engine. Lately Sir Charles Parsons has introduced gear for reducing the necessarily high turbine speed to one more suitable for the propeller, and this will much extend the use of the turbine in marine engineering.

The development of the internal-combustion engine belongs almost entirely to the last half-century. On it has depended all aircraft and submarines, and most mechanical road transport. The first satisfactory gas engine was that of Dr. Otto in 1876. Dowson, in 1878, introduced producer gas, emancipating the engine from dependence on illuminating or town gas; and Benier soon after invented the suction producer. The Germans developed the large-cylinder, high-powered gas engine chiefly for utilising blast-furnace and coke-oven gas—a waste product. Sir Dugald Clerk, who has led the way in this country in developing the gas engine, and especially in studying its theory, estimates that there were gas engines of $5\frac{3}{4}$ million h.p. at work in 1909.

The first paraffin engine was that of Priestman in 1885. The Diesel oil engine, introduced in 1893, has perhaps the greatest thermal efficiency of any heat engine.

The petrol engine, which has made the conquest of the air possible, was greatly improved during the war, and is the lightest of heat motors. An aeroplane engine of 850 h.p. is stated to weigh only 1.63 lb. per h.p.

The future of air transport has very great promise, but it looks as if for commercial purposes the airship has advantages over the aeroplane. In coastal patrol and anti-submarine work naval airships carried out 9000 patrols covering $1\frac{1}{2}$ million miles. Engineers interested believe that an airship capable of carrying 1000 persons at 80 miles an hour is in reach of present practice. Attempts are being made to produce helium to replace hydrogen in the envelope, removing one source of danger.

Mr. Lanchester has reminded us that, with

Government help largely withdrawn, the aeronautical industry is in the position of a youth luxuriously brought up who finds himself face to face with the fact that he has to earn his own livelihood.

Structures and machines should be designed with adequate strength and at the same time with the least necessary material. In the old view the strength limit was the statical breaking weight, and the ratio of this to the working stress was termed the factor of safety. Wöhler's research in 1871 proved that, in ordinary conditions of continual variation of stress, fracture occurred with much less than the statical breaking weight, and depended on the range of variation of stress. Bauschinger showed that the position of the elastic limit changed with repetition of straining action, and that the range of elasticity appeared to be the same as the range of stress, which could be sustained indefinitely. Bairstow and Stanton have confirmed this. Osborne Reynolds constructed a machine in which continuous changes of stress in a test bar could be produced by the inertia of reciprocating weights.

In the period under consideration there has been a great extension of public and private mechanical testing laboratories. The National Physical Laboratory and the Bureau of Standards, Washington, are now Government institutions. In the U.S.A. very large testing machines have been constructed, several of 600 tons capacity, and one of 5000 tons at Pittsburgh. For testing full-size members such as bridge ties, reinforced concrete columns, etc., such machines are necessary. Though new tests of materials must be adopted with great caution, tests of hardness and tests of brittleness have been found useful. Guest, Scoble, and others have investigated compound stress, and found that in ductile materials the limit of resistance is the greatest shear stress. A very great advance has been made in the delicacy and accuracy of strain measuring instruments.

THE TREND OF MODERN METALLURGY.

BY PROF. H. C. H. CARPENTER, F.R.S.

METALLURGY is the art of extracting metals from their ores, refining them, and working them up into finished products for the use of mankind *at a profit*. The inevitable corollary of this is that the economic factor is always decisive as to the applicability or otherwise of any new scientific discovery which bears upon the industry. The art is one of the oldest in the world, but in spite of its highly diversified character and the profound influence that scientific methods have had upon its scope and technique, it does not differ to-day in essence from the ancient art except in the fact that to an ever-increasing extent the applications of science are found to be payable.

In attempting a survey of the present position
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and tendencies of the great metallurgical industries, only the broadest treatment is possible. Accordingly, no account will be taken of the usual subdivision of the subject into ferrous and non-ferrous metallurgy. Rather does there appear to be an advantage in omitting this distinction which has no scientific basis, but is purely one of custom.

