

The Alusaf aluminium smelter at Richards Bay

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SYNOPSIS

A description is given of the aluminium smelter at Richards Bay, which operates on the Hall-Héroult electrolysis principle. The annual output of metal (average 99,7 per cent aluminium) is approximately 75 000 tons.

Since its commissioning in 1971, the plant has fulfilled South Africa's total demand for low-alloy rolling slabs, extrusion billets, remelt ingots, and electrical conductor rod. The plant layout allows for sufficient expansion of its capacity to meet longterm increases in demand.

SAMEVATTING

Die aluminiumsmelter by Richardsbaai wat volgens die Hall-Héroultelektrolisebeginsel werk, word beskryf. Die jaarlikse metaalopbrengs (gemiddeld 99,7 persent aluminium) is ongeveer 75 000 ton.

Hierdie aanleg het sedert sy ingebruikneming in 1971 in Suid-Afrika se totale vraag na laag gelegerde walsblokke, ekstrusieknuppels, gietblokke vir hersmelting en elektriese geleistaaf voorsien. Die aanleg is so uitgelê dat sy vermoë voldoende uitbrei kan word om in die langtermyn-toename in die vraag te voorsien.

Introduction

The production of primary aluminium started in South Africa during the first half of 1971 at the Alusaf plant at Richards Bay, which had an initial capacity of 50 000 tons per year. An approximate expansion of 50 per cent was commissioned in May 1974, from which time South Africa's total needs for primary metal have been satisfied.

There was no specific knowledge, expertise, and skills pertaining to the reduction of aluminium available in South Africa before the establishment of the smelter, although this country's entry into the industry was made after about a century of world-wide technological development in this field. The gap in know-how was largely closed in South Africa by Alusaf's incorporation of the latest design concepts into the processes and techniques through consultation with Aluisse, who supervised the construction of the project and have a financial interest of 22 per cent in Alusaf.

Plant Layout

The layout of the plant and the flow of materials are shown in Fig. 1. Arrows indicate the direction of flow of materials and products. Provision is made in the layout to accommodate a production output of up to six times the present installed capacity. Casting and anode handling are reserved for the centre of the site, while all services functions are located on the east side of the layout.

Compressed air, heavy and light fuel, gas, and water services are accommodated in a spacious underground utility tunnel. Sea water is used for scrubbing the gases, and fresh water in a closed system serves as the coolant for casting. Materials and products are moved mainly by overhead cranes, forklift trucks, and tractor/trailer units. The raw materials and finished products are carried mainly by rail.

From a production planning point of view, this layout can be criticized as being initially costly because of its geographical dispersion. However, a long-term view has been taken in respect of the growth of activities to prevent future congestion and cross-flows of materials.

*Alusaf Pty Ltd, Richards Bay, Natal.

The Potroom

All the reduction cells are housed in the potroom. A sectional view of the potroom (Fig. 2) indicates the three important functional segments of the building:

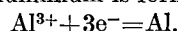
- (1) the basement at ground level to facilitate the replacement of individual pots and as an air intake for ventilation,
- (2) the operating floor, which has access to the cells, and
- (3) the gas-scrubbing or absorption system over the whole length of the building.

The cells are of the modern high-current pre-baked anode version of the well known Hall-Héroult concept. Individual parts of a cell are illustrated in Fig. 3, this particular pot being equipped with 26 anodes. The size of the anode provides for a normal anode life of 28 days.

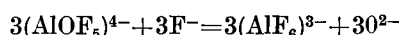
Process Reactions

This process involves the decomposition of alumina (Al_2O_3) into aluminium metal and oxygen. For the electrolytic reaction, the alumina must first be dissolved in an electrolyte and molten cryolite (Na_3AlF_6) is used for this purpose. The natural constituents of cryolite are sodium fluoride (NaF) and aluminium fluoride (AlF_3). Under the influence of direct current, the liquid aluminium collects at the cathode while the oxygen reacts exothermically with the anodic carbon to form carbon monoxide and dioxide gases. For this reason, the anode is a consumable raw material.

