

CHAPTER VII.

FUEL.

Classification of Fuel.—The term fuel is applied to substances that may be burned by means of atmospheric air with sufficient rapidity to evolve heat capable of being applied to economic purposes. In some cases the products of combustion are used for effecting metallurgical reactions, while in others the fuel is consumed simply for the sake of the heat generated.

Fuels may be of ancient or modern origin, and may be divided into two classes—(I.) Natural fuels, and (II.) Prepared fuels.

The first class includes—(1) wood and the various kinds of mineral fuel, (2) turf or peat, (3) lignite, (4) bituminous coal, and (5) anthracite. Besides these, various liquid hydrocarbons, such as petroleum, are found in sufficient quantity to render their employment possible on a large scale. At Pittsburg in Pennsylvania and at other localities combustible gas occurs naturally, and in the United States is largely used for metallurgical purposes.

The second class includes—(1) compressed fuels, which are composed of more or less pulverulent material consolidated into bricks, with or without cementing agents; (2) dried fuels, or those in which the water and a certain proportion of the more volatile constituents have been expelled by heat, examples being afforded by wood, lignite, and peat; (3) carbonised fuels, such as coke and charcoal; (4) liquid fuels, obtained by distillation or as by-products; and (5) gaseous fuels, obtained (a) by the distillation, partial or entire, of natural fuels, or (b) by their incomplete combustion.

The value of all these fuels depends upon the amount of carbon and hydrogen they contain. The majority of them contain oxygen, nitrogen, sulphur, and phosphorus, as well as a certain amount of inorganic material which ultimately forms the ash. The amount and nature of this ash is of great importance, and it will be evident that if the fuel can be deprived of its ash-giving constituents by treatment before combustion its value will be

greatly increased. The hydrogen that is in excess of the quantity required to form water with the oxygen in the fuel is alone available for combustion, and is termed the available hydrogen. The remainder of the hydrogen is regarded as being already in combination as water, and may be viewed as an actual source of loss, because this water has to be vaporised when the fuel is burned. Cellulose ($C_6H_{10}O_5$) contains no available hydrogen, whilst cannel coal contains a considerable quantity.

The temperature at which fuels kindle varies considerably. Slow oxidation may, it is true, take place at ordinary temperatures, but in metallurgical practice it is only comparatively rapid combustion that is really useful. Extreme density and, on the other hand, great tenuity equally hinder inflammability. For the former reason, anthracite, diamond, and graphite are ignited with great difficulty. Fuels richest in hydrogen are the easiest to ignite, the inflammability of resinous wood and of bituminous coal being due to this fact. Combustible gases, however, do not ignite below a cherry-red heat, on account of the extreme dispersion of their molecules.¹ The inflammability of vegetable charcoal depends upon the temperature at which it is prepared. Thus, when wood is carbonised at 300° to 400°, the charcoal ignites at 360°; and when a temperature of 1200° to 1300° has been employed, ignition cannot be effected below 600° to 800°. This is due to the fact that the hydrogen is driven off almost entirely at the higher temperatures. Peat ignites at 225°; pine wood at 295°; ordinary coal at 325°; coke, anthracite, hydrogen, and carbonic oxide at a dull-red heat.

The length of flame given by fuel in burning is so important that coals have advantageously been classed as "long-flaming" and "short-flaming." Certain fuels disengage at the moment of combustion a large proportion of volatile matter, and these constitute the long-flaming varieties. The manner in which the fuel is burned, however, has a great effect upon the flame. Charcoal, for example, if burned with free access of air, merely glows; but if burnt with a limited supply of air in a thick layer so arranged that the products of combustion from the lower portion pass through the upper, carbonic oxide will be formed, which will burn with a blue flame. The volume of the flame depends, amongst other conditions, upon the velocity of the current of air by which the combustion is effected, the volume decreasing as the velocity rises.

Calorific Power.—The calorific power of a fuel is the total heat generated by the combustion of a unit of weight of the fuel. The heat is measured in two ways, either by the number of units of weight of water raised 1°, or by the number of units of water evaporated. The latter method, which was proposed by Prof.

¹ Frankland, *Phil. Mag.*, vol. xxxvi. (1868), p. 309. See also Ernst, *Chemisches Repertorium*, vol. xvii. p. 2.

Rankine, gives numerical results equal to the former divided by 537 when the centigrade scale is used. In expressing the calorific power of a fuel, the amount of heat generated on the combustion of carbon to carbonic anhydride is taken as the standard of comparison. This calorific power of carbon is expressed by the number of parts by weight of water capable of being heated from 0° to 1° C. by the combustion of one part by weight of carbon. It is found by direct experiment to be 8080 units. The unit of heat varies with the thermometric scale and the unit of weight employed. The unit most largely adopted, the metric unit or *large calorie*, is the quantity of heat required to raise 1 kilogram of water from 0° to 1° C.; whilst the British thermal unit is the amount of heat required to raise 1 lb. of water 1° Fahr. Thus 1 *calorie* = 3.96832 British units, and 1 British unit = 0.251996 *calorie*. Expressed in equivalent foot-pounds, 1 *calorie* = 1390.

For experimentally determining the calorific power of a fuel, a *calorimeter* is employed. Count Rumford's calorimeter consisted simply of a vessel filled with water, containing a worm-pipe through which the products of combustion passed from a funnel outside. In this way they imparted their heat to the water, whose rise in temperature was noted. All calorimeters are similar in principle to Rumford's. In the more modern instruments, however, the vessel in which the combustion takes place is entirely surrounded by water and by an air jacket.¹

If a fuel consists only of carbon and hydrogen, its calorific power may be calculated by multiplying the weight of each of the elements in one part of the fuel by their respective calorific powers as found by experiment. For example, a fuel consists of 85.71 per cent. of carbon and 14.29 per cent. of hydrogen. What is its calorific power? The calorific powers of carbon and hydrogen are respectively 8080 and 34,462, and

$$\begin{aligned} 85.71 \times 8080 &= 692536.80 \\ 14.29 \times 34462 &= 492461.98 \end{aligned}$$

$$\hline 1184998.78$$

which is the heat evolved on the combustion of 100 parts of the fuel. This, when divided by 100, gives 11849.98 as the calorific power of the fuel. So simple a case as this is rarely met with, it being usually necessary to determine the amount of available hydrogen in the fuel, and to multiply the result by 34,462.

When a compound is burned in oxygen or air, the heat evolved is not the same as would be evolved by the combustion of proportional weights of the constituent elements in the free condition, but may be either greater or less, according to whether the body

¹ On calorimeters, consult *Gas and Fuel Analysis*, A. Gill, 1901; *The Calorific Power of Fuels*, H. Poole, 1905; *Fuel, Water, and Gas Analysis*, J. B. C. Kershaw, 1907.

was formed with absorption or evolution of heat, and the difference will be the heat of formation of the body. In the case of solid fuels, the heat of formation of the different constituents is quite unknown, and it is usual, in calculating the calorific power, to assume that the constituents give out in burning the same amount of heat they would do if in the free state.

For commercial purposes, actual experiment is the best method for obtaining the calorific power of fuels.

Calorific Intensity.—The calorific intensity or pyrometric effect of a fuel is the highest temperature which the fuel is capable of producing when burnt in air. Measurements of calorific intensity are based on the fact that the heat produced by combustion is transferred to the product of combustion, and it may be determined by calculation on the assumption that the calorific intensity of a simple combustible body burnt in oxygen is equal to its calorific power divided by the product of the relative weight of its products of combustion and the specific heat of those products, or, expressed as an equation,

$$t^{\circ} = \frac{W \times C}{w \times c},$$

where W represents the weight of the substance, C the calorific power of the substance, w the weight of the product of combustion, and c its specific heat. For example, the calorific intensity of carbon burnt to carbonic anhydride in oxygen is—

$$\frac{12 \times 8080}{(12 + 32) \times 0.22} = 10016^{\circ}.$$

The calorific intensity of carbonic oxide burnt to carbonic anhydride is—

$$\frac{28 \times 2403}{(28 + 16) \times 0.22} = 6950^{\circ}.$$

If the substance is a mixture, the weights and specific heats of the various products of combustion must be introduced. In determining the calorific power of hydrogen, the water obtained is assumed to be in the liquid state. In determinations of the calorific intensity, however, the water is in the form of gas. From the calorific power, therefore, must be subtracted the amount of heat which would be given out on cooling the steam to 0°. For one part of water at 100° this would be 537 *calories*. Again, in raising the product of combustion from 0° to t°, a greater amount of heat will be needed to raise it the first 100° while that product is liquid than would have been required if it had been gaseous. These two amounts of heat are in the proportion of the specific heats of steam and water, that is, as 0.4805 is to 1. Hence the extra quantity of heat to be added

to the 537 calories is $(1 - 0.4805) 100$, or 51.95 calories. The calorific power must therefore be decreased by $(51.95 + 537) 9$, or 5300.5 calories, since 1 part of hydrogen yields 9 parts of water. Hence the calorific intensity of hydrogen is—

$$\frac{1 \times (34462 - 5300.5)}{9 \times 0.4805} = 6743^\circ.$$

The calorific intensity is merely a theoretical quantity, as it is based on the assumptions that the products of combustion of the fuel have constant specific heats for all temperatures, and that they absorb all the heat produced. Neither of these assumptions is true, inasmuch as the specific heats of gases generally increase with the temperature and there is a considerable amount of heat lost by conduction and by radiation; dissociation also limits the temperature. The computation of calorific intensity has consequently but little commercial value.

The calorific intensity of a fuel may be found by direct experiment by means of *pyrometers*.

I. NATURAL FUELS.

1. **Wood.**—When dry, wood consists of 96 per cent. of woody tissue (cellulose, $C_6H_{10}O_5$) and 4 per cent. of sap. A small proportion of inorganic matter is also present, and, when recently felled, all wood contains a large proportion of water. The mean composition of well-dried wood is—

Carbon.	Hydrogen.	Oxygen.	Nitrogen.
50.0	6.0	42.0	2.0

—or, roughly, 50 per cent. of carbon and 50 per cent. of chemically combined water. Air-dried wood contains 40 per cent. of carbon, 40 per cent. of chemically combined water, and 20 per cent. of hygroscopic water. The proportion of ash-giving constituents varies from 1.2 to 2.3 per cent., the average percentage being 1.5. The ash consists of about 70 per cent. of calcium carbonate, 20 per cent. of alkaline carbonates, together with varying amounts of alkaline sulphates and chlorides, silica, phosphoric anhydride, magnesia, ferric oxide, manganous oxide, and alumina. The specific gravity of wood varies considerably. Air-dried woods, with 20 per cent. of moisture, having a specific gravity of more than 0.55, are classed as *hard*; with a lower specific gravity they are classed as *soft*. After the air has been completely expelled from the pores of the wood, the specific gravity is in all cases nearly the same, varying only from 1.48 to 1.53. The calorific intensity of wood is small, but its combustibility and the amount of flame it gives are very great. The large percentage of hygroscopic water renders wood unsuitable as a fuel in cases where

high temperatures are required, and the rapid demolition of forests tends to increase its cost.

2. **Peat.**—Peat or turf is the product of the slow decay of plants under conditions in which the supply of air is limited. It is formed chiefly from the mosses *Sphagnum* and *Hypnum*, with other plants. It may be classed, according to the localities where it has been produced, as highland and lowland peat, according to its age as recent peat, and as old peat with only traces of organic texture, and, lastly, according to the mode in which it has been extracted, as “cut peat” or “dredge peat.”

Peat deposits are widely distributed throughout the world. In Ireland it is estimated that the peat area is not less than one-seventh of the island. That of Great Britain covers six million acres, with an average depth of 12 feet. Extensive deposits are met with in the United States, Canada, and Russia, where peat is of metallurgical importance, in North Germany, Austria, and Scandinavia.

The composition of peat is extremely variable, the proportion of water and of ash-giving constituents having so great an influence that it is almost impossible to estimate its average composition. The best air-dried peat still contains 25 per cent. of hygroscopic water. From numerous analyses, the composition of pure peat, exclusive of moisture, has been found to be as follows:—

Carbon.	Hydrogen.	Oxygen.	Nitrogen.
49.6 to 63.9	4.7 to 6.8	28.6 to 44.1	0.0 to 2.6

—in which the ratio of the oxygen (with the nitrogen) to the hydrogen is as 5 or 6 : 1.

The proportion of ash-giving constituents varies from 1 to 30 per cent. and more, being rarely below 10 per cent. The ash consists chiefly of lime, ferric oxide, and silica, together with phosphoric acid, sulphuric acid, and carbonic acid, and, in considerable quantities, alkalies, alumina, and magnesia. Raw peat also frequently contains iron pyrites. The high percentage of ash and of water, together with its bulk, are the main objections to the use of peat as fuel. For an equal evaporative power, its bulk is from 8 to 18 times that of coal.

Numerous methods have been adopted for freeing peat from ash and moisture. They consist chiefly in the subdivision of the peat into minute fragments. These are washed and dried, with or without compression.

The calorific power of peat varies inversely as the amount of water and ash it contains. For peat without ash and water, the calorific power is 5237, whilst for ordinary air-dried peat it does not exceed 3000.

The specific gravity of peat varies, with the proportion of ash and the mode of preparation, from 0.25 to 1.4.

3. **Lignite.**—Brown-coal and lignite occupy an intermediate place between peat and true coals, there being no abrupt break in the compositions. Indeed, the transition from woody tissue to anthracite is gradual, as is well shown by the following tabular statement, in which the carbon is represented as a constant quantity:—

	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

(Percy.)