The first stage in the passage from the mineral as mined to the manufactured metal is "ore-dressing," and here a very notable advance, made in the last few years, has to be recorded. The old method of "gravity" concentration, whereby the ore after being crushed was suspended in water and treated in a variety of machines for the concentration of the metallic contents, which,

being specifically heavier, tended to sink, while the lighter gangue floated, never, at its best, gave an extraction of more than 82 per cent. In the "flotation" process of to-day the sulphide ore particles are made to float on a froth produced by the agitation of the pulp with the addition of a small amount of oil and acid, while the gangue, although specifically lighter, sinks. The flotative agent is air, the froth being stabilised by the particular oil mixture used. Surface tension and not gravity is the principle utilised in the separation. The method has been principally applied to the concentration of copper sulphide and mixed lead and zinc sulphide ores. Its largest application has been in copper reduction work in America, where many millions of tons of ore are being treated to-day. At Anaconda the total recoveries in the concentration process have been raised from 76 per cent. to as much as about 95 per cent. There can scarcely be any doubt that flotation has a great future as a concentrator of metal values. At the present, however, it is limited to sulphide materials. For that reason it has had no effect on the metallurgy of iron, where the mineral is either an oxide or a carbonate; but it seems likely to have a very wide application to the principal economic minerals of copper, lead, zinc, gold, and silver, especially when the two latter contain base metal values.

Thus far the concentration has been mechanical—i.e. there has been no change in the chemical composition of the mineral itself. In the next stage, in the great majority of cases, "smelting" or "reduction" begins, which has for its object the conversion of the ore into a metal, usually unrefined. Hitherto the shaft or blast furnace has held its own, with coke as the fuel. This furnace has had its principal recent development along the lines of better charge distribution, and, in the iron industry, more efficient hot blast stoves and more economical power plants. Fifteen years ago many furnacemen were satisfied with almost any distribution of charge they happened to get from the apparatus installed, but this most important operation cannot be ignored without causing low output and high coke consumption. Distributors are now in use which give the charge a columnar structure with alternate columns of coarse and fine ore, instead of uniform layers produced by most systems of filling. Highly beneficial results are claimed for this improvement.

Hitherto the reverberatory furnace has been markedly inferior to the shaft furnace from the point of view of thermal efficiency. For this reason only the ore which was in too fine a state of division for treatment in a shaft furnace was smelted in a reverberatory. The very extensive application of gravity and flotation concentration, particularly to copper ores, with the fine grinding which these processes involve, has, however, necessitated the smelting concentration of such materials in these furnaces. Until comparatively recently the best practice in the reverberatory furnace concentration of copper ores was about 4.8 tons of charge per ton of coal, against about

8 tons of charge per ton of coke in the blast furnace. Here, too, a remarkable improvement during the last five years has taken place. This is due, in the main, to three factors:—

(1) To the increased efficiency of burning coal in the form of dust as compared with burning it on a grate.

(2) To maintaining a very large mass of the charge piled along each side of the furnace, which increases the speed of heat absorption.

(3) To the augmented size of the hearth, which has now reached a length of about 143 ft. and a width of 30 ft.

For successful practice, the coal, before pulverising, must be dried to a maximum of 1 per cent. of moisture. It must be finely pulverised, since the increased surface thus obtained has a direct bearing on the efficiency. Upwards of 80 per cent. should be capable of passing through a 200-mesh sieve. The delivery of coal and air must be controlled so that the proper proportion between them is maintained, and the coal itself must contain enough volatile combustible matter to give the required combustion. Only a few years ago it used to be reckoned that to smelt from 230 to 270 tons of charge per 24 hours was good work. The current practice to-day in the new furnaces is to smelt between 600 and 700 tons, and the ratio of charge to fuel has been brought up to about 7:1, which raises the reverberatory furnace almost to a level with the blast furnace from the thermal efficiency point of view. Certain of these large reverberatories are fired with oil, and very satisfactory results, as regards both economy in fuel consumption and weight of charge smelted, have been obtained.

Passing next to the refining of the metal, it is here that "electric heat" is tending in some cases to supplement, in others to supplant, fuel heat. An instance is furnished by the refining of steel on a large scale in the so-called triplex process, in the second stage of which fuel heat, in the form of producer gas, is used (the charge being worked first in a converter and afterwards in an open-hearth furnace), while in the third stage an electric resistance furnace is utilised which permits the refining of the steel to a considerably further degree. It is widely held that the quality of steel which can be produced in this way is superior to that obtained in the open-hearth furnace. This is due to the fact that, owing to the high temperature employed, more refractory basic fluxes can be used which permit of a greater removal of sulphur and phosphorus, with a consequent improvement in the properties of the refined steel. Moreover, in the electric furnace the charge is decidedly less contaminated with gases. For high-grade materials, such as high-speed cutting tools, where quality is of paramount importance, the electric furnace seems to have a field all its own, and, owing to the fact that, under special conditions, current for it can be bought from public service companies during "off peak" periods, its installation cost is not necessarily high. This permits of its use in plants smaller

than otherwise would be justified in making their own steel. The rapid growth of the electric furnace is shown by the fact that the total number in operation in March, 1910, was 114, and in January, 1917, 471.