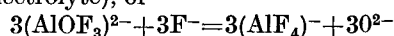
Various electrolytic reactions take place both at the anode and the cathode of the cell at an operating temperature of approximately 970°C. Primary aluminium is formed at the cathode:



According to the newest theories¹, the anodic reactions are as follows:



(the dissociation of complex oxygen ions at an Al_2O_3 concentration of less than 5 per cent by mass in the electrolyte), or



(when the Al_2O_3 concentration is between 5 and 11 per cent by mass in the electrolyte).

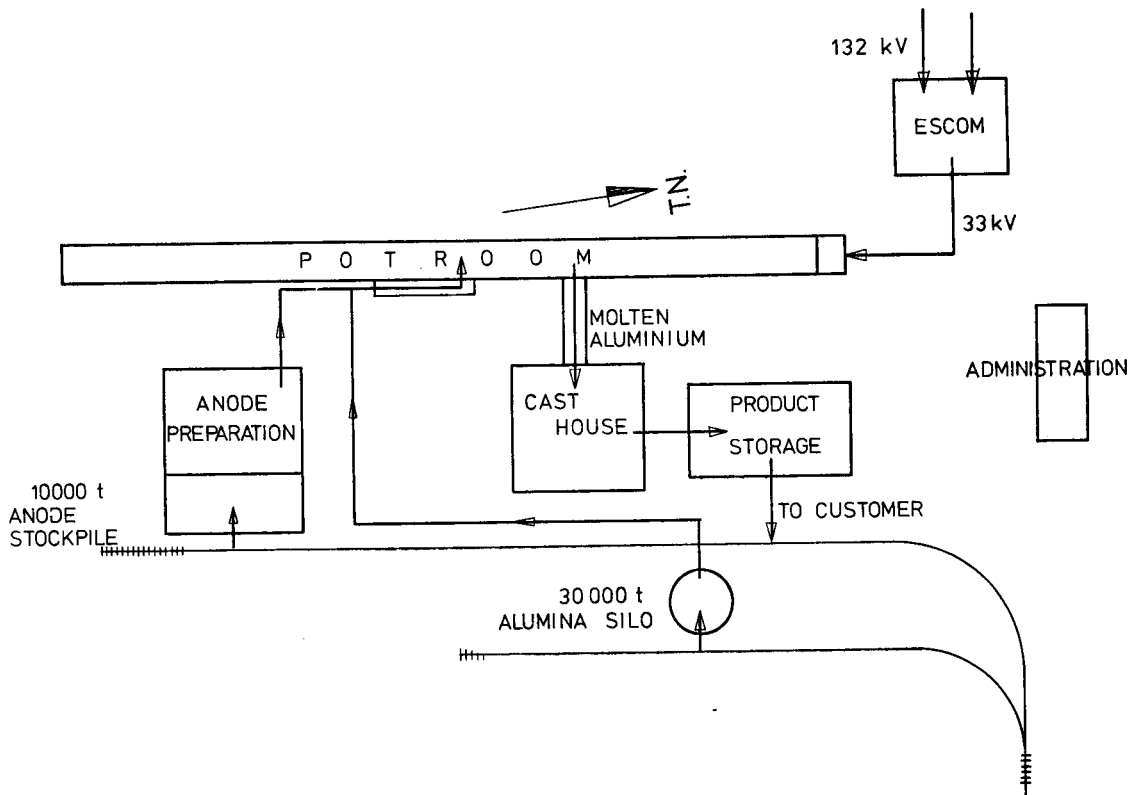


Fig. 1—The flow of materials at Alusaf

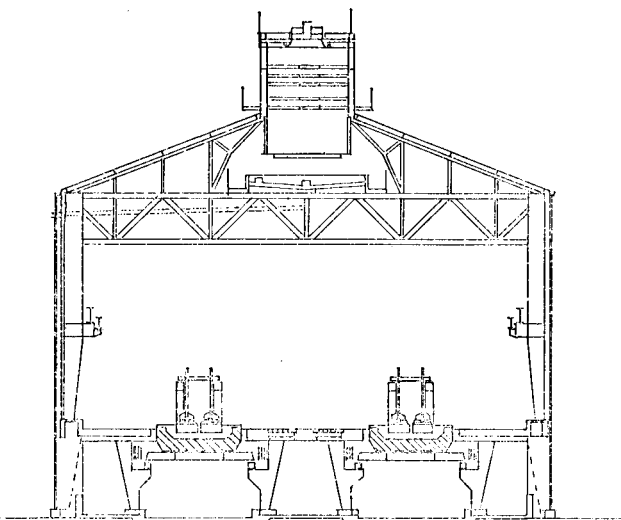
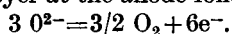
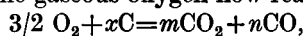


Fig. 2—Section through the potroom

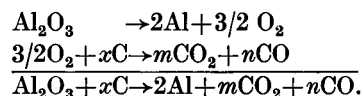
The discharge of O^{2-} ions at the CO_2 - CO gaseous layer at the anode follows:



The gaseous oxygen now reacts with anode carbon:



where x , m , and n are as follows²:

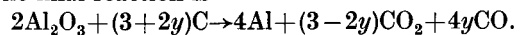


The molecular values of CO and CO_2 are determined by

y , which is the excess carbon present in the system and where $y = x - 1.5$. It follows that

$$x = 1.5 + y, m = 1.5 - y, n = 2y, n \leq y \leq 1.5.$$

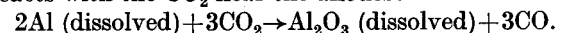
The final reaction is



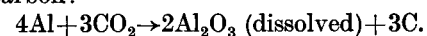
The ratio of CO_2 to CO is determined by the combined or individual influences of the anodic current density, the reactivity of the anodic carbon, and the temperature of the electrolyte.

Current Efficiency

The mass of electrolytically produced metal is proportional to the current intensity and time of current application according to the Law of Faraday, and amounts to 0,3356 g of aluminium per Ah. However, a certain portion of the aluminium particles dissolves in the electrolyte, and reoxidation occurs when this metal reacts with the CO_2 near the anodes:



Also, under certain conditions of high bath turbulence, the production of a cell can be further reduced when cathodic metal is reoxidized with the formation of carbon:



Both reactions reduce the amount of metal effectively produced by a cell. The current efficiency of a cell is defined as the actual production relative to the theoretical Faraday production and reaches 85 to 90 per cent for modern cells.

