

## Production of Aluminium

As the preceding paragraphs have indicated [*A brief history of aluminium*], aluminium came late into the world of major metals for the reason that it was an electrolytic process product and required the electric furnace at a high stage of development for its production. The Industry is only half a century old and the principal producing countries have developed the production of aluminium on the basis of one process and one ore: the process being the Hall-Héroult process, in which the oxide of aluminium, alumina, produced by chemical treatment of the bauxite ore, is reduced electrolytically; and the ore being high-grade bauxite, which is a mixture of hydrated oxides of aluminium containing silica, ferric oxide and other impurities.

There have been essentially no fundamental changes in process or equipment since the beginning of the industry, although great improvements have been made in the design of the furnaces and in the electrodes.

### RAW MATERIALS

The aluminium industry has been oriented with reference to the raw materials bauxite, electric power, coal and caustic soda used in the preparation of alumina for electrolysis, and carbon for the manufacture of electrodes.

One metric ton of aluminium requires three to four horse-power years (roughly equivalent to 20,000-25,000 kWh) of electrical energy, four to five tons of bauxite, four to five tons of coal, a substantial amount of water, about one ton of caustic soda (of which the greater part is, however, recoverable) and 0.5-0.6 tons carbon electrodes--that is to say, in all more than ten tons of material plus a large quantity of power. These are optimum figures under the best production conditions with the best materials

Labour requirements depend upon the scale of operations, in the largest plants being about 5 to 6 man-hours per ton of alumina produced and about 30 man-hours per ton of aluminium produced from alumina. In smaller plants the labour may work out as high as double this figure.

With the above starting point it is apparent that aluminium can be produced at the cheapest rate where the combination of cheap power, good bauxite and cheap coal exist: since there is, however, no region in the world where these three raw materials are coincident--in other words, since no one country enjoys sufficient preferential advantages to grant it a monopoly--the process of aluminium production based on the Hall-Héroult process and on bauxite has involved one main dichotomy, it having been found more economical to produce the alumina for reduction close to coal rather than to bauxite, whilst the electrolytic reduction plants must, of course, be located close to the source of power. This dichotomy immediately introduces the factor of transport, which becomes a further vital "raw material."

In Europe, France and the U.S.S.R. are the most advantageously situated in respect of aluminium production and the United States is probably placed about equally with the U.S.S.R. (except that the ore position is not so satisfactory in the United States). Apart from political considerations, the purely technico-economic position in Europe, excluding Russia, would have made France, Switzerland and Norway the largest European producers of aluminium, using French bauxite converted to alumina in Germany or England for the electrolytic process. In the last period before Europe began to head for the recent War, there did in fact exist a unified economic unit

between the French, Swiss and German industries, French bauxite being converted into alumina in Germany, where: coal (brown coal) was cheap, the aluminium being then manufactured in Switzerland where water power was freely available: low freights were charged for carrying French ore to German coal. Because of political implications and the consequent necessity for the development of national industries - for example, in this country - dichotomy has not always been adequate and the industry has had to work on a triangular basis of (imported) ore, alumina production and aluminium reduction. The question of transport then virtually resolves itself into the question of sea transport so far as favourable ore supply is concerned.

## AVAILABILITY OF POWER

In the early days of the aluminium industry power was almost universally construed in terms of water power; hydro-electric energy was then becoming an important factor in industrial economy and strenuous efforts were made by the major industrial nations to secure favourable locations and development of water power. At that time the modern conception of electric power stations with alternative sources of energy based on alternative fuels such as powdered coal, mineral oil, or even peat on a large scale (as used in certain regions of the U.S.S.R.) was non-existent and hydraulic power represented a unique advantage in the newly developing electrolytic process industries in which aluminium was one of the major products. Capital investment in hydraulic power stations varied greatly with the natural resources but viewed as a long-term project it was always a good economic proposition and in favourable instances it provided remarkably cheap power, as for instance, on the Saguenay river or at Niagara. In Europe, conditions were, of course, at their best in Switzerland and Norway. Since the situation of the source of power is nearly always unfavourable for the location of a major industrial undertaking, power derived from hydraulic stations was commonly relayed to selected centres which could serve as the loci for assembly of the other raw materials and for the erection of works and their concomitant towns and satellite industries.

These factors, with their geographic and economic background, are complementary to the technical aspects of the use of water power in the cheapest manner. An important consideration in all electrolytic processing is the necessity for a continuous supply of electric energy (in contrast with part-time utilization for engineering and municipal requirements, e.g., for lighting and heating) which implies a very high load factor. From this angle the needs of an electrolytic industry such as aluminium are both favourable and unfavourable as regards power consumption: on the one hand, the power undertaking can count on disposing of an otherwise unused capacity and on the other hand, it is essential that the production cost of the energy shall be low and the power supply steady. A hydro-electric system normally expects to provide for commitments for a certain amount of firm power which has to be based upon the lowest level of water during the year, taking into account normal storage provision. Due to irregular volume of water flow, both annual and seasonal, the minimum may be exceeded during certain years and for certain months in every year and this excess power, known as secondary power, has been utilized successfully in the electrolytic industry and to some extent in the aluminium industry. In this industry, however, most of the big producers have their own power undertakings or own at least a controlling interest in them.

## COAL AND FUEL

Fuel is one of the most important materials consumed in the production of aluminium, being essential to fire the kilns in the production of alumina. Until the outbreak of the second world war, the only fuel used in the manufacture of alumina was coal; but during the war years and particularly in America, some shift has taken place towards other fuel sources, for example, natural gas, oil or electricity may also be used in the production processes according to the situation of the works relative to a supply at a favourable cost.

In Europe the most favourably situated countries from the angle of coal supply for alumina

production were Germany and England, with Italy as a runner-up. In the United States a good supply of high-quality coal is available in the State of Washington and there is plenty of lower grade bituminous coal for most of the plants producing alumina, although oil was substituted for coal at four or five plants distributed through the States in recent years.

## CAUSTIC SODA

In general the aluminium industry has concerned itself only with the mining of bauxite and the manufacture of alumina and metallic aluminium and has not entered into the production of the caustic soda utilized in the alumina process. Both the processes used on a large scale for the production of caustic soda, namely the soda-ammonia and the electrolytic process, belong essentially to the heavy chemical industry and large quantities are available at a low price. The raw material for caustic soda production, which is chiefly soda ash, is available in abundant supply. This material also enters directly into the process of alumina production by the Bayer method in some instances.

## ELECTRODE CARBON

The anodes used in the electrolysis cells are prepared from a mixture of petroleum coke and ordinary pitch, roughly in 70-30 ratio, but this figure varies according to the quality of the coke. Petroleum coke is a by-product of petroleum refining, being actually the residue after the volatile and fuel oils have been withdrawn. Before it is ready for service for the production of anodes, the crude materials from the petroleum stills have to be calcined and this process requires special plant and consumes one-fifth to one-quarter of the weight of crude coke processed in fuel supply.

## BAUXITE

Bauxite is the raw material peculiar to the aluminium industry. and the chief producers prior to the First World War were France and the United States. With the coming of that war and afterwards, when the status of the aluminium industry rose from a minor to a major industry, a scramble took place for the hitherto undeveloped deposits of bauxite in Europe (the best being in Hungary, Dalmatia, Istria, smaller deposits occurring in Yugoslavia, Rumania and Greece) and in the Guianas (the most important though not the only deposits in South America). Ore availability was not, of course, uncontrolled; the Great War Peace Settlement made reference to the European deposits and the British Colonial Office attempted to restrict grants for the British Guiana ore to British capital and enterprise.

By the latter part of the post-First War decade, the position was roughly that a very large part of the better ore in the Guianas was in the hands of the American aluminium-producing industry which had also acquired Istrian and Yugoslavian ore. In Europe the Germans acquired about 20 million tons of bauxite in Hungary, Yugoslavia and Rumania (principally the former); whilst, the rest of the then explored deposits were distributed between British, French and Canadian producers.

In the next ten years, before the Second World War, the exploitation of the bauxite mines developed full swing, the total world output in 1940 being over 4½ million tons. The chief producers are shown in the next chapter. The immediate position of the aluminium industry at the outbreak of and during the Second War, tied as it was to the high-grade bauxite production process in the majority of producing countries, was very closely linked with the acquisition of the ore reserves and this situation had considerable influence in barring new entrants to the producing industry.