As an alternative to flotation concentration and smelting operations, which, as mentioned, are particularly suitable for sulphide ores, the achievements of hydrometallurgy have also to be considered. The cyanide process, which has long been established as the most suitable method of extracting gold and silver from low-grade ores, depends on the fact that the dilute solutions employed exercise a selective solvent action on the precious metals, and is the best-known instance of the application of leaching on a large scale.

Recently the extraction and refining of copper by hydrometallurgical and electrolytic methods direct from the ore has become a commercial process. Many of the low-grade ores of copper, particularly the vast porphyry deposits in the highly mineralised mountainous country in the south-west of U.S.A. and Mexico, are oxidised and not amenable to flotation concentration. For their beneficiation leaching is the most suitable method. A famous example of this kind is the treatment of the ore obtained from the mine of the Chile Exploration Co. situated at Chuquicamata, which, as regards tonnage and contents of valuable metal, is one of the greatest known copper deposits in the world. The high point of the mine lies at an altitude of 9890 ft., while the extraction plant is situated at 9023 ft. on a plateau of the Andes, 160 miles north-east of Antofagasta. Here a plant of 10,000 tons daily capacity has been designed and erected in a desert 5000 miles away from the base of supplies. The ore, which carries about 2 per cent. of copper, is an oxysulphate known as "brochantite."

The process chosen utilises its sulphuric acid ion for the solution of the copper, and allows a percentage discard of the liquid after each operation, thus avoiding its fouling by continual use. The ore is crushed to about half-an-inch mesh and leached with sulphuric acid. The greater part of the chlorine is eliminated in tube mills by treatment with metallic copper. The remaining copper is precipitated from solution by electrolysis and the cathodes are melted and cast into commercial wire bars. In this way a high-grade commercial metal is produced direct from the ore in three operations, in only the last of which is a furnace treatment necessary. Against this the ordinary concentrating, smelting, and refining operations involve no fewer than seven stages. The output of refined copper from this plant is at the rate of 200 tons per day.

The refining of metals by electrolysis, of which the previous process is an illustration, is one of the most important features of the industry of to-day. It derives its importance from two considerations which are inter-related: first, that it permits the production of the commercial metal in a highly purified form; secondly, arising out of this, it allows the complete recovery of the

precious metal values from base metal ores, which thus increases their commercial value. To-day, iron, copper, zinc, lead, aluminium, sodium, magnesium, nickel, gold, and silver are obtained in a marketable form by such methods. To take one instance only, upwards of 90 per cent. of the world's annual production of copper, which in 1913 was about a million tons, was refined by electrolysis within 20 miles of New York City. The cathode copper thus produced did not contain more than 2-3 parts of impurities in 10,000. As a by-product of this refining, there was obtained nearly 20 per cent. of the world's entire output of silver, a substantial amount of gold, small amounts of platinum and palladium, together with notable quantities of nickel, selenium, and tellurium.

Viewing the industry to-day, it is manifest that there is a notable trend towards the substitution of furnace- or pyro-metallurgy by hydro- and electro-metallurgy. Even where furnace operations still hold the field, attempts are being continually made towards the substitution of fuel heat by electric heat. Iron is being produced commercially in Sweden, Canada, and the U.S.A. by electric smelting and refining. There is a clear trend of a similar character in the metallurgy of certain ores of copper which are not amenable to direct flotation or leaching. Metals such as aluminium, sodium, and magnesium are produced direct by electrolysis. The great importance of this tendency, as already suggested, is that it permits of a more complete beneficiation of any given ore, and, indeed, brings a far wider range of raw materials within the scope of economic exploitation than otherwise would be the case. How clearly this is so may be seen from the following instances:—

Previous to the introduction of the cyanide process, it did not pay to extract gold from any sulphide ore unless it contained at least 0.5 oz. of this metal. By means of this process, however, the limit of such payable ores has been brought down to about 1 dwt. per ton, and in the case of clean gravel containing native gold to as low as 3 grains—i.e. 0.006 of an oz. of gold per ton. Similarly in the case of the sulphide ores of silver, the previous limit of 20 oz. has been lowered to about 2 oz. per ton by the same process. As regards copper, the economic percentage was about 5 per cent. down to the year 1890. By the introduction of leaching processes this figure was quickly reduced to about 2 per cent. Progress has been continuous in lowering the limit, and to-day tailings from concentrating tables containing only 0.5 per cent. of copper are being treated for extraction at Cananea (Mexico) and Anaconda (U.S.A.). In regard to such materials it is more than possible that the flotation process will lower the limit still further.

Limits of space prevent any reference to the trend of current practice in the mechanical and thermal treatment of metals and alloys and the ever-deepening influence of metallography on this great branch of the metallurgical industry.