Cell Operation

For the feeding of alumina into the molten electrolyte,

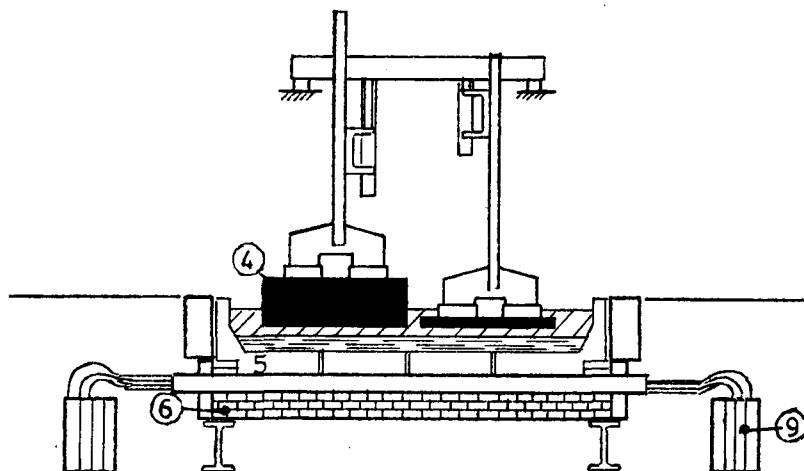
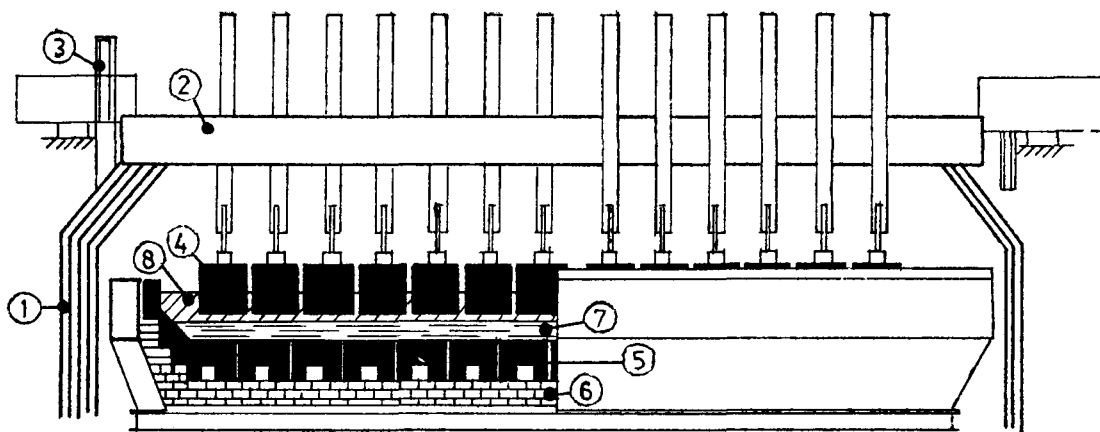


Fig. 3—The parts of an aluminium reduction cell

- | | |
|-----------------------------|----------------------|
| 1 Power supply | 6 Firebricks |
| 2 Anode beam | 7 Molten metal |
| 3 Jacks (beam, up and down) | 8 Molten electrolyte |
| 4 Carbon anode | 9 Main busbars |
| 5 Carbon cathode | |

the solidified electrolyte crust is broken on a programmed basis.

Specially designed vehicles are used for the alumina distribution, anode changing, crust breaking, and metal tapping. Metal is unconventionally sucked out of each pot once a day by compressed-air induced vacuum into tapping crucibles. Metal from three to four pots is collected in 4 t transport crucibles on trailers and conveyed to the casthouse.

Pot Operating Control

Individual pot voltage control has been automated since early 1975. Cell operation, apart from the physical feeding of alumina and crust breaking, is controlled by a closed-loop computer control system, which measures cell voltage and anode beam position on average every 10 seconds and also monitors the state of a number of operator push buttons at every cell.

These data are fed to the central computer via field multiplexer units. The data are compared against a number of control models, which also take trends and history of the cell into account. The computer then

commands the activation of the anode-beam jacking motors in order to adjust the cell voltage if required.

The system immediately reports to the operator in charge any alarm conditions that may exist on any cell. Additionally, a large amount of data logging and data reduction is carried out by the system on a continuous basis, and both periodic (i.e., shift, day, etc.) reports and reports on request are provided for the use of the cell operators.

Statistical analysis of production information is also carried out. The reduction cells are wired to multiplexer units, each of which handles both the input and the output functions on a group of 24 cells. These multiplexers are then again multiplexed by a central unit, which also interfaces to the digital computer.

The computer used is a very powerful mini-computer with 64 K words of available core memory and 3600 K words of magnetic disc storage. The real-time disc-based operating system permits the simultaneous operation of numerous programmes on a multiprogramming basis, and facilitates the use of the processor for batch jobs without interruption of the reduction-control process.

Control models and programmes (approximately 200) were developed in conjunction with Alusuisse, and all maintenance and modifications are handled by in-house staff.

The system is in operation 24 hours a day and has been found to permit closer tolerance control of the reduction process than was possible manually. The information provided allows faster reaction by personnel to process variations, as well as allowing a degree of cell-behaviour prediction to be made. The operating staff, although having experienced difficulty at first in accepting the effects of automatic control, now find the system an indispensable tool.

Potroom Emission Control

The aluminium reduction process generates considerable quantities of undesirable fumes and gases, large volumes of carbon dioxide and carbon monoxide being produced by the reaction between the carbon anodes and the oxygen liberated in the reduction cell. To a lesser extent, sulphur dioxide, hydrogen sulphide, and carbonyl sulphide are formed from the sulphur impurities present in the anode, and fluorides, which are a major component of the pot flux, are partly liberated into the atmosphere mainly as silicon tetrafluoride and hydrogen fluoride. Solids in the fume consist mainly of carbon, alumina, cryolite, and aluminium and calcium fluorides, together with a small amount of iron oxide.

Pot emissions can be removed from the working environment by two principal methods. The first method involves the closure of each pot with an extraction hood. Extractive efficiency is the main advantage of this technique, but these hoods give rise to many manipulative difficulties during routine servicing of the pots. The second method relies upon efficient ventilation throughout the potroom. A strong updraught of air sweeps the gaseous emanation into the roof of the potroom, where it can be treated before being emitted into the environment.

The pollutant of main concern to a primary aluminium smelter is fluorine and its components. Although there is a wealth of literature regarding the toxic properties of fluorides with respect to plant and animal life, many results are either inconclusive or conflicting. Conifers and certain species of flowers are specially sensitive to the effect of fluorides.

Two basic techniques are employed for the treatment of pot emissions before their release into the atmosphere. The older, well-established method is thorough scrubbing of the emissions with fine sprays of water, which is the process used at Alusaf. This process effectively removes the soluble fluorides and greatly reduces the solids content. A more recent development is the passing of potroom emissions through a fluidized bed of alumina powder, the fluorides, together with many other contaminants, being adsorbed onto the surface of the fine alumina particles. An advantage of this technique is that valuable fluorides can be recycled to the reduction cell.

At Alusaf, the air inside the potroom is purged continuously, both by natural ventilation and by the movement of air induced by powerful roof fans. Under

optimum conditions, there are approximately forty complete changes of air per hour. The roof of the potroom is equipped with a system of fabric-covered screens, and a high-pressure jet of sea water is drawn from Richards Bay and forced under pressure through the scrubbing system. The pH value of the spent water is adjusted with lime, and the solids are settled by natural gravitation in large settling ponds.

Metal Casting

The double-furnace principle (Fig. 4) is used at Alusaf. The liquid metal is collected in fixed open-hearth types of mixing furnaces, which are oil fired, and major corrections to the composition are made by the addition mostly of pure alloying elements but also of hardeners. Before the charge is transferred to the tilting-type casting furnaces, remelted scrap arisings help to reduce the temperature of the metal from 850°C, which is its temperature as delivered from the potroom, to approximately 750°C. Refining agents like AlTiB and AlTi are added to the metal either during the transfer of the charge or in the casting furnace.

This concept of two-stage mixing and casting furnaces is in contrast to the newer system of a single furnace with a metal filter, which is used by Alcoa and BACO.

Also shown in Fig. 4 is the layout of the direct-chill (D.C.) machine, which is used for the casting, in 7-metre lengths, of rolling slabs and extrusion billets. These qualities are sawn to customer specification on high-speed metal saws.

Of the other products, remelt ingot qualities are formed on continuous casting belts, and rod is cast on a continuous Properzi caster in the Alustang plant, which is adjacent to the Alusaf casthouse.

Control of Grain Structure

During the subsequent customer processing of aluminium slabs and billets by hot or cold working, heating, annealing, and cooling, the shape and size of the metal grains change, and the grain structure has a marked effect on the quality of the products. Ingot structures that display a predominance of large equi-axial grains or columnar (feathery) grains are considered undesirable for certain wrought applications. Large grains can influence the non-uniform deformation of the metal during working, resulting in grains of differing shapes and causing the development of cracks through severe strain at the grain boundaries. Conversely to this, fine-grained ingots ensure uniform deformation of the grains during working, the inclusions are smaller, and the tendency to crack is much less.

Transformation of the cast ingot to the wrought product involves progressive enhancing of the metal condition for hotwork, coldwork, and annealing stages. The initial quality of the ingot and its processing history determine its performance during subsequent working and heat-treatment operations, and it is generally expected that the wrought product will exceed the cast product in all aspects of quality and mechanical properties.

The quality as cast is dependent on the combined effects of metal degassing, low casting temperatures,

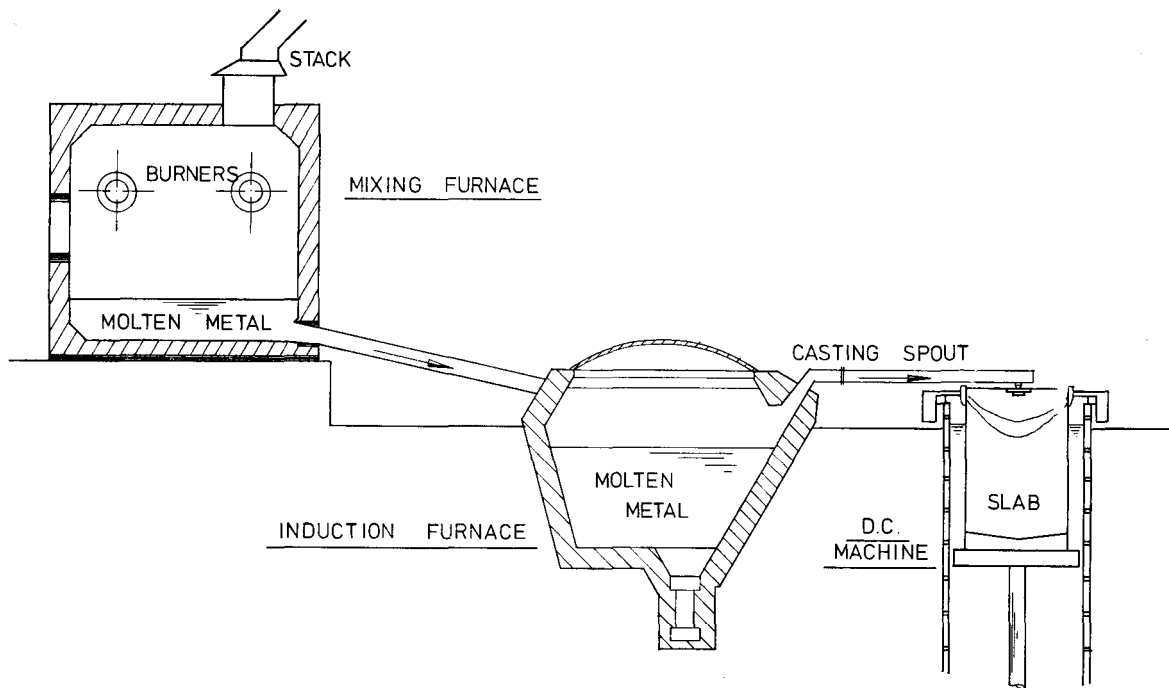


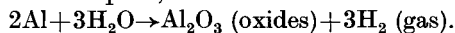
Fig. 4—Double furnace and direct-chill machine

and a metal resting or holding period before casting to remove excesses of dissolved hydrogen and metal oxides.

Contamination by Oxides

Hydrogen and metal oxides are the most important impurities in aluminium and its alloys. Although normally present in only small quantities, the influence of these two impurities on the properties of castings and wrought alloys is considerable, the most common cause of scrap in the finished product being the presence of hydrogen gas or oxides. Blisters, porosity, lower conductivity or tensile strength, streaked sheeting, and damaged tooling are all indications of the possible presence of gas or oxides.

The main source of hydrogen and oxides in aluminium is water vapour, which reacts as follows:



Water vapour is introduced through a number of ways such as damp refractory material and furnace tools, water-containing fuels, and humid atmosphere. Oxides can result from added scrap, and from turbulent transfer and careless stirring of the metal.

Hydrogen is soluble in liquid aluminium to more than 1 cm^3 per 100 g of metal, the solubility being dependent upon the pressure, temperature, and composition of the aluminium alloy. Solid aluminium, on the other hand, dissolves only a limited amount of hydrogen — about 0.001 cm^3 per 100 g of metal. Therefore, hydrogen will be released by the metal on solidification, either to the atmosphere or trapped within the solid metal as gas porosity. The oxides formed by the reaction are insoluble in the alloy but remain suspended in it because the specific gravities of the oxides and the alloy are almost equal. On solidification of the liquid metal, the oxides remain within the metal and form

finely divided or gross oxides, depending upon the degree of coalescence.

The following are efficient and reliable methods for the removal of these impurities from the molten aluminium.

(1) *Pre-solidification*

Because the solubility of hydrogen in solid aluminium is very low, if the metal is allowed to cool slowly, most of the dissolved gas will be liberated on solidification. This technique is often used with primary remelt metal.

(2) *Holding of the metal at rest*

Given sufficient time, gases and oxides will float to the surface of a bath of liquid metal.

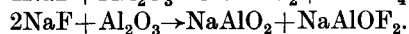
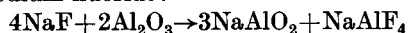
(3) *Treatment with gases such as nitrogen or chlorine*

Degassing is carried out by the slow bubbling of a suitable gas through the molten metal. Hydrogen is removed because of the difference in partial pressure between the hydrogen and the introduced gas, the hydrogen diffusing into the bubble of gas until equilibrium is attained. The bubbles carrying the hydrogen gas escape into the atmosphere, effectively reducing the overall level of hydrogen in the metal. Some of the gases used, such as chlorine, are active in that they combine with the aluminium to form compounds that are gaseous at the temperatures involved. These active gases are found to be more effective in degassing, possibly owing to the formation of smaller bubbles, which have a larger gross surface area. Unfortunately, chlorine gases pose pollution problems and are therefore generally used in combination with a larger volume of some inert gas. This technique also effectively removes finely divided oxides, which

are often associated with the entrapped hydrogen gas.

Aluminium oxide is removed by the use of fluxing salts. The fluxes react either mechanically or chemically with the impurities to clean the metal.

Active fluxes, based on halides, are intimately mixed with the metal by stirring. The resulting products float to the surface with the flux and are removed by skimming. A typical flux is cryolite with an excess of sodium fluoride:



Passive fluxes, which are based on mixtures of alkali chlorides with additions of fluorides and oxidizing compounds, are used to protect the surface of the melt from oxidation and prevent further pick-up of hydrogen. The aim is to produce a dry slag that will effectively absorb aluminium oxide with as little metal as possible and that can easily be skimmed.

Products of Alusaf

Of the total aluminium output of Alusaf, extrusion billets represent 25 per cent, rolling slabs 25 per cent, electrical conductor rod 40 per cent, and remelt ingots 10 per cent.

The extrusion billets are used mostly in low- to medium-alloy structural sections and vary from 108 to 254 mm in diameter. Most of the rolling slabs are destined for the production of aluminium foil and low-alloy sheets, the largest slabs being 1900 mm wide and 410 mm thick. Of the total output of conductor rod, most is supplied to Escom and the South African Railways and Harbours via the manufacturers of cables for overhead electrical conductors. The rod is mostly 9 mm in diameter and is delivered in 1500 kg coils. The standard mass of the remelt ingots is 20,5 kg, and they have a standard purity of 99,5 and 99,7 per cent, although a grade of up to 99,9 per cent can be supplied in small quantities. These ingots find their final application in various foundries.

Quality Control

The metal from the Alusaf potroom has an average aluminium content of 99,70 per cent, which is the level of purity prescribed by the demands of the market and which represents a fair average for primary metal products. The iron content is approximately 0,20 per cent, with silicon at 0,07 per cent. All the other impurities are individually less than 0,003 per cent. The major sources of impurities are the raw materials, the steel spades of the anode rods, and the iron that slowly dissolves from the steel conductors embedded in the bottom of the cathode as the cathode deteriorates progressively towards the end of the shell campaign.

Samples of metal and electrolyte are collected from each cell and analysed twice a week, the results being used in monitoring the total impurity level and in determining the composition of the casthouse charge. Most quality-control functions are arranged around the activities of the casthouse, the spectrographic section being organized on a 24-hour basis. Print-outs of the analyses are available in the casthouse within ten

minutes of the sampling and give complete analyses for iron, silicon, magnesium, manganese, vanadium, titanium, chromium, boron, copper, and zinc.

Routine macro-etchings are made from each cast of slabs and billets, and the etchings are then compared with sets of standards for the following features:

- (1) evenness of grain size with respect to shape, surface area, growth pattern, grain refining, evidence of precrystallization areas, width of shell zone, and columnar (feathery) structures,
- (2) inclusions (foreign and oxides), and
- (3) porosity, cracks, shrinkage, and segregation effects.

Tests of electrical conductivity and tensile strength are done on the rod. In addition, the quality controllers are trained to make physical examinations of the processes and operating techniques.

Plant and Production Statistics

Potroom

The average daily output per pot is 1000 kg of metal.

The potroom building is 1300 m long by 30 m wide, and ten spare shells are in rotation for the 222 installed pots. The average pot life is three years. The normal current load is 140 kA at 1000 V for the series arrangement of pots. Escom supplies power from the national grid at 132 kV, and a complete stand-by line guarantees operating continuity.

Casthouse

Installed furnace capacities consist of two 30 t, three 25 t, and three 15 t mixing furnaces, as well as five 25 t and three 15 t casting furnace units.

The products are cast on five D.C. machines, two ingot casters, and one Properzi rod plant. A small 2 t coreless induction furnace is employed to remelt saw chips.

A 5 t rotating furnace, in a separate building, is used to remelt the metal that is reclaimed from metal dross.

Services Functions

Spent pots are cleaned and relined in a cathode repair shop. A separate anode repair shop is provided adjacent to the potroom for the continuous supply of new anodes. Workshops for the maintenance of vehicles, and mechanical, electrical, and instrument workshops support the production function. The transportation of raw materials and the product handling are organized centrally.

Potential for the Industry

The total primary aluminium industry has become increasingly aware of the world-wide sensitivity to energy costs and scarcity. The trend is firmly towards cells of higher current density with increased outputs at lower specific energy requirements.

The advance of automation through on-line computer tends to reduce the dependency on pot supervision, and various plants in America and Europe operate successfully with hooded or closed pots. Most of the high costs of installation can then be recovered by the reclamation of volatile electrolyte components via filter systems.

Large overhead multiple-purpose cranes provide the

alumina supply, can change the anodes, and perform the metal tapping and general services functions. These pots are equipped with centre crustbreaking mechanisms and alumina-dosing devices.

In the field of alternative raw materials, the present dependence on bauxite through the Bayer process will probably not change significantly in the foreseeable future. Most alternative processes have not gone beyond

the pilot-plant or small-scale stages. Equally uncertain is the possibility of replacing the traditional carbon anode on an economic basis with an inert material.

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2. WITTNER, H. *Ullmans Encyklopädie der technischen Chemie*, Band 7. Weinheim, Verlag Chemie GmbH, 694. 1973.

Company Affiliates

The following members have been admitted to the Institute as Company Affiliates.

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Tvl Cons. Land & Exploration Co.
Tsumeb Corporation Limited.
Union Corporation Limited.
Vaal Reefs Exploration & Mining Co. Limited.
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Vlakfontein G.M. Co. Limited.
Welkom Gold Mining Co. Limited.
West Driefontein G.M. Co. Limited.
Western Areas Gold Mining Co. Ltd.
Western Deep Levels Limited.
Western Holdings Limited.
Winkelhaak Mines Limited.