More recently attempts have been made to open up hitherto untouched supplies of bauxite. The ore is fairly widely distributed but the grades suitable for the Hall-Héroult process are not inexhaustible and may prove to be rather limited. There has been, for instance, some concern about the surprisingly rapid exhaustion of the Guiana deposits worked in the interests of the

American aluminium industry: whilst this country has interested itself in newly worked deposits in Australia (New South Wales and Victoria) and has acquired new reserves in Africa (Gold Coast). Substantial reserves are reported to be available in India, but production of bauxite has until recently been restricted to a small output of high-grade ore near Bombay and in Madras.

In view of the political implications of the aluminium industry and of the geographical availability of bauxite, attempts have recently been made to consider possible substitutes for bauxite, chief of which are clay and leucite. Next to bauxite the kaolinite clays are the richest source of aluminium, containing some 39% of alumina; and in view of their almost ubiquitous distribution in unlimited supply a great variety of processes for the extraction of the alumina have been tried out. The difficulties inherent in the production of a pure alumina from clay are bound up with the silicious nature of the matrix material which renders the removal of all the impurities extremely cumbersome and expensive even where a particular process has proved it possible.

Another mineral which has attained some importance in the production of aluminium ores alternative to bauxite is leucite, on which the Italian industry before the recent War was branching out on a large scale. Leucite is a silicate of alumina and potassium and processing of this ore is faced with the same difficulty as the production of alumina of a grade suitable for aluminium production from clay.

One further ore has been tried and utilized with some success in Manchuria and in U.S.S.R., namely alunite, which is a hydrous potassium aluminium sulphate.

Some details of the various processes developed for the working of these alternative ores will be found in subsequent references.

### The Production Process

It has already been noted above that there are two essential stages in the production of ingot aluminium from the ore - which is normally bauxite but may be alternatively clay, leucite, alunite, nephelin or other minerals giving rise to aluminium oxide. These two essential stages are the production of pure aluminium oxide from the ore: and the

