

Environmental Guidelines for Aluminum Manufacturing

Industry Description and Practices

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

At the alumina plant the bauxite ore is further crushed and/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” 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 which causes the alumina to dissociate to form liquid aluminum and oxygen which 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. Note: There are two prominent technologies for aluminum smelting—prebake and Soderberg. This guideline 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. Scrap pretreatment by shredding, sieving magnetic separation, drying, etc. is designed for the removal of undesirable substances, which 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 processing and re-utilization is possible. Other processes, smelting in induction furnaces and hearth furnaces, need no or substantially less salt and are associated with lower energy demand. However, 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. Dioxins and dibenzofuranes may result. Other less hazardous methods such as adding chlorine salts are available. As it is difficult to remove alloying elements such as copper and zinc from an aluminum melt the separate collection and separate re-utilization of different grades of aluminum scrap is necessary. It should be noted that secondary aluminum production uses substantially less energy than primary production: <10-20 giga joules per metric ton (GJ/t) of aluminum produced compared to 164 GJ/t of aluminum produced (mine to aluminum metal)..

Waste Characteristics

At the *bauxite production facilities*, dust is emitted to the atmosphere from dryers and materials

handling equipment, by vehicular movement, and from blasting. While not hazardous, the dust can be a nuisance if containment systems are not in place, especially on the dryers and handling equipment. Other air emissions could include NO_x , SO_2 , and other products of combustion from the bauxite dryers.

Ore washing and beneficiation may result in process waste waters containing suspended solids. Run-off 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 (red mud is the insoluble part of the bauxite that is removed and impounded -- stacked); caustic aerosols from cooling towers; and products of combustion such as SO_2 and NO_x from boilers, calciners, mobile equipment and kilns. The calciners may also emit alumina dust and the kilns burnt lime dust.

While alumina plants do not normally discharge effluents, heavy rainfalls can result in surface run-off that is in excess of what the plant can use in the process. The excess may require treatment.

The main solid waste from the alumina plant is the red mud (as high as 2 t of mud per ton of alumina produced) which contains oxides of alumina, silicon, iron, titanium, sodium, calcium and others. The pH will be in the range of 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 will 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, and tars/PAHs¹ 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 (CF_4) and carbon hexafluoride (C_2F_6) which are greenhouse gases. Organic fluorides such as CF_4 and C_2F_6 are of concern because of their potential for global warming. Emissions numbers that have been reported for uncontrolled gases for smelters are: 20-80 (kg/t) for particulates; 6-12 kg/t for HF; and 6-10 kg/t for fluoride particulates. Corresponding concentrations are: 200-800 milligrams per cubic meter (mg/m^3); 60-120 mg/m^3 ; and 60-100 mg/m^3 . These values are for a pre-baked 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/cell linings) being the major fraction. These 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 (average 16% of the carbon lining), fluorides (average 34% of the carbon lining), and cyanide compounds (~ 400 parts per million (ppm)). Contaminant levels in the refractories portion of linings that have failed are generally low. Other byproducts for disposal include: skim, dross, fluxing slags, and road sweepings.

Atmospheric emissions from secondary aluminum melting include hydrogen chloride, fluorine compounds. Demagging may result in 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.

¹ Polynuclear aromatic hydrocarbons.

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 is 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 concentration of 25-30% can be achieved through gravity settling in a tailings pond; the tailings can be further concentrated to 30-50% using a thickener and a substantially 'volume reduced' slurry results.

The *alumina plant* discharges red mud in a 25-30% solids slurry and this also presents an opportunity to reduce disposal volumes. Today's technology in the form of high efficiency, deep thickeners or large diameter conventional thickeners can produce a mud of 50-60% solids concentration. The lime used in the process forms insoluble solids which leave the plant 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 which is normally added at this point. And finally, effluent volume from the alumina plant can be minimized and/or eliminated by good design and operating practices: reducing the water added to the process; segregation of condensates and recycling to the process; and use of rain water in the process.

Using the prepake technology rather than 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 organic fluorides (e.g. CF₄ reductions to <0.1 kg/t aluminum). Energy consumption is typically 14 megawatts hours per ton (MWh/t) of Al (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 enables the recycle of fluorides. The use of low sulfur tars for baking anodes will help control sulfur dioxide emissions. Spent pot linings (SPL) are removed after they fail, typically due to cracking and/or heaving of the

lining. The age of the pot linings can vary from 3-10 years. By improving the life of the lining through better construction and operating techniques less pollutants are discharged.

Note: 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, etc., 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 with implementation of Good Industrial Practices.

Treatment Technologies

At *bauxite facilities*, the major source of dust emissions are the dryers and control is provided by either electrostatic precipitators (ESPs) or bag house 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 stock piled material can be minimized by the use of water sprays or by enclosure in a building.

At the *alumina plant* pollution control is effected for the various production and service areas 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 SO₂ emissions, however this is not normally a problem since most of the SO₂ that is formed is absorbed in the kiln.
- Calciners: Alumina dust losses are controlled by ESPs; SO₂ 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 top soil, and planting with vegetation.

In the *smelter*, primary emissions from the reduction cells are controlled by collection and treatment using dry sorbent injection; fabric filters or electrostatic precipitators are used for controlling particulate matter. Primary emissions comprise 97.5% of the total cell emissions—the balance are 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 and/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 result in 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.

Where anodes are baked on site the dry scrubbing system using aluminum oxide as the adsorbant is used, with the advantage of being free of waste products, and all enriched alumina and absorbed material being recycled directly to the reduction cells. Dry scrubbing may be combined with incineration for controlling tar and VOC emissions, and to recover energy. Wet scrubbing can also be used however this 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 (SPL), are disposed in engineered landfills which include clay or synthetic lining of disposal pits, provision of soil layers for covering and sealing, and control and treatment of any leachate. Note: treatment processes are available to reduce hazards

associated with SPL 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 in landfill sites.

Modern smelters using good industrial practices are able to achieve the following in terms of pollutant loads (all values expressed on an annualized basis): hydrogen fluoride (HF)—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 <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. Aluminum scrap pretreatment waste gases containing organic compounds of concern may be treated by post combustion.

Emission Guidelines

Emission levels for the design and operation of each project must be established through the Environmental Assessment (EA) process, based on country legislation and the *Pollution Prevention and Abatement Handbook* as applied to local conditions. The emission levels selected must be justified in the EA and acceptable to MIGA.

The following guidelines present emission levels normally acceptable to the World Bank Group in making decisions regarding provision of World Bank Group assistance, including MIGA guarantees; any deviations from these levels must be described in the project documentation.

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

For aluminum smelters the following air emission levels should be achieved:

Air Emissions from Aluminum Smelting

<i>Parameter</i>	<i>Maximum value milligrams per normal cubic meter (mg/Nm³)</i>
Particulate matter	30
Hydrogen fluoride (HF)	1
Total fluoride	2
Volatile organic compounds (VOCs)	20

Liquid Effluents

If there is a process effluent from the aluminum smelter, then the following effluent emissions levels should be achieved:

Liquid Effluents from Aluminum Smelting

<i>Parameter</i>	<i>Maximum value milligrams per liter (mg/L)</i>
pH	6-9
Total suspended solids (TSS)	50
Fluoride (F)	20
Aluminum (Al)	0.2
Chemical oxygen demand (COD)	150
Hydrocarbons (HC)	5
Temperature increase	Less than or equal to 3°C ¹

¹The effluent should result in a temperature increase of no more than 3 degrees Celsius 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.

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

Ambient Noise

Noise abatