

Aluminum Manufacturing

Industry Description and Practices

The production of aluminum begins with the mining and beneficiation of bauxite. At the mine (usually of the surface type), bauxite ore is removed to a crusher. The crushed ore is then screened and stockpiled, ready for delivery to an alumina plant. In some cases, ore is upgraded by beneficiation (washing, size classification, and separation of liquids and solids) to remove unwanted materials such as clay and silica.

At the alumina plant, the bauxite ore is further crushed or ground to the correct particle size for efficient extraction of the alumina through digestion by hot sodium hydroxide liquor. After removal of "red mud" (the insoluble part of the bauxite) and fine solids from the process liquor, aluminum trihydrate crystals are precipitated and calcined in rotary kilns or fluidized bed calciners to produce alumina (Al_2O_3). Some alumina processes include a liquor purification step.

Primary aluminum is produced by the electrolytic reduction of the alumina. The alumina is dissolved in a molten bath of fluoride compounds (the electrolyte), and an electric current is passed through the bath, causing the alumina to dissociate to form liquid aluminum and oxygen. The oxygen reacts with carbon in the electrode to produce carbon dioxide and carbon monoxide. Molten aluminum collects in the bottom of the individual cells or pots and is removed under vacuum into tapping crucibles. There are two prominent technologies for aluminum smelting: prebake and Soderberg. This document focuses on the prebake technology, with its associated reduced air emissions and energy efficiencies.

Raw materials for secondary aluminum production are scrap, chips, and dross. Pretreatment of scrap by shredding, sieving, magnetic separa-

tion, drying, and so on is designed to remove undesirable substances that affect both aluminum quality and air emissions. The prevailing process for secondary aluminum production is smelting in rotary kilns under a salt cover. Salt slag can be processed and reutilized. Other processes (smelting in induction furnaces and hearth furnaces) need no or substantially less salt and are associated with lower energy demand, but they are only suitable for high-grade scrap. Depending on the desired application, additional refining may be necessary. For demagging (removal of magnesium from the melt), hazardous substances such as chlorine and hexachloroethane are often used, which may produce dioxins and dibenzofurans. Other, less hazardous methods, such as adding chlorine salts, are available. Because it is difficult to remove alloying elements such as copper and zinc from an aluminum melt, separate collection and separate reutilization of different grades of aluminum scrap are necessary. It should be noted that secondary aluminum production uses substantially less energy than primary production—less than 10–20 gigajoules per metric ton (GJ/t) of aluminum produced, compared with 164 GJ/t for primary production (mine to aluminum metal).

Waste Characteristics

At the bauxite production facilities, dust is emitted to the atmosphere from dryers and materials-handling equipment, through vehicular movement, and from blasting. Although the dust is not hazardous, it can be a nuisance if containment systems are not in place, especially on the dryers and handling equipment. Other air emissions could include nitrogen oxides (NO_x), sulfur dioxide (SO_2), and other products of combustion from the bauxite dryers.

Ore washing and beneficiation may yield process wastewaters containing suspended solids. Runoff from precipitation may also contain suspended solids.

At the alumina plant, air emissions can include bauxite dust from handling and processing; limestone dust from limestone handling, burnt lime dust from conveyors and bins, alumina dust from materials handling, red mud dust and sodium salts from red mud stacks (impoundments), caustic aerosols from cooling towers, and products of combustion such as sulfur dioxide and nitrogen oxides from boilers, calciners, mobile equipment, and kilns. The calciners may also emit alumina dust and the kilns, burnt lime dust.

Although alumina plants do not normally discharge effluents, heavy rainfalls can result in surface runoff that exceeds what the plant can use in the process. The excess may require treatment.

The main solid waste from the alumina plant is red mud (as much as 2 tons of mud per ton of alumina produced), which contains oxides of alumina, silicon, iron, titanium, sodium, calcium, and other elements. The pH is 10–12. Disposal is to an impoundment.

Hazardous wastes from the alumina plant include spent sulfuric acid from descaling in tanks and pipes. Salt cake may be produced from liquor purification if this is practiced.

In the aluminum smelter, air emissions include alumina dust from handling facilities; coke dust from coke handling; gaseous and particulate fluorides; sulfur and carbon dioxides and various dusts from the electrolytic reduction cells; gaseous and particulate fluorides; sulfur dioxide; tar vapor and carbon particulates from the baking furnace; coke dust, tars, and polynuclear aromatic hydrocarbons (PAHs) from the green carbon and anode-forming plant; carbon dust from the rodding room; and fluxing emissions and carbon oxides from smelting, anode production, casting, and finishing. The electrolytic reduction cells (pot line) are the major source of the air emissions, with the gaseous and particulate fluorides being of prime concern. The anode effect associated with electrolysis also results in emissions of carbon tetrafluoride (CF₄) and carbon hexafluoride (C₂F₆), which are greenhouse gases, of concern because of their potential for global

warming. Emissions numbers that have been reported for uncontrolled gases from smelters are 20–80 kilograms per ton of product (kg/t) for particulates, 6–12 kg/t for hydrogen fluoride, and 6–10 kg/t for fluoride particulates. Corresponding concentrations are 200–800 milligrams per cubic meter (mg/m³); 60–120 mg/m³; and 60–100 mg/m³. These values are for a prebaked-technology plant built in 1983.

An aluminum smelter produces 40–60 kg of mixed solid wastes per ton of product, with spent cathodes (spent pot and cell linings) being the major fraction. The linings consist of 50% refractory material and 50% carbon. Over the useful life of the linings, the carbon becomes impregnated with aluminum and silicon oxides (averaging 16% of the carbon lining), fluorides (34% of the lining), and cyanide compounds (about 400 parts per million). Contaminant levels in the refractories portion of linings that have failed are generally low. Other by-products for disposal include skim, dross, fluxing slags, and road sweepings.

Atmospheric emissions from secondary aluminum melting include hydrogen chloride and fluorine compounds. Demagging may lead to emissions of chlorine, hexachloroethane, chlorinated benzenes, and dioxins and furans. Chlorinated compounds may also result from the melting of aluminum scrap that is coated with plastic. Salt slag processing emits hydrogen and methane. Solid wastes from the production of secondary aluminum include particulates, pot lining refractory material, and salt slag. Particulate emissions, possibly containing heavy metals, are also associated with secondary aluminum production.

Pollution Prevention and Control

Pollution prevention is always preferred to the use of end-of-pipe pollution control facilities. Therefore every attempt should be made to incorporate cleaner production processes and facilities to limit, at source, the quantity of pollutants generated.

In the bauxite mine, where beneficiation and ore washing are practiced, a tailings slurry of 7–9% solids is produced for disposal. The preferred technology is to concentrate these tailings and dispose of them in the mined-out area. A con-

centration of 25–30% can be achieved through gravity settling in a tailings pond. The tailings can be further concentrated, using a thickener, to 30–50%, yielding a substantially volume-reduced slurry.

The alumina plant discharges red mud in a slurry of 25–30% solids, and this also presents an opportunity to reduce disposal volumes. Today's technology, in the form of high-efficiency deep thickeners, and large-diameter conventional thickeners, can produce a mud of 50–60% solids concentration. The lime used in the process forms insoluble solids that leave the plant along with the red mud. These lime-based solids can be minimized by recycling the lime used as a filtering aid to digestion to displace the fresh lime that is normally added at this point. Finally, effluent volume from the alumina plant can be minimized or eliminated by good design and operating practices: reducing the water added to the process, segregating condensates and recycling to the process, and using rainwater in the process.

Using the prebake technology rather than the Soderberg technology for aluminum smelting is a significant pollution prevention measure. In the smelter, computer controls and point feeding of aluminum oxide to the centerline of the cell help reduce emissions, including emissions of organic fluorides such as CF_4 , which can be held at less than 0.1 kg/t aluminum. Energy consumption is typically 14 megawatt hours per ton (MWh/t) of aluminum, with prebake technology. (Soderberg technology uses 17.5 MWh/t.) Gas collection efficiencies for the prebake process is better than for the Soderberg process: 98% vs. 90%. Dry scrubber systems using aluminum oxide as the adsorbent for the cell gas permits the recycling of fluorides. The use of low-sulfur tars for baking anodes helps control SO_2 emissions. Spent pot linings are removed after they fail, typically because of cracking or heaving of the lining. The age of the pot linings can vary from 3 to 10 years. By improving the life of the lining through better construction and operating techniques, discharge of pollutants can be reduced. Note that part of the pot lining carbon can be recycled when the pots are relined.

Emissions of organic compounds from secondary aluminum production can be reduced by thoroughly removing coatings, paint, oils,

greases, and the like from raw feed materials before they enter the melt process.

Target Pollution Loads

Experience in Europe has shown that red mud produced at the alumina plant can be reduced from 2 t/t alumina to about 1 t/t alumina through implementation of good industrial practices.

Treatment Technologies

At bauxite facilities, the major sources of dust emissions are the dryers, and emissions are controlled with electrostatic precipitators (ESPs) or baghouse dust collectors. Removal efficiencies of 99% are achievable. Dust from conveyors and material transfer points is controlled by hoods and enclosures. Dust from truck movement can be minimized by treating road surfaces and by ensuring that vehicles do not drop material as they travel. Dusting from stockpiled material can be minimized by the use of water sprays or by enclosure in a building.

At the alumina plant, pollution control for the various production and service areas is implemented as follows:

- *Bauxite and limestone handling and storage:* dust emissions are controlled by baghouses.
- *Lime kilns:* dust emissions are controlled by baghouse systems. Kiln fuels can be selected to reduce SO_2 emissions; however, this is not normally a problem, since most of the sulfur dioxide that is formed is absorbed in the kiln.
- *Calciners:* alumina dust losses are controlled by ESPs; SO_2 and NO_x emissions are reduced to acceptable levels by contact with the alumina.
- *Red mud disposal:* the mud impoundment area must be lined with impervious clay prior to use to prevent leakage. Water spraying of the mud stack may be required to prevent fine dust from being blown off the stack. Longer-term treatment of the mud may include reclamation of the mud, neutralization, covering with topsoil, and planting with vegetation.

In the smelter, primary emissions from the reduction cells are controlled by collection and treatment using dry sorbent injection; fabric fil-

ters or electrostatic precipitators are used for controlling particulate matter. Primary emissions comprise 97.5% of total cell emissions; the balance consists of secondary emissions that escape into the potroom and leave the building through roof ventilators. Wet scrubbing of the primary emissions can also be used, but large volumes of toxic waste liquors will need to be treated or disposed of. Secondary emissions result from the periodic replacement of anodes and other operations; the fumes escape when the cell hood panels have been temporarily removed. While wet scrubbing can be used to control the release of secondary fumes, the high-volume, low-concentration gases offer low scrubbing efficiencies, have high capital and operating costs, and produce large volumes of liquid effluents for treatment. Wet scrubbing is seldom used for secondary fume control in the prebake process.

When anodes are baked on site, the dry scrubbing system using aluminum oxide as the adsorbent is used. It has the advantage of being free of waste products, and all enriched alumina and absorbed material are recycled directly to the reduction cells. Dry scrubbing may be combined with incineration for controlling emissions of tar and volatile organic compounds (VOCs) and to recover energy. Wet scrubbing can also be used but is not recommended, since a liquid effluent, high in fluorides and hydrocarbons, will require treatment and disposal.

Dry scrubber systems applied to the pot fumes and to the anode baking furnace result in the capture of 97% of all fluorides from the process.

The aluminum smelter solid wastes, in the form of spent pot lining, are disposed of in engineered landfills that feature clay or synthetic lining of disposal pits, provision of soil layers for covering and sealing, and control and treatment of any leachate. Treatment processes are available to reduce hazards associated with spent pot lining prior to disposal of the lining in a landfill. Other solid wastes such as bath skimmings are sold for recycling, while spalled refractories and other chemically stable materials are disposed of in landfill sites.

Modern smelters using good industrial practices are able to achieve the following in terms of pollutant loads (all values are expressed on an

annualized basis): hydrogen fluoride, 0.2–0.4 kg/t; total fluoride, 0.3–0.6 kg/t; particulates, 1 kg/t; sulfur dioxide, 1 kg/t; and nitrogen oxides, 0.5 kg/t. CF₄ emissions should be less than 0.1 kg/t.

For secondary aluminum production, the principal treatment technology downstream of the melting furnace is dry sorbent injection using lime, followed by fabric filters. Waste gases from salt slag processing should be filtered as well. Waste gases from aluminum scrap pretreatment that contain organic compounds of concern may be treated by postcombustion.

Emissions Guidelines

Emissions levels for the design and operation of each project must be established through the environmental assessment (EA) process on the basis of country legislation and the *Pollution Prevention and Abatement Handbook*, as applied to local conditions. The emissions levels selected must be justified in the EA and acceptable to the World Bank Group.

The guidelines given below present emissions levels normally acceptable to the World Bank Group in making decisions regarding provision of World Bank Group assistance. Any deviations from these levels must be described in the World Bank Group project documentation. The emissions levels given here can be consistently achieved by well-designed, well-operated, and well-maintained pollution control systems. The guidelines are expressed as concentrations to facilitate monitoring. Dilution of air emissions or effluents to achieve these guidelines is unacceptable.

All of the maximum levels should be achieved for at least 95% of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours.

Air Emissions

The air emissions levels presented in Table 1 should be achieved.

Liquid Effluents

If there is a process effluent from the aluminum

Table 1. Air Emissions from Aluminum Smelting*(milligrams per normal cubic meter)*

<i>Parameter</i>	<i>Maximum value</i>
Particulate matter	30
Hydrogen fluoride	1
Total fluoride	2
VOCs	20

Table 2. Liquid Effluents from Aluminum Smelting*(milligrams per liter, except pH and temperature)*

<i>Parameter</i>	<i>Maximum value</i>
pH	6–9
TSS	50
Fluoride	20
Aluminum	0.2
COD	150
Hydrocarbons	5
Temperature increase	≤ 3°C ^a

Note: Effluent requirements are for direct discharge to surface waters.

a. The effluent should result in a temperature increase of no more than 3°C at the edge of the zone where initial mixing and dilution take place. Where the zone is not defined, use 100 meters from the point of discharge.

smelter, the effluent emissions levels presented in Table 2 should be achieved.

Ambient Noise

Noise abatement measures should achieve either the levels given below or a maximum increase in background levels of 3 decibels (measured on the A scale) [dB(A)]. Measurements are to be taken at noise receptors located outside the project property boundary.

<i>Receptor</i>	<i>Maximum allowable log equivalent (hourly measurements), in dB(A)</i>	
	<i>Day (07:00–22:00)</i>	<i>Night (22:00–07:00)</i>
Residential, institutional, educational	55	45
Industrial, commercial	70	70

Monitoring and Reporting

Frequent sampling may be required during start-up and upset conditions. Once a record of consistent performance has been established, sampling for the parameters listed in this document should be as described below.

Air emissions should be monitored regularly for particulate matter and fluorides. Hydrocarbon emissions should be monitored annually on the anode plant and baking furnaces.

Liquid effluents should be monitored weekly for pH, total suspended solids, fluoride, and aluminum and at least monthly for other parameters.

Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Records of monitoring results should be kept in an acceptable format. The results should be reported to the responsible authorities and relevant parties, as required.

Key Issues

The key production and control practices that will lead to compliance with emissions requirements are summarized here.

Bauxite Production

- Concentrate bauxite tailings prior to disposal.
- Control dust emissions at the bauxite mine and in the alumina plant by using ESPs and baghouses.

Alumina Plant

- Thicken and concentrate red mud in the alumina plant, using high-efficiency thickeners, and then dispose of it in engineered and managed stacks.

Primary Aluminum Smelting

- Give preference to the prebake process for smelting.
- Use computers to control the bath and limit anode effects.
- Incinerate baking furnace gases for energy recovery.

- Use dry scrubber systems with aluminum oxide absorbent for control of emissions from reduction cells and from anode bake ovens.
- Maximize the reuse of spent pot linings.
- Dispose of nonreusable spent pot linings in engineered landfills.

Secondary Aluminum Production

- Take advantage of processes for reusing salt slag.

Sources

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- World Bank. 1995. "Industrial Pollution Prevention and Abatement: Aluminum Smelting." Draft Technical Background Document. Environment Department, Washington, D.C.