CHAPTER V.

COMBUSTION OF COAL.

Fuel.—Fuel expresses in a word, and in general terms, any substance which may be burned by combination with the oxygen of atmospheric air, with sufficient rapidity to evolve heat capable of being applied to economic purposes. The economic value of any fuel will depend upon its heating power. The two elements contributing to this property of fuel are carbon and hydrogen. The more important varieties of fuel include wood, peat, lignite, coal, natural and producer gas, and petroleum. The elements of which fuel is constituted are carbon, hydrogen, oxygen, and nitrogen, inorganic matter constituting the ash. The gradual process by which woody tissue is converted into anthracite is shown in the following analytical results, in which the hydrogen and oxygen percentages are based on that of carbon.

TABLE I.—Composition of Fuel.

Fuels.	Carbon.	Hydrogen.	Oxygen.
Wood, . . .	100	12·18	83·07
Peat, . . .	100	9·85	55·67
Lignite, . .	100	8·37	42·42
Bituminous Coal, .	100	6·12	21·23
Anthracite, . .	100	2·84	1·74

(Abstract—"Combustion of Coal," by William M. Barr, M.E.)

The following table shows the chemical alterations in

approximate percentages of carbon, hydrogen, and oxygen as occurring in the different fuels :—

TABLE II.—Composition of Fuel.

Fuels.	Carbon.	Hydrogen.	Oxygen.
Wood, . . .	52·65	5·25	42·10
Peat, . . .	60·44	5·96	33·60
Lignite, . .	66·96	5·27	27·76
Bituminous, . .	76·18	5·64	18·07
Semi-Anthracite, .	90·50	5·05	4·40
Anthracite, . .	92·85	3·96	3·19

Coal is defined by Dr. Percy as a solid stratified mineral substance, black or brown in colour, and of such a nature that it can be burnt economically in furnaces or grates. It is made up of various proportions of carbon, hydrogen, oxygen, and nitrogen, and it is believed that in bituminous coals there exists ready formed definite compounds at all events of hydrogen and carbon.

Besides these ingredients, organically derived, coals contain varying amounts of what must be regarded as impurities, in the shape of mineral matters which constitute the ash and pyrites or bisulphide of iron. Sulphur in the free state is sometimes present in coal. The commercial classification of coals separate them broadly into hard and soft coals, or into anthracite and bituminous coals. The anthracite consists of semi- or gaseous, and the bituminous coals included semi-bituminous, caking, non-caking, cannel, block, and other varieties, as well as all the gradations of lignite.

In Gruner's classification of coals the following physical properties predominate :—

1. Anthracite or lean coals burning with a short flame: having a black colour and a specific gravity of 1·33 to 1·4. These coals form the transition to true anthracite. This coal is adapted for domestic use.

2. Caking coals (fat coals) burning with a short flame,

colour black, shining often with lamellar structure. Specific gravity 1·30 to 1·35. Yields 74 to 82 per cent. fairly hard coke, caked together very densely, and 12 to 15 per cent. gases. Evaporative factor 9·2 to 10. Adapted for coking and for heating steam boilers.

3. Caking coals proper or furnace coals. Burning with longer flame, in colour black, shining, lustre more marked. These coals swell under the action of heat more than those of classes 1 and 2. Specific gravity 1·30. Yields 68 to 74 per cent. caked, fairly dense coke and 13 to 16 per cent. gases. Evaporative power 8·4 to 9·2. Adapted for coking and smithy use.

4. Caking coals, long flaming (gas coal). These coals burn with a long flame. Colour dark, high lustre, hard and tough, specific gravity 1·28 to 1·30. Yields 60 to 68 per cent. caked but very friable coke, and 17 to 20 per cent. gases. Evaporation factor 7·6 to 8·3. Adapted for gas manufacture and for reverbatory furnaces.

5. Dry coals burning with a long flame, colour intense black, hard, break with conchoidal fracture (splint coal), Specific gravity 1·25. Yields 50 to 60 per cent. pulverulent coke and 20 per cent. gas. Evaporative factor 6·7 to 7·5. Adapted for reverbatory furnaces.

The ash forming constituents of coal vary from 0·5 to 30 per cent. averaging from 4 to 7 per cent. in the best coals, 8 to 14 in medium, and upward of 14, with 0·5 to 2 per cent. of sulphur in the worst. The evaporative factor as employed by Gruner means the number of times its weight of water is evaporated by a unit weight of coal starting at 100° C. or 212° F.

Anthracite is the most rich in carbon, is greatest in density, and the hardest of all varieties of coal.

Typical anthracite coal contains :—

Carbon, ...	90	to	95	per cent.
Hydrogen, ...	1	„	3	„
Oxygen and Nitrogen, . .	1	„	3	„
Moisture, ...	1	„	2	„
Ashes, ...	3	„	5	„

It is slow to ignite, conducts heat badly, burns at a high temperature, radiates an intense heat, and once ignited is difficult to quench.

Anthracite coals from Wales and Pennsylvania :—Heat unit in one pound of coal = 13,648, which is equal to an equivalent evaporation of 14·13 pounds of water from, and at, 212° F. per pound of coal. Bituminous coal is between lignite and anthracite, it is very inflammable and burns with a red smoky flame. All coals containing 18 or 20 per cent. of volatile combustible matter are classed amongst bituminous coals. Some contain as much as 50 per cent. of volatile combustible.

Coke is the solid product left after the expulsion of the volatile matter from coal by the action of heat. Coke contains from 80 to 96 per cent. of carbon, ash 2 to 15, hygroscopic moisture 1 to 5, and is capable of absorbing from 5 to 10 per cent. additional water if exposed to the weather.

Combustion is any manifestation of chemical energy by combination, and accompanied by the evolution of heat. In steam engineering it means the controlled chemical combination of the elements, carbon, and hydrogen in the fuel, with the oxygen of the atmosphere, by which an evolution of heat is secured and maintained in a suitably constructed furnace, for generating steam or heating metals. In this sense combustion means incandescence or the glowing whiteness of a body caused by intense heat, which is quite characteristic of burning carbon. Combustion, then, consists in the union of the oxygen of the atmosphere with the substance which is being burnt, and the visible signs of combustion—*i.e.*, the heat and light, are the result of chemical energy.

Coal is mainly composed of two elements, carbon and hydrogen, both of which have an affinity for oxygen, but before they unite chemically to produce heat it is necessary that certain conditions be fulfilled, the first of which is that a considerable quantity of the coal must be heated to the point of ignition before the oxygen in the air will unite with it. The oxygen having a choice of two partners, as Professor Tyndall happily puts it, closes with that for which it has the strongest attraction. It first unites with the hydrogen and sets the carbon free. Innumerable solid particles of carbon thus scattered in the midst of burning hydrogen are raised to a state of incandescence. The carbon, however, in due time closes with the oxygen, and becomes, or ought to become, carbonic acid.

An isolated piece of coal will not burn in the open air because the temperature will soon fall below the point of ignition and consequently chemical action will cease, but an ignited mass of coal, as in a furnace or a stove, will give off great heat, depending upon the quality and quantity of coal burned : but once the hydrogen having united with the oxygen to form water, and the carbon with the oxygen to form carbonic acid gas, their mutual attractions are satisfied and all the heat has been evolved that is possible under any conditions.

Oxygen and hydrogen unite in the ordinary processes of combustion in one proportion only, viz., 2 atoms of hydrogen unite with 1 atom of oxygen, the product of the combustion being aqueous vapour, or water, H_2O. Oxygen and carbon unite in the ordinary process of combustion in two proportions, viz., 1 atom of carbon and 2 atoms of oxygen, the product being carbon dioxide, CO_2, but in the absence of sufficient oxygen 1 atom each of carbon and of oxygen will unite, the product being carbon monoxide, CO. Thus oxygen is an active supporter of combustion, and will unite chemically with the hydrogen and the carbon in the fuel, with characteristic flame followed by a body of incandescent carbon on the grate which will continue to burn at high temperature and with great brilliancy until entirely consumed, if a proper supply of atmospheric oxygen is furnished.

By weight, air consists of 23 per cent. of oxygen and 77 per cent. of nitrogen. Therefore 77 ÷ 23 = 3·347 pounds of nitrogen accompanies each pound of oxygen. By volume 1 pound of air averages 12·5 cubic feet, of which 21 per cent. or 2·625 cubic feet is oxygen, and 79 per cent., or 9·875 cubic feet is nitrogen. One pound of Carbon requires for its complete combustion to CO_2 about 12 pounds of air or 150 cubic feet, of which 21 per cent. or 31·5 cubic feet is oxygen and 79 per cent. or 118·5 cubic feet is nitrogen.

One pound of hydrogen requires, for its complete combustion to H_2O, 8 pounds of oxygen supplied by 31 pounds of air or 387·5 cubic feet, of which 21 per cent. or 81·375 cubic feet is oxygen and 79 per cent. or 306·125 cubic feet is nitrogen.

Ignition is simply the act of raising to the point of chemical change, and must not be confused with combustion, which is the chemical change. Every combustible must be heated to a certain definite temperature before it will combine with oxygen. This temperature is usually called the point of ignition, or, its kindling temperature.

In furnace combustion the temperature of ignition cannot be much less than dull red, say, 800° to 900° F., and this will maintain an active fire. For steam boiler furnaces the combustion is quite active even for moderate fires, and the temperature of the incandescent bed of fuel seldom if ever below 1,100° to 1,200° F., and usually much higher than that, while the full furnace temperature may range from 2,000° to 3,000° F. One pound of carbon combining with 2 pounds of oxygen results in perfect combustion, the product being carbonic acid gas, CO_2, developing 14·500 heat units, but if insufficent air, which means insufficent oxygen, is present, then the ultimate product will be carbon monoxide, CO, and only 4·450 heat units are developed—*i.e.*, 10·050 less than when CO_2 is formed. This represents a loss approximating 60 per cent. of the fuel merely as a result of insufficient air in the fire at the right time and place. The effect of too much air in the fire is the mechanical one of cooling the furnace. The carbon having united with its full combining weight of oxygen to form CO_2, can take up no more oxygen, and any surplus air in the furnace is merely a diluent of the gases. Inasmuch as the free air abstracts heat from the furnace, and does no useful work, its presence acts against the economy of the furnace. One hundred and fifty per cent. excess air in steam boilers is no uncommon thing.

Products of Combustion.—The principal products of the combustion of coal are: carbonic acid gas, carbonic oxide, nitrogen, air (if furnished in excess), and unconsumed gaseous steam. Hydrogen unites with oxygen forming gaseous steam which upon cooling is condensed into water, H_2O. This chemical combination is complete and the product incombustible.

As stated previously, the products of the combustion of carbon in oxygen are two in number, carbon dioxide, CO_2, and carbon monoxide, CO. Each compound is sharply defined and exhibits properties distinct from the other, and of the elements of which it is composed. The quantity of carbon remaining the same, the quantity of oxygen must be doubled in order to form the other compound. These proportions constitute the only two direct inorganic compounds of carbon and oxygen.

"Carbonic acid gas," CO_2, is composed of one part or atom of carbon and two parts of oxygen, its atomic weight being $12 + (16 \times 2) = 44$. By percentage of volume, carbon = 27·27, oxygen = 72·73 = 100·00. Its specific gravity is 1·53, air = 1·00. It is a colourless inodourous, heavy gas, neither combustible nor a supporter of combustion.

Carbon monoxide, CO, is composed of 1 part or atom each of carbon and oxygen, its atomic weight being $12 + 16 = 28$. By percentages of volume carbon = 42·86, oxygen = 57·14 = 100·00. Its specific gravity

is 0·9678, air = 1·0000. It is a colourless, tasteless, combustible gas. Pure carbon monoxide forms a colourless transparent liquid under 200 to 300 atmospheres pressure at —139° C., and it solidifies to a snowy mass in vacuo at —211° C.

It burns with a blue flame which by previous heating becomes red, producing carbonic acid gas, CO_2. The temperature of its flame in air is about 1,400° C. It is a highly poisonous gas, producing giddiness and ultimate asphyxia when inhaled.

Sulphur combines with oxygen to form sulphurous oxide, SO_2, a colourless gas with a suffocating odour. It is a non-supporter of combustion, instantly extinguishing flame when brought within its influence.

Whatever the quantity of air required for the perfect combustion of carbon or hydrogen, there will remain in the furnace 3·35 pounds of nitrogen for every pound of oxygen combined with the fuel, or by volume, 3·76 volumes remain in the furnace for each volume of oxygen uniting with the fuel. Nitrogen is incombustible, and so far as the other products of combustion in the furnace are concerned it is wholly inert.

The term ashes includes all the mineral matter left on the grates after the complete combustion of fuel. Coal ashes are found to consist mainly of silica, alumina, lime, and oxide and bisulphide of iron.