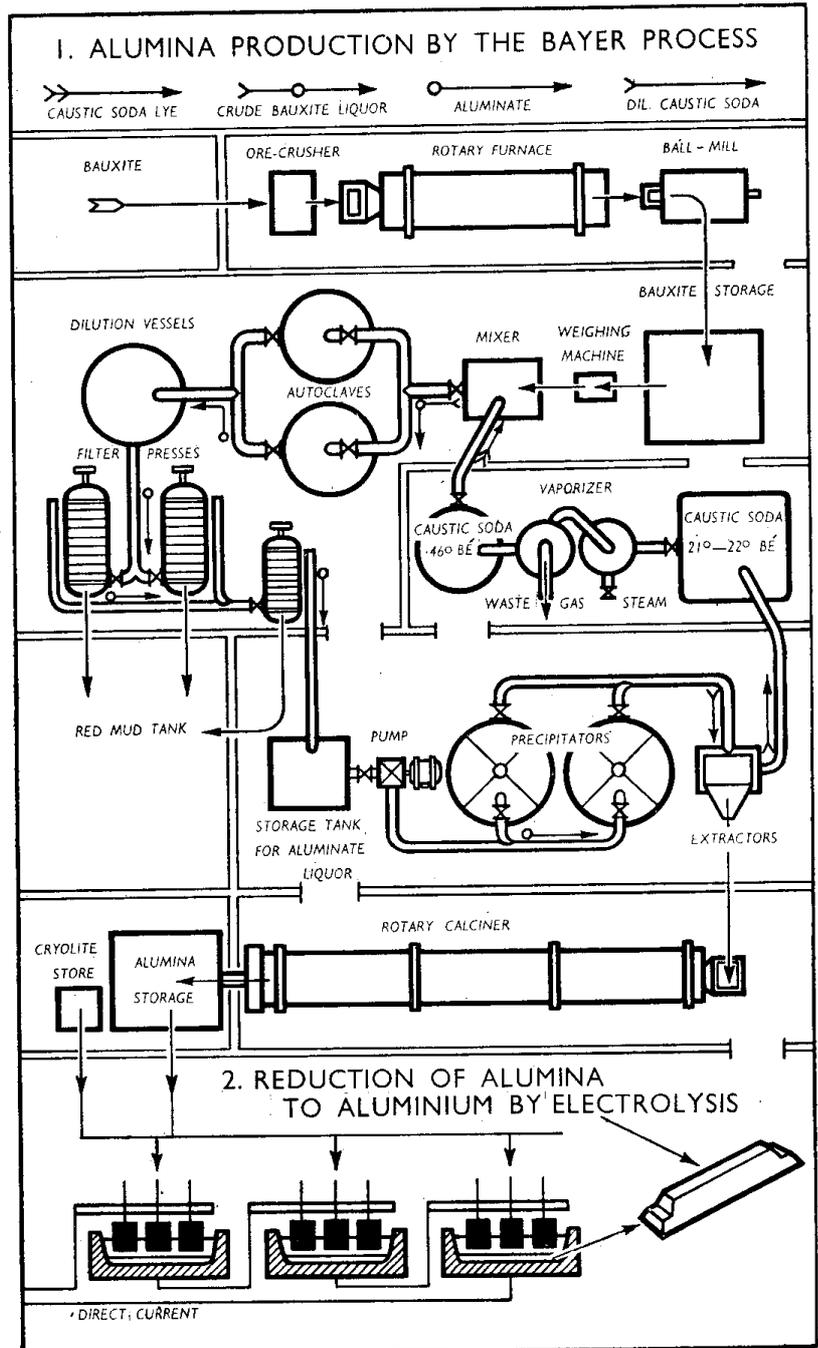


Fig. 1. Diagrammatic Representation of the Main Processes of Production of Alumina and its Subsequent Reduction.

reduction, by fused electrolysis, of the oxide to yield pure aluminium.

In addition to these main processes there are ancillary operations such as the manufacture of synthetic cryolite for the molten electrolysis bath and the production of anodes for the electrolysis cells.

## ORE PROCESSING

About 90% of the world production of aluminium from bauxite for the aluminium industry was carried out, prior to the last war, by the Bayer process. The essential features of this process are shown in the accompanying Figure (see Fig. 1). Modifications of the process in different producers' procedures are many and varied, but the main outlines of the process remain the same. The crushed, ground bauxite is subjected to calcining, with the threefold objective of (1) partial dehydration, (2) further, finer grinding, (3) removal of any organic matter present in the ore, which would accumulate in the aluminate liquors and interfere with the separation of the hydrated oxide. Calcining is usually carried out in rotary furnaces, from which the product is transported mechanically by elevators to the fine-grinding mills. From the mills it passes to storage containers.

Exactly weighed amounts of this product are treated in large mixers with caustic soda liquor of about 46° Be concentration and fed into autoclaves in which the reaction proceeds under pressure and at controlled temperature. The resulting sodium aluminate liquor is immediately pumped into presses for filtration under pressure, where the liquor is separated from the insoluble residue (the so-called "red mud"). The clear aluminate liquor is ultimately pumped into the precipitating tanks where it is mixed with a "seed" charge of aluminium hydrate from a previous cycle: the precipitators are provided with efficient agitators and controlled cooling is applied to aid the precipitation of coarsely crystalline aluminium hydrate. With properly controlled concentrations and cooling temperatures a yield of about 60% of hydrate is precipitated and continuously removed from the solution, washed and sent to the calciners. Calcination is carried out in rotary kilns in which the alumina passes from top to bottom in contra-direction to the heating gases: the temperature required is over 1,200° C., as the alumina has to be "dead-burned" in order to withstand subsequent tendencies to deliquescence during storage. Modern calciners are sometimes also equipped with electric dust-extractors which continuously withdraw the fully calcined product.

Apart from the Bayer process, many alternative methods have been from time to time proposed for the extraction of alumina, as shown in the Table on pp. 14 and 15.

