CHAPTER XIV

THE GENERATION OF POWER: TRANSPORT

CHEMICAL compounds and even elements may be regarded as stores of energy. During a chemical reaction some of this energy may be dissipated in the form of external work, and there will also occur an evolution of energy as heat or perhaps an absorption of heat from the surroundings. Often both the work done and the heat developed are utilised as potent sources of energy. This is true of the fuel substances such as coal, coke, petrol, gas, oil. A valuable source of mechanical and electrical power is that of water flowing through a turbine. Though this power does not happen to be the outcome of a chemical reaction, advantage is frequently taken of the chemical reactions that occur in the various storage batteries or accumulators used for its storage. Thus in the ordinary lead accumulator, and the Edison iron-nickel accumulator, charging consists of oxidising the metals to higher stages of oxidation and discharging involves the decomposition of the higher compounds previously formed, and the re-liberation of energy as electric power. In the simple primary cells, chemical reactions take place on closing the external circuit which then converts chemical energy into electrical energy. Chemistry has also provided means of rectifying alternating currents in the form of both " wet " and " dry " rectifiers.

The fuels that are used to-day are, as a rule, rich in carbon which is more or less in a state of chemical combination. This applies to coal, petroleum, wood, peat and " natural gas." Another fuel-substance found in these materials is hydrogen. It is a remarkable fact that in using these materials we are deriving heat and power from the products of the decomposition of the vegetation and animals of remote ages. Whilst it is generally held that coal is the final product of decomposing vegetable matter, there is much to indicate that petroleum and natural gas owe their origin, if not entirely, to the animal kingdom.

Natural Gas.

" Natural gas " is usually found in the earth associated with petroleum, though this is not exclusively the case, for there are places in the U.S.A. where natural gas is found unassociated with petroleum. For instance, many unsuccessful attempts have been made to locate petroleum in economic quantities in the celebrated Monroe, Louisiana, gas-field. On emerging from the ground, natural gas is a complex mixture of gases, of which hydrocarbons form the major portion. Nitrogen, carbon dioxide, oxygen, sulphuretted hydrogen and helium are sometimes present in very small amounts. After purification, a dry gas can be prepared which contains approximately 80% to 85% of methane, 15% to 20% of ethane and the remainder of nitrogen. Ordinary coal gas has a heating value of 500 to 560 British Thermal Units. Natural gas has a calorific value of about 1,000 B.T.U. (1 B.T.U. = heat required to raise

1 lb. of water through 1° F = 0·25 kg.-cals. = 250 calories). Because of its high heating value, its cleanliness and convenience in use, natural gas is finding considerable use in public and home lighting, cooking and heating, and in industry. Of this gas no less than 1,568,139,000,000 cubic feet were utilised in 1928. Natural gas is distributed over extensive districts in the U.S.A. by means of long pipe-lines, some being nearly 500 miles in length, whilst one from Panhandle to Chicago, a distance of 900 miles, is being seriously proposed. Besides serving as a valuable fuel, natural gas is an important material in the catalytic production of synthetic chemicals and in the manufacture of lamp-black, a finely divided carbon obtained by burning methane and required in making telephones and for incorporation in rubber.

HELIUM.

Some reference will here be given to helium, in view of its occurrence in certain natural gases in amounts that are sufficiently large to render its recovery economic. Although this rare gas is found in the atmosphere, the amount is much too small to serve as a commercial source of helium. The United States Government is operating helium plants near Amarillo, Texas, and at Fort Worth. The capacity of the Amarillo works is stated to be 24 million cubic feet per annum, whilst in the year ending June, 1930, 9,801,060 cubic feet were actually produced. While the original use of helium was that of filling dirigibles, the supply has assumed a magnitude that exceeds the present requirements of the U.S. Army and Navy, and new uses are now being sought, e.g., in food preservation. Exportation of the gas is expensive owing to its bulk and cost of containers. Although helium is not quite so light as hydrogen, it has a lifting effect of roughly 65 lbs. per 1,000 cubic feet which, coupled with its not being inflammable, makes the gas extremely valuable in airship construction. Some details of the new airship, ZRS—4, at present being built by the Goodyear-Zeppelin Corporation for the U.S. Navy, will illustrate the relative merits of helium and hydrogen. This airship will have a capacity of 6,500,000 cubic feet of helium, which will enable a gross weight of over 210 tons to be lifted, including the weight of the helium itself, viz., 35 tons. Using hydrogen instead of helium, the gross lift would be 203 tons, of which 17 tons would be hydrogen, so that by inflating the airship with helium the net weight actually lifted would be 175 tons compared with 186 tons in the case of the hydrogen-filled airship. The difference in lifting power is thus seen not to be great, and when the safety conferred on the airship by using helium is considered, it will be realised that we have in it a gas that will play a great part in airship construction. It has been estimated that about £55,000 would purchase 5½ million cubic feet of helium which would have been necessary to fill the ill-fated hydrogen-filled British Airship R 101.

The use of hydrogen constitutes a great source of danger on account of its inflammability, and incidentally the losses of gas by diffusion through the gas-bags are greater when hydrogen is used.

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We shall now consider some of the principles underlying the use of fuels as sources of heat-energy, and for the sake of simplicity, we shall confine our attention to the heat developed during the combustion of carbon, this being the chief constituent of fuels. The various stages in the combustion of carbon in oxygen are (1) the conversion of the carbon into carbon monoxide and (2) the combustion of the carbon monoxide with more oxygen to form carbon dioxide, the final product of combustion. The first stage may be expressed thus :

$$2C + O_2 \longrightarrow 2CO + 58 \text{ Calories},$$

i.e., during the combustion of 24 grams of carbon with 32 grams of oxygen to form 56 grams of carbon monoxide, 58 Calories of heat are emitted. (See page 128.) The second stage is :

$$2CO + O_2 \longrightarrow 2CO_2 + 136 \text{ Calories},$$

or expressed in words : 56 grams of carbon monoxide on complete combustion (with 32 grams of oxygen) cause 136 Calories to be evolved. Hence, if the original 24 grams of carbon undergo complete combustion, 58 + 136 = 194 Calories will be liberated. In other words, 1 lb. of carbon on burning to carbon monoxide, of which $2\frac{1}{3}$ lbs. will be formed, will cause 1,096 Calories to be emitted. On complete combustion to carbon dioxide ($3\frac{2}{3}$ lbs.), a further supply of 2,571 Calories will result, so that on subjecting the pound of carbon to complete combustion in one step 3,667 Calories will be given out. Thus it is seen that in burning carbon to carbon monoxide, approximately one-quarter of the total possible heat is obtained. Moreover, the volume of carbon monoxide formed is considerable and unless a plentiful supply of oxygen is available much of this gas will escape without undergoing the final and greater heat-giving stage of combustion. It is extremely likely that in the ordinary fire and even in the furnace fire, in which solid fuel is used, the maximum amount of heat is never realised through incomplete combustion. On the other hand, where gas (which contains a large proportion of carbon monoxide) is the fuel, together with an adequate supply of air, it is possible to effect the second reaction completely with the development of the maximum heat.

The problem of securing complete combustion is very intimately connected with the question of smoke abatement. The ideal condition for complete combustion is to get the fuel into the gaseous state, for then it is in the form of simple molecules which seems to be essential for their reaction with oxygen. Thus with liquid fuels even though they can be vapourised and mixed with oxygen previous to ignition, it is found that the process of burning is somewhat complicated owing to the greater complexity of the molecules. For this reason, the heavier oil fuels necessitate "atomisation" by forcing through fine jets in order that the subsequent vaporisation may be as effective as possible. Solid fuels, such as coal, however, are made up of aggregates of exceedingly complex molecules which themselves cannot be gasified. The consequence is that the oxygen required to cause complete combustion is unable to get into contact with all the fuel molecules and even those molecules which come into contact with the oxygen are so complex that they often do not undergo complete disruption. Burning occurs, but not with the complete molecule. This results in carbon as soot and less complex molecules, e.g., those of the higher hydrocarbons, passing off from the fire in the hot gases. Complete combustion seems to be possible only with carbon monoxide and gaseous mixtures of the type of "water-gas," viz., a mixture of equal volumes of carbon monoxide and hydrogen. As the molecules become more complicated such as those of methane, CH_4; acetylene, C_2H_2; benzene, C_6H_6; ethane, C_2H_6; the higher hydrocarbons, e.g., those found in petrol, the possibility that each molecule will always encounter the requisite number of oxygen molecules for complete combustion at the same instant becomes increasingly unlikely. In consequence, free carbon may be liberated as in the old-fashioned luminous gas flame, which may subsequently burn or produce a sooty smoke, or in the case of the petrol engine, a deposition of carbon on the cylinder walls. Combustion of complex molecules occurs in successive stages, before the final products, carbon dioxide and water, are formed. On account of the difficulty of bringing solid fuels into contact during combustion with sufficient oxygen, attempts are being made to increase the heat-output by the utilisation of pulverised fuels. In England the practical application of pulverised fuel is still in its infancy, but in the U.S.A. 25 million tons of coal were consumed in that manner in 1928. Pulverised fuel is being adopted in the engines of steamships. Burning is carried out by forcing jets of powdered coal into combustion chambers through which air is passed.

The desire to obtain efficiency in regard to the fuelling of furnaces has at the same time tended to reduce the passage into the atmosphere of tarry and sooty smoke. This striving for the efficient and clean combustion of coal in the domestic grate has not been so marked. Until the modern and, unfortunately, more expensive methods of smokeless heating have through a pipe to a burner fixed near the ceiling in one of the rooms of his house. Outdoor illumination was shown to be possible in 1802, when it was used to celebrate the Peace of Amiens. The streets of London were lit by coal gas in 1812. Naked gas flames were then the source of light. They obtained their luminosity from the partial combustion of such ingredients of coal gas as olefines, acetylene and benzene and the consequent existence of glowing particles of carbon in the flame. The introduction and adoption of the incandescent gas mantle has eliminated the need of these illuminants, as it is now only necessary that the flame shall acquire sufficient temperature when in contact with the mantle to make the thorium oxide incandescent. Hence the heating capacity of the gas is its essential property, whether it be used for lighting or heating. For this reason, charges are now made for gas, not on the volume consumed, but on its total heat energy, estimates of which are based on measurements of its calorific value when exploded, together with an excess of oxygen, in a calorimeter (see page 130). The Gas Regulation Act of 1920 decreed that gas should be sold by the "Therm," being 100,000 B.Th.U. The ordinary process of manufacturing gas is to heat the coal in retorts, which nowadays are usually vertical, at a temperature in the vicinity of 1,000° C. The gas so obtained contains about 50% of hydrogen, 30% of methane, 8% of carbon monoxide and the remainder of impurities, viz., nitrogen, carbon dioxide and oxygen. The gas is often enriched as far as heating is concerned by increasing the proportions of carbon monoxide and hydrogen. This is done by blowing steam through the white hot coal in the retorts,

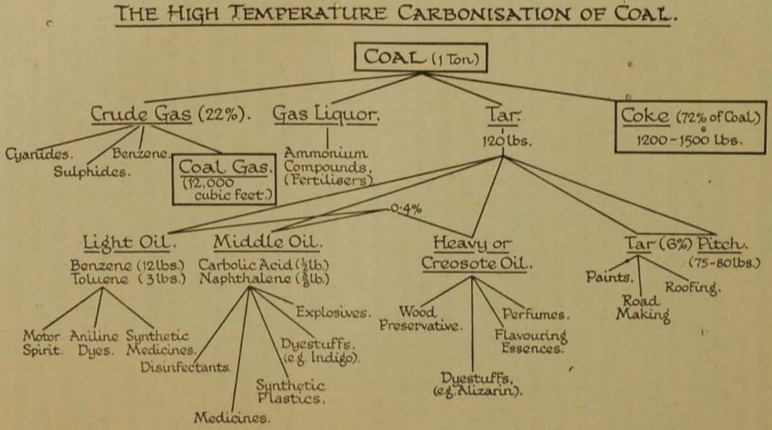
THE HIGH TEMPERATURE CARBONISATION OF COAL.
COAL (1 Ton)
Crude Gas (22%).
Gas Liquor.
Tar.
120 lbs.
Coke (72% of Coal)
1200 – 1500 lbs.
Cyanides.
Sulphides.
Benzene.
Coal Gas.
(12,000 cubic feet.)
Ammonium Compounds, (Fertilisers).
0·4%
Light Oil.
Benzene (12 lbs.)
Toluene (3 lbs.)
Middle Oil.
Carbolic Acid (½ lb.)
Naphthalene (⅜ lb.)
Heavy or Creosote Oil.
Tar (6%) Pitch.
(75-80 lbs.)
Motor Spirit.
Aniline Dyes.
Synthetic Medicines.
Disinfectants.
Medicines.
Synthetic Plastics.
Dyestuffs, (e.g. Indigo).
Explosives.
Wood Preservative.
Dyestuffs, (e.g. Alizarin).
Flavouring Essences.
Perfumes.
Paints.
Road Making
Roofing.

Fig. 61.

somewhat reluctant to substitute coke, even the newer type of coke, for coal.

With the ever increasing demands being made for motor fuels and the various countries desiring to become independent of foreign supplies, another source has been found by Dr. Bergius, of Mannheim,

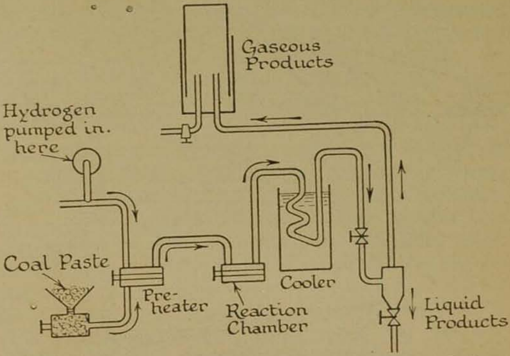

FIG. 62.—Bergius Process for the Production of Oil from Coal.

wherefrom 110 to 130 gallons of distillable oil per ton of coal treated can be obtained. Much of this can be used as motor fuels and lubricants, as shown in the chart on page 232. Bergius' method, "berginisation," consists of acting on ground coal, mixed with a liquid organic vehicle so as to form a paste, with hydrogen under an initial pressure of 200 atmospheres and a final pressure of 60 atmospheres at temperatures ranging from 460° to 490° C.

A possible source of a useful fuel gas, methane, is that of anærobic fermentations, such as those which tioned that gas derived from sewage tanks has been passed into the main gas-pipes of Essen during the last five years.

We have seen in the previous paragraph that one of the products of the putrefaction of organic matter is the hydrocarbon, CH_4. Petroleum, which is a mixture of liquid and solid hydrocarbons of increasing molecular complexity, is, in all probability, the outcome of animal and vegetable decomposition. In general, the great petroleum deposits of the world are found in sands, sandstones and other porous rocks which are superimposed on impermeable beds. These oil-bearing strata are usually buried beneath impermeable strata, so much so, that the submerged petroleum becomes subjected to terrific pressures. Hence on boring through the upper stratum and perforating an oil-bearing stratum, the sudden diminution in pressure may be so great as to cause the petroleum to force its way up through the well to form "gushers." A well struck in the Baku field in 1886 projected the oil at times more than 350 feet above the surface, and could not be got under control until a fortnight had elapsed. Another excellent example is that of a well struck near Tampico, Mexico, during the Great War. No less than 9 million gallons of oil were forced into the air in the first day. Usually, the supplies are not so plentiful and require to be drawn up by means of pumps.

The existence of petroleum was known to the ancients. Herodotus referred to the petroleum exuded from the earth in Persia in 460 B.C. The petroleum deposits of Baku yielded natural gas which was considered to produce "sacred fire," and in consequence fire temples were established. The Pitch Lake, of

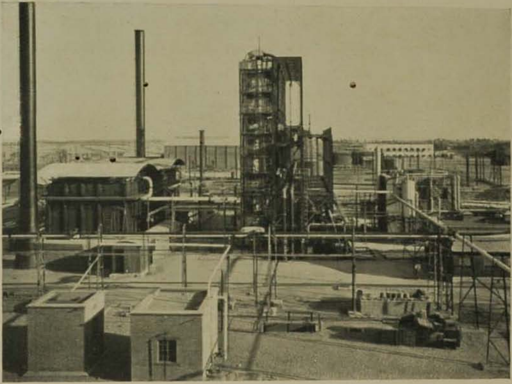

FIG. 64.—Modern Crude Oil Distillation Plant—Side View.
(Courtesy, Messrs. Anglo-Persian Oil Company, London.)

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For years, lamp oil, lubricants and paraffin wax were the only valuable products that could be derived from crude petroleum oil. Very little use could be found for the most volatile fractions which distilled over first, in fact if they were allowed to remain in the fraction used as lamp oil they became a positive source of danger. As the oil-vessel became heated they evaporated and there being no outlet in the old wick lamps, explosions and fires often resulted. This risk became so great that legislation was necessary concerning the production of kerosene. But oil-lamp lighting and candle-lighting were doomed to fall into disuse owing to the improvements made in gas and electric lighting. If no other use for petroleum products could have been found, it is certain that the petroleum industry would have fallen into insignificance. The situation, however, was changed, almost miraculously, by the invention of the internal combustion engine. Although this engine can work on such fuels as benzene and alcohol, supplies were expensive and limited, and would not permit of any great application of the petrol engine. There were, however, large and cheap supplies of the light boiling fractions of petroleum. Hitherto, they were the waste products of the petroleum industry. Now they had become the most important products, in fact the petrol engine and petrol are complementary factors, which together have been responsible for the wonderful strides that have been made in modern locomotion on the land and the sea and in the air.

Petrol has now become one of the necessities of modern civilisation. Unfortunately, nearly 90% of the world's population live in Europe, Africa and Asia, but the present output of these continents of tor, for which His Law calls before it can answer in active response. Thus the beautiful prayers of others are their prayers, not ours. We share their beauty in the admiration and inspiration which it conjures in us, but their turning to God is their own, as ours is our own. Only on our own wish, expressed in our own way, or not expressed, will God, by His Law, turn helpfully toward us. We know this by that free will and choice with which He has endowed us.

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There, at its Convention in Cleveland, "Reform Judaism" is talking about the "perpetuation of Judaism." Yes, the perpetuation of theirs is in question. But it is not Judaism; it is many removes from it. Judaism is not in question, can never be, however Jews may be. Judaism is of eternal verity. It rests in the Shema with its consequent "Love thy neighbor as thyself". Therein works the Law, comprised of God's beneficent, so-loving laws. How can anything affect this in the least? We can affect ourselves but not the Law. We do affect ourselves according as we are related or not related, to the Law. The light of the dear God and all the warmth of His love works therein.

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solvent in which the gases happen to be soluble, or (*c*) absorption by "activated charcoal."

Various substances, which can be made to acquire a structure made up of an intricate system of very fine capillaries, are able to absorb vast quantities of gases by passage into their interior. Such substances are charcoal, so-called silica gel, spongy platinum, etc. Advantage is often taken of this property in the purification of gases from which impurities may thereby be removed by preferential absorption if a suitable absorbing agent has been employed. In petroleum refining, the undesired hydrocarbons are thus removed by the charcoal. Silica gel has been used to remove water vapour from damp air. Thus if any moisture is present in the air blown through the glowing charge of a blast-furnace, a reaction occurs which causes a lowering of the temperature. This difficulty is now being overcome in certain works by submitting the air to silica-gel, whereby any water vapour is preferentially absorbed. The treatment of air with silica-gel before being passed into hospital wards set aside for respiratory cases in the John Hopkins Hospital, U.S.A., has found to yield beneficial results.

The next stage in the refining of petroleum is that of fractional distillation in which a volume of oil is heated in a retort, so that on gradually raising the temperature, fractions, that boil within any desired range of temperature, distil off and may be collected in the order of their increasing boiling points. The following gives some idea of the fractions usually collected: (1) aviation spirit (petroleum ether), 40° to 70° C.; (2) solvent naphtha, 80° to 120° C.; (3) motor spirit, 40° to 190° C.; (4)

Hydrogenation of cracked oils may ultimately be employed to increase the production of motor-spirit.

In the internal combustion engine (see Fig. 66) an explosive mixture of air and petrol vapour passes from the carburettor into the cylinder. Immediately the piston has been pushed back as far as possible, the piston commences its compression stroke in which it pushes the explosive mixture back into the combustion space. At this point, the gas is ignited by the timed action of the sparking plug. The gas in the immediate vicinity of the spark inflames and the flame is propagated in wave motion throughout the whole volume of the gas. The products of the reaction :

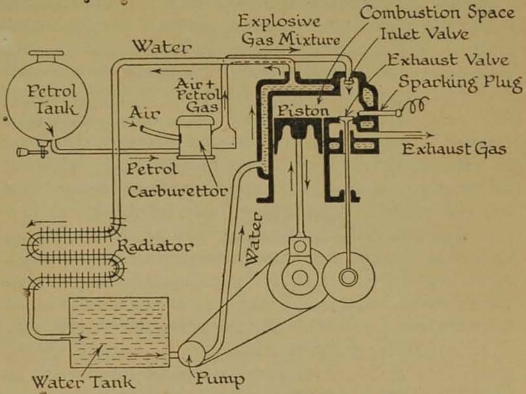

FIG. 66.—Schematic Diagram of the Petrol Engine.

of the experiments of Egerton, would appear to lie in their power to raise the temperature at which ignition normally occurs and thus to render the " knocking " explosion difficult. It is a curious fact that the higher saturated hydrocarbons assist knocking, whereas benzene, alcohol and methyl alcohol prevent it. A " dope " now widely used as an anti-knock is lead tetraethyl, $Pb(C_2H_5)_4$. A compound of iron and carbon monoxide, iron carbonyl, is similarly used in Germany. When added to petrol (Shell), Egerton has found that lead tetraethyl raises the ignition temperature from 460° C. to 542° C. He states that one part of lead tetraethyl in 1,500 parts of petrol (i.e., about 5 c.c. of ethyl fluid per gallon) will permit of the use of a compression ratio up to 6 : 1 and give an increase of at least 10% of power thereby. If all petrol were thus " doped " it would entail about 40,000 tons of lead per annum, which is about 2% of the world's production. Petrol so treated is marketed as " Ethyl Petrol." In it, ethylene dibromide, $C_2H_4Br_2$, is also placed to prevent the sparking plug points from being covered with finely divided lead.

Much anxiety exists in those countries that have no natural oil supplies in regard to the production within their borders of possible substitutes for petrol. Provided suitable engines are constructed, alcohol may be successfully used. Unfortunately many of the materials now used in its manufacture are important foods, e.g., potatoes and sugar. Catalytic methods of synthesising alcohols especially methyl alcohol, have now become commercial realities in Germany, England and the U.S.A. Countries that are able to manufacture calcium carbide by virtue of possessing cheap water-power are also converting