressure of 5.2 pounds per square foot under the above conditions we have the equation:—

$$0.076H - 0.048H = 5.2.$$

whence

$$H = 186 \text{ feet.}$$

We have now to consider the determination of internal sectional area of flue and chimney. As a guide in proportioning the height and diameter of a chimney it may be stated that it is considered good practice to so design the chimney that its height shall be about thirty times its internal diameter at the top.

The weight of the flue gases to be disposed of is calculated by assuming that for 16 per cent. of carbon dioxide in these gases, the amount of air required per pound of fuel will be 14.25 pounds. The amount of air to be dealt with is proportional to the percentage of carbon dioxide, so that if 8 per