### **Reduction of Alumina**

The reduction of alumina to aluminium is universally undertaken by the electrolytic process originally developed by Hall and Héroult. The electrolyte is a mixture of sodium-aluminium fluoride (cryolite) and alumina with a melting point lying between 900° C.--950° C. This mixture is fused in the electrolysis vats which are provided with carbon linings which function as cathode. The anodes are made from very low-ash pitch-coke or petroleum-coke mass bound together with a highly viscous tar as agglutinant. The operating voltage is 5-6 volts, the amperage load of a furnace being in the region of 10,000 to 30,000 amps. The molten aluminium collects at the bottom of the furnace and is tapped off at intervals. The oxygen of the alumina is liberated at the anode and burns iron carbon dioxide.

## THE REDUCTION FURNACE

The older furnaces in use are circular in shape and provided with a single anode: the need for larger furnaces and increased anode section has led to the development of multiple-anode rectangular-shaped cells or "pots," as they are commonly called in the aluminium industry, which are now nearly universal, although oval cells have been designed as part of the newer equipment

in some modern Continental works. Interior dimensions of the common rectangular furnaces now in use are about 8 X 4 ft by 2-2½ ft. in depth: larger furnaces with cross section increased to double or treble the capacity are being introduced in newer works. The furnace hearth, constructed of baked carbon block, is slanted downwards to a tapping hole at one end of the cell.

Anodes are of two main types, the older pre-baked anode and the modern so-called continuous anode of which the best-known and most widely used is the Soderberg anode. In the continuous anode the carbon is fed continuously in the form of paste, baking being accomplished within the furnace itself. The current is fed through flexible conductors to steel stubs inserted into the anode container, the anode consumption being compensated by the rise in level of the bath: when metal is removed from the furnace by tapping, the anode has to be lowered to regain its proper working distance and as the anode descends the conductors are transferred from the lowest stub rows (which are removed) and connected to a higher stub row./Improvements are constantly being introduced into the design of the continuous anodes and their mechanized manipulation.

According to the size of the furnace different numbers of anodes may be employed. Furnaces are commonly connected in series and arranged (often diagonally, to facilitate tapping operations) in two opposite banks with the electrodes mounted in pairs. The electrodes are carried on some form of jack, which, in the newest plants, may be individually motor-operated and controlled by a separate switch at each furnace. A modern furnace room may contain up to fifty pairs of furnaces and it is customary to leave a few pairs unconnected as "spares" for bringing into operation when furnaces have to be dismantled or taken out of action for any reason.

The technical control of the reduction furnaces in action is very exacting: proper regulation of temperature, depending on the maintenance of optimum working distance of anodes, depth of bath, metal content and flux composition, requires careful control. Anode polarization, known as "anode effect" and popularly referred to as an "up," which is caused by impoverishment of alumina in solution in the flux is of frequent occurrence --every few hours--in each furnace and requires the attention of skilled furnace operators to stir the solid alumina risen into the solid crust back into solution. Warning of this polarization effect, which is accompanied by a very rapid and steep rise in voltage, is arranged by signal lights. The changing of the anodes in the older type of furnace is also a routine operation calling for skill and care.

Reduction furnaces are normally enclosed and provided with exhaust systems to remove flux fumes and, in the case of continuous electrodes, the escape of tar pitch volatiles arising from the