The term "lignite" is used by British and American writers as synonymous with the brown-coal of the Germans. It is usually applied to those varieties of coal which are older than peat and more recent than the coals of carboniferous age. Many writers, however, erroneously confine the term "lignite" or "brown-coal" to coals of the Tertiary epoch. Four fairly distinct types of lignite may be distinguished:—(1) Fossil wood, fibrous brown-coal, the lignite of the Germans, which has a distinct ligneous texture; (2) Earthy lignite, without structure and earthy in fracture; (3) Conchoidal lignite, without any distinct vegetable structure, and with a conchoidal fracture; (4) Bituminous lignite, a black, shiny fuel, sometimes resembling anthracite, and having a conchoidal or earthy fracture. For metallurgical purposes the first three types only are of importance, the fourth type being used more frequently as material for the production of tar than as a fuel.

When recently raised from the mine, lignites contain as much as 33 per cent. of moisture, and even more. When air-dried, however, they lose half this amount. The proportion of ash varies from 3 to 30 per cent. The ash contains lime, alumina, and silica, together with magnesia, some alkalies, and ferric oxide, and an appreciable quantity of sulphuric acid, but, as a rule, no phosphoric acid. The mean percentage composition of lignite is as follows:—

Variety.	Carbon.	Hydrogen.	Oxygen.
1. Fibrous	57 to 67	5 to 6	28 to 37
2. Earthy	45 to 70	5 to 6	25 to 30
3. Conchoidal	65 to 75	4 to 6	21 to 29
4. Bituminous	70 to 80	6 to 8	12 to 24

Lignite burns with a long, smoky flame. The calorific power varies considerably, the mean calorific power of the four varieties being—(1) 5000, (2) 5700, (3) 6500, and (4) 7000 *calories* respectively. The value of lignite as fuel would thus appear to be considerable, but in practice complete desiccation is hardly attainable, and a high percentage of moisture is always retained. The only practical method of increasing the calorific power of lignite is by removing this moisture, and for this purpose drying in air, heating in kilns, or compression has been attempted with considerable success.¹

Lignite, however, is very little used for metallurgical purposes, except in districts where no other fuel is available.

4. **Coal.**—Coals formed previously to the Cretaceous period are distinguished from lignites by their deep-black streak, great density, and friability. The fracture is more lamellar, the ligneous texture having disappeared. When subjected to dry distillation they yield a greater amount of carbonaceous residue, and the condensed products contain less water than is the case with fuels of more recent age. Coals contain very little water, and when dried at 100° they are considerably less hygroscopic than wood and lignite. The specific gravity of pure coal, with a low percentage of ash, varies from 1·2 to 1·4, the density being in direct proportion to the percentage of carbon. A cubic yard of coal averages 18 cwt. in weight. The proportion of coke left on distillation varies from 50 to 90 per cent., and the composition of coal varies within the following limits:—

Carbon.	Hydrogen.	Oxygen.
75 to 93	6 to 4	19 to 3

With the oxygen is included 1 to 2 per cent. of nitrogen. In coals, the ratio of the oxygen (with the nitrogen) to the hydrogen varies between the wide limits of 1:1 to 4:1.

Coals may be classified according to the length of the flame and the character of the residue which is left when they are subjected to dry distillation. The old classification, based solely on the character of the coke produced, divided coals into two classes, *caking* and *non-caking*, according as the coke produced formed a compact or pulverulent mass. Percy classed coal into three varieties—(1) non-caking or free-burning, rich in oxygen; (2) caking; (3) non-caking, rich in carbon. This classification is based on the chemical composition of the coals, and therefore on their calorific power. Grüner was led to adopt a more detailed classification, in which five types are distinguished:—

(1) *Non-caking Coals with Long Flames.*—These coals, which most closely approach lignites, when subjected to dry distillation yield 55 to 60 per cent. of pulverulent coke, the evolution of

¹ Zincken, *Physiographie der Braunkohle*, Hanover, 1867-71.

volatile gases giving rise to a long, smoky flame. The composition varies within the following limits:—

Carbon.	Hydrogen.	Oxygen and Nitrogen.
75 to 80	4.5 to 5.5	15.0 to 19.5

—the ratio of the oxygen to the hydrogen being 3:1 or 4:1. The calorific power generally varies from 8000 to 8500. Coals of this type are of common occurrence in Scotland, Derbyshire, and Staffordshire.

(2) *Caking, Long-flame Gas-coal.*—Coals of this type contain—

Carbon.	Hydrogen.	Oxygen and Nitrogen.
80 to 85	5 to 5.8	10 to 14.2

—the ratio of the oxygen to the hydrogen being 2:1 or 3:1. They yield on slow distillation 60 to 68 per cent. of caked, but very friable and porous, coke, and 32 to 40 per cent. of volatile matter, of which 17 to 20 per cent. is gas. The calorific power generally varies from 8500 to 8800.

(3) *Bituminous or Furnace Coal.*—These coals are black, not very hard; they burn with a smoky flame, at the same time softening and intumescing in the fire. They contain—

Carbon.	Hydrogen.	Oxygen and Nitrogen.
84 to 89	5 to 5.5	5.5 to 11

—the ratio of the oxygen to the hydrogen being 1:1 or 2:1. They yield 68 to 74 per cent. of caked and swollen coke, and 15 to 16 per cent. of gas. The calorific power varies from 8800 to 9300.

(4) *Caking Coals with Short Flame.*—These contain—

Carbon.	Hydrogen.	Oxygen and Nitrogen.
88 to 91	4.5 to 5.5	5.5 to 6.5

—the ratio of the oxygen to the hydrogen being 1:1. They yield 74 to 82 per cent. of caked and very compact coke, and 12 to 15 per cent. of gas. The calorific power varies from 9300 to 9600.

(5) *Anthracitic Coals.*—These burn with a short flame, and have the following composition:—

Carbon.	Hydrogen.	Oxygen and Nitrogen.
90 to 93	4 to 4.5	3 to 5.5

—the ratio of the oxygen to the hydrogen being 0.5:1 or 1:1. These coals form the transition to true anthracites. On coking, they yield 82 to 92 per cent. of pulverulent or fritted coke, and 12 to 8 per cent. of gases. The calorific power varies from 9200 to 9500. Coals of this type are met with in South Wales and in Pennsylvania.

The percentage of ash yielded by the several varieties of coal ranges from 1 to 30, but seldom exceeds 7. The ash consists

mainly of silica, with alumina, lime, magnesia, ferric oxide, and manganic oxide. Sulphur is also frequently present, but the proportion of phosphorus is usually inconsiderable.

5. *Anthracite.*—This is the ultimate product of the conversion of vegetable matter into coal. Its colour is jet black, with a vitreous lustre; its structure homogeneous, and its fracture conchoidal.

The mean of a large number of analyses gave the following as the composition of true anthracite, free from ash:—

Carbon.	Hydrogen.	Oxygen and Nitrogen.
93 to 95	2 to 4	3.0

The proportion of nitrogen varies from 0.55 to 2.85 per cent.; and the ratio of the oxygen to the hydrogen 1:1 to 1:0.5. Anthracite burns almost without flame, and the carbonaceous residue remaining after distillation shows no signs of caking. The anthracite of Pennsylvania is employed on a large scale in the manufacture of pig-iron. In the United Kingdom this is not the case, as our anthracites will not stand a high temperature without disintegration.

It must be borne in mind that "coal" is a popular rather than a scientific name, as it is frequently applied not only to beds of fossilised vegetation, but to all mineral substances capable of being used as fuel. According to Frémy,¹ true coal may be distinguished from lignites by its insolubility in hypochlorites, and its very imperfect solubility in nitric acid.

Coals having widely different properties may be proved by analysis to contain exactly the same amounts of carbon, hydrogen, and oxygen, so that in the respective cases the grouping of these elements must vary greatly. Coals, in fact, may be isomeric.

It is found that the calorific power of true coal and lignites increases with the proportion of coke left by distillation, and the student will do well to bear in mind that the calorific value of a coal may be better estimated by weighing the coke left after strongly heating the coal in a covered crucible, and taking into consideration the percentage of ash, than by calculations based on a chemical analysis of the sample. The class to which the coal belongs may also be best determined by this method of distillation in a closed vessel, which enables the relative amounts of water, bituminous matter, and coke to be ascertained. The method of coking in a covered crucible also gives valuable information as to the nature of the coke.

6. *Liquid Fuels.*—Under the general term of *petroleum* is included a series of natural hydrocarbons. These usually occur in nature impregnating clay, marl, sand, and schist, sometimes sufficiently to render the rock combustible. The high percentage of ash in such fuels prevents them from being used direct, and, as a

¹ *Comptes Rendus*, vol. lii. (1861), p. 114.

rule, renders it necessary to subject them to distillation, which yields tar products, oils, and gases. The so-called "Boghead mineral," a bituminous schist of the Scotch coal measures, yields—

Ash.	Fixed Carbon.	Combustible Gases.
19.60	10.13	70.10

Cannel coal is a fuel of a similar character, but with a low percentage of ash. It burns with a long, smoky flame, and has the following percentage composition:—

Carbon.	Oxygen.	Hydrogen.	Ash.
85.0	8.0	5.0	2.0

It yields 42 per cent. of volatile matter. When the bituminous constituents of these rocks occur in sufficient quantity, naphtha and petroleum springs, or deposits of solid asphalt, are formed. At Baku in the Caspian Sea and in Pennsylvania mineral oils are obtained in enormous quantities by means of deep boreholes. The oil regions of the United States produced in 1906 over 130,000,000 barrels, each of 42 gallons, and in the same year Russia produced over 7,000,000 metric tons, equal to 50,000,000 42-gallon barrels.

Petroleum contains a very high proportion of hydrogen. On distillation from crude petroleum a product is obtained containing 79.82 to 88.5 per cent. of carbon and 11.5 to 20.18 per cent. of hydrogen. The boiling-point of petroleum varies from 110° to 280°, and the calorific power of the crude oil is 10,000 *calories*, a calorific power which is greater than that of refined oil.

The oil is employed in practice by burning it in a trough, by effecting its combustion in a spray or finely divided form by injecting it with a jet of steam or air, or by converting it into gas before combustion.¹

7. **Natural Gas.**—In the oil regions of Pennsylvania and of the adjoining States, natural gas issues from the strata at a depth of 500 to 2000 feet below the surface; and when boreholes are sunk to the accumulated gas, it rises under a pressure of some 200 lbs. per square inch. When first reached, the gas is sometimes evolved at the enormous pressure of 1000 lbs. per square inch. Compared with air, the gas has a density of 0.45 to 0.55, and varies in volumetric composition within the following limits:—

CH ₄ .	H.	N.	C ₂ H ₆ .	C ₂ H ₄ .	CO ₂ .	CO.
60 to 80	5 to 20	1 to 12	1 to 8	0 to 2	0.3 to 2	trace

It has a calorific power of 14,000 to 15,600 *calories*, and a calorific intensity of 2745° to 2765°. Natural gas has long been used in

¹ On petroleum, consult Redwood, *Petroleum and its Products*, C. Griffin & Co., Ltd., 1907.

Pennsylvania to a limited extent for heating purposes. Since 1883, however, it has attained a remarkably rapid development for industrial purposes, and is now largely used in Pittsburg for metallurgical purposes.

The territory containing the source of natural gas includes a section of country extending from Western New York, through Pennsylvania, into West Virginia and Ohio, and to Canada.

II. PREPARED FUELS.

1. **Compressed Fuels.**—Numerous attempts have been made to prepare a good fuel by mixing some binding material with small coal in proportions sufficient to enable the particles to cohere so as to be pressed into a block or *briquette*. Potato-meal, soluble glass, asphalt, and turpentine have been used as binding materials, but abandoned, whilst coal-tar and pitch have been successfully used for the purpose.

2. **Dried Fuels.**—The advantages derived from the expulsion of the water and a certain proportion of the more volatile constituents of wood, peat, and lignite have already been pointed out.

3. **Carbonised Fuels.**—On heating fuels without access of air, their constituents rearrange themselves in the form of solid, liquid, and gaseous compounds. For metallurgical purposes, the object of this operation is often only to obtain the solid constituent, charcoal or coke, which consists of carbon with subordinate amounts of hydrogen, oxygen, and ash-giving constituents, and which has a high calorific intensity. At the same time, the by-products obtained during the carbonisation are frequently utilised. The carbonised fuels to be considered are—(a) charcoal, and (b) coke.

(a) **Charcoal.**—This name is given to the carbonised residue remaining after the dry distillation of wood. When wood is heated to 200° without access of air it remains unaltered; at 220° it becomes brown; and at 270° to 300° it suffers decomposition, torrefied wood (*Rothholz*) being formed. At 350° it is resolved into a fixed residue, or charcoal, and volatile products. Good charcoal prepared at a temperature of 350° to 400° retains the structure of the wood from which it was derived, the volume being less. It is black, porous, and burns without smoke, and, in separate pieces, without flame. The specific gravity of porous charcoal varies from 0.28 to 0.54 according to the nature of the original wood and the temperature at which it was made. Charcoal prepared at 350° is considerably lighter than that prepared at the melting-point of platinum. Hard woods give a dense and heavy charcoal, whilst soft woods give soft and friable charcoal. The chemical composition also varies considerably, the percentage composition of charcoal

prepared at 340° (I.), and at the melting-point of platinum (II.), being as follows:—

Carbon.	Hydrogen.	Oxygen and Nitrogen.
I. 75.20	4.41	19.96
II. 96.52	0.62	0.94

The ash of the first charcoal was 0.48, and of the second 1.94 per cent. On an average, dry charcoal contains 90 per cent. of carbon, 3 per cent. of hydrogen, and 7 per cent. of oxygen and nitrogen.

The charcoal used in metallurgical operations is prepared by various methods, which may be divided into two groups—viz. methods of charring (1) in the open air and (2) in closed chambers. For charcoal-burning in the open air a suitable site is necessary. This should be dry, and sheltered from any prevailing wind. Water should be at hand for quenching the charcoal when made. The wood employed must be mature, cut while free from sap, barked, and air-dried for some months.¹

When the charring is effected in circular piles, or *meilers*, the bed is made to slope from the circumference to the centre at an inclination of 1 in 15. Three stakes, 10 to 15 feet high, are driven in near the centre, so as to form a central triangular chimney. Around this, the timber, cut into suitable lengths, is stacked horizontally and radially. The mass is then covered with a mixture of fine charcoal and clay, and then with sods, with the grassy side inwards. To keep this covering up, wedges are driven in, and props put in so as to form hoops around the lower part of the pile. Brushwood is then thrown down the chimney and ignited, vents being made near the top of the pile. This causes a cone, with the apex downwards, of the pile to be charred, and, by opening vents lower down, the angle of the cone is enlarged. This process is continued until the base is reached. When the smoke issuing from the pile is seen, by its blue colour, to be free from aqueous vapour, the charring is complete. The charcoal is then drawn from the bottom of the pile, and in small quantities quenched with water or dust. Small piles are carbonised in six to fourteen days; but if the diameter be more than 30 feet, the process occupies a month.

Logs as much as 24 feet in length may be charred in rectangular piles. They are laid together in the form of a wedge, of which the breadth is limited by the length of the logs. The heap is 20 to 30 feet long, and 7 to 9 feet high at the upper end, and only 3 feet high at the lower end. It is surrounded on all sides with a layer of sods and charcoal dust, and by a wooden covering supported by vertical stakes. On the top is placed a

¹ On charcoal-burning, consult G. Svedelius' *Handbook for Charcoal Burners*, translated from the Swedish by R. B. Anderson and W. J. L. Nicodemus (New York, 1875).

roof of twigs, leaves, and charcoal dust. At the lower end a horizontal chimney is left. Vents are opened at the opposite end so as to give planes of charring. Rectangular piles are used in Sweden and in Austria. In China the carbonisation is effected in pits provided with a chimney communicating with the bottom.

Experiments, on a large scale, on the amount of charcoal yielded gave the following results:—In France, with circular piles of 2120 to 3180 cubic feet, the yield by weight was 17 to 21.3 per cent.; in Belgium, on charring wood fifteen to twenty years old, half hard, half soft, the yield at the ordinary rate was 15 to 17 per cent., but when charred more slowly, 20 to 22 per cent.; in Sweden, from pine wood, the yield was 20 to 28 per cent. By volume, the yield of charcoal varies from 50 to 75 per cent.

By using closed ovens the yield of charcoal may be somewhat increased, and valuable by-products obtained from the gases, which may afterwards be used for heating the ovens. Peat may be charred, like wood, in heaps or in kilns. Peat-charcoal, however, on account of its lightness, friability, and its high percentage of ash, is not adapted for metallurgical purposes, and its application has not advanced beyond the experimental stage.

(b) *Coke*.—Coke is the carbonaceous residue from the dry distillation of coal. Good coke should possess sufficient strength to withstand the pressure in a blast furnace without crushing. For this reason only those coals which give on dry distillation a coherent residue can advantageously be used. The coals of the second, third, and fourth groups of Gruner's classification are suitable for coking. A high percentage of ash has a detrimental influence on the coke produced, and must therefore be removed by subjecting the coal to a preliminary washing.

Coke varies considerably in its external characters. It may be porous and light, or compact and heavy; black and dull, or light grey and bright, with a semi-metallic lustre. The porosity of coke induces a tendency to absorb gas. Like charcoal, coke is hygroscopic, absorbing 1 to 2.5 per cent. of water from air at the ordinary temperature. When dipped in water, coke will absorb 20 to 50 per cent. The calorific power of coke, free from ash, is 8000, or nearly that of pure carbon.

The earliest method of preparing coke was by carbonising coal in the open air in heaps without any external covering. A more economical method is by carbonising the coal in mounds, piled round a central octagonal chimney. The mound is ignited at the top, and the operation proceeds exactly as in charcoal-burning. The mounds are usually 12 to 21 feet in diameter and 9 to 15 feet high. The yield after five days' coking is 65 per cent. of the theoretical quantity.

In Upper Silesia, rectangular kilns have been used for coking for many years. They are cheap, easy to work, and give a large output, but, like the mounds, they do not yield a uniformly coked

product. They are chiefly used for coking coal slack. These kilns, or Schaumburg coke-ovens, fig. 122, have two fixed parallel walls 18 yards long and 5 feet high. The walls are 8 feet apart, and are provided with a series of square openings 2 feet apart and 1 foot above the sole, the apertures, *c*, in one wall being opposite those in the other. From each aperture ascends a vertical flue, *d*, which may be closed with a tile. In order to charge the kiln one of the open ends is bricked up, and moistened coal slack is stamped in up to the level of the apertures. From the apertures in one wall wood stakes are placed across, the ends passing into the corresponding apertures on the opposite side, and the whole kiln is filled with moistened slack and covered with loam. On withdrawing the stakes, the passages formed communicate with the horizontal apertures and with the vertical flues in the side walls. The process consists merely in starting the combustion and regulating the air current in the flues, and is complete in

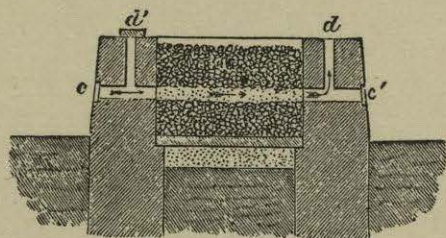


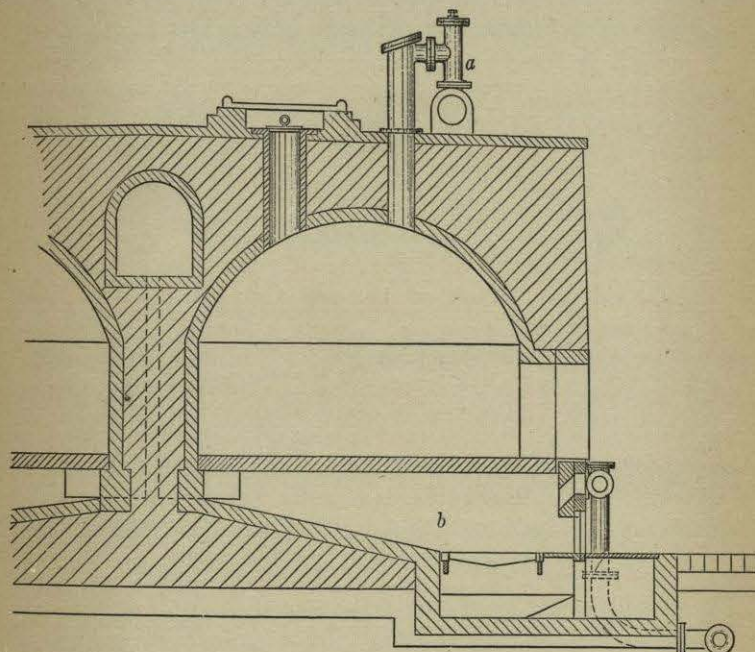
FIG. 122.

about six days. The flues are then closed, and the coke, after cooling for two days, is withdrawn at the open end.

These wasteful methods of coking are now generally superseded by coking in ovens of brick or stone, in which carbonisation is effected mainly by the heat resulting from the combustion of the volatile products evolved during the process, the aim of the coke-burner being to bring air into contact with these gases, but to prevent its contact with the coke formed.

The coke-ovens that have been introduced to obviate the loss of heat occurring in heaps and kilns are of very various types. The simplest form resembles a beehive or a baker's oven. This is a sort of covered-in mound or meiler. It is lined with fire-bricks, and air is admitted through a doorway closed with loosely piled up fire-bricks. There is thus, as in cases of the mound and kiln, partial combustion in the coking space itself, and so some coke is burnt. The cavity of the oven is 6 to 12 feet in diameter and $4\frac{1}{2}$ to 9 feet in height. The doorway is about $2\frac{1}{2}$ feet square, and the coke is drawn through it and quenched in the open air. In some cases the coke is cooled in the ovens before it is drawn, by watering it by means of a hose. This quenching, by

double decomposition, removes some of the sulphur from the coke in the form of sulphuretted hydrogen. Sometimes the ovens have the form of a rectangular chamber 10 feet deep, 12 feet wide, and 10 feet high. The working of the ovens is very simple. On the base, heated from the last charge, or on a layer of slack, the coal ($1\frac{1}{2}$ to $4\frac{1}{2}$ tons) is charged in. The door is then closed and carbonisation commenced. If the oven is cold, before shutting the door, fire is introduced, and the lower holes in the doorway are left open. The coking proceeds from the top downwards, the draught-holes being successively

FIG. 123.—Pernolet Coke-oven. *a*, gas outlet; *b*, bottom firing flue.

stopped as the level of the carbonisation sinks. The coking lasts from seventy-two to ninety-six hours, and the coke is often left in a further ten or twelve hours before being drawn.

Of modified beehive ovens, designed with a view to effecting a saving of by-products, the three following have received some recognition.

The Pernolet coke-oven (fig. 123) differs but little from the ordinary beehive, but it has a fireplace and grate, and the gas is carried into the upper collecting-tube, *a*, and returned to the bottom flue, *b*, where it is fired with solid fuel.

At the Almond Ironworks, Falkirk, Mr H. Aitken¹ adapted

¹ *Trans. N. Eng. Inst. M.E.*, vol. xxix. (1879).