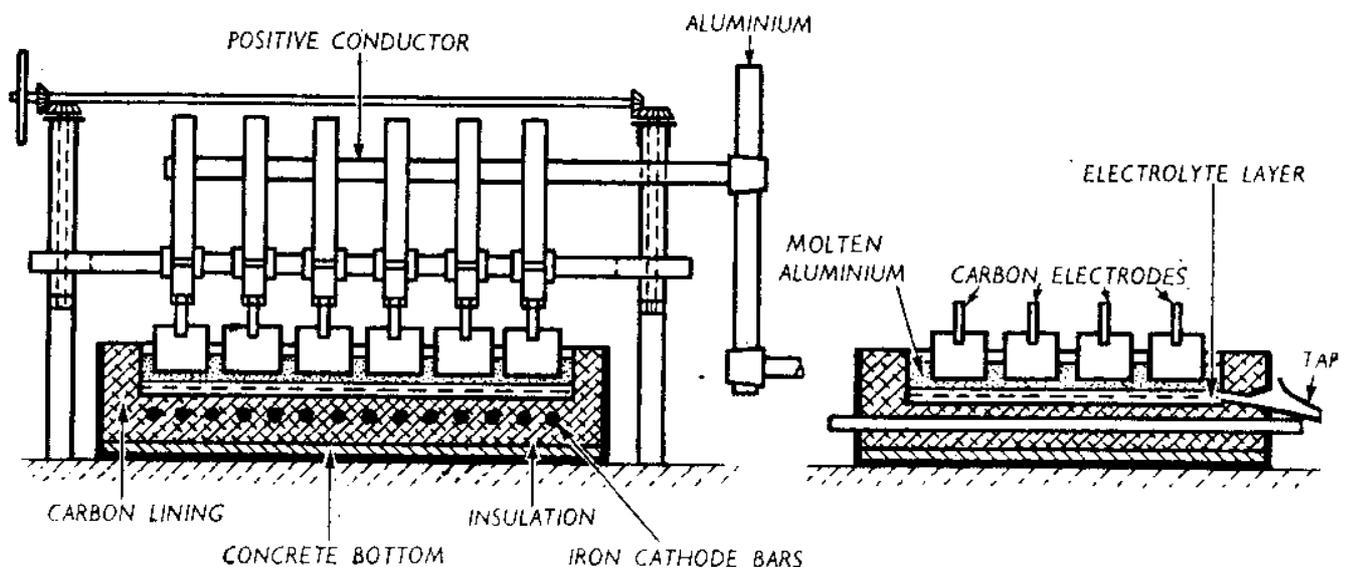


Fig. II. Diagram of an Aluminium Reduction Furnace.

baking of the anodes. The exhaust systems in modern plants are equipped with scrubbing plains from which cryolite is recovered as a by-product.

The life of a reduction furnace is dependent on the life of the carbon lining: it averages 2-4 years in the older type of furnace and may reach 5 or 6 years in furnaces of good up-to-date design.

CRYOLITE Originally all the cryolite used for aluminium production was the natural ore drawn from Greenland. Although the natural product has certain slight advantages which make it a more acceptable product to most aluminium producers, the bulk of the material in use to-day is the synthetic product prepared from hydrofluoric acid derived from fluorspar. The acid is made to react with sodium aluminate in stoichiometric proportions to produce the double fluoride of sodium and aluminium.

#### INGOT CASTING: REMELTING

The aluminium tapped from the electrolytic cells may contain traces of electrolyte or of metallic sodium and the solidifying metal is usually first cast directly into crude pigs which are then remelted either in an electric or reverberatory furnace before casting into ingots. Large ingots are mostly cast plain in form; they mostly weigh up to 50 lb., but the normal size in this country is about 22 lb. Smaller ingots are put on the market in the familiar form of the notched bar, which is also sometimes known as a "ten-notcher" or otherwise according to the number of notches. This type of ingot is very practical in use, since properly chosen notch dimensions allow of nesting for stacking; and in the case of small ingots they may be conveniently made into bundles without risk of slipping. Further, the notches allow of conveniently breaking into fractional parts. Sizes of commercial ingots vary widely in different countries: the commonest size in this country is the 15-in. bar with ten notches, weighing between 2 and 2¼ lb.

The actual process of ingot casting is elaborate and is usually now done in so-called continuous casting machines in which the ingot moulds are arranged in the form of a continuous band which moves mechanically under the pouring spout of the crucible or furnace.

#### INGOT TO FABRICATED PRODUCT

Aluminium appears in its final form of fabricated products by way of two main channels of manufacture, depending on whether the metal is worked by forging or is cast. Wrought products are first semi-manufactured into sheet or strip by rolling, into sections by extrusion, or into wire by drawing (these are the main categories, but there are also other methods of semi-manufacture). Cast products are produced directly from ingot in the foundries, which are not necessarily connected with the primary producing works. The forged "semis," as they are called, go on to the fabricators for further manufacturing processes, e.g., by spinning, pressing, impact extrusion or deep-drawing: or they may find themselves in other industries in direct use as constructional materials or units.

***It should be noted that this is an historical record and relates to processes in use before and during the 1939-45 war. Many things have changed since this was written. In particular the scale of operation and casting of the aluminium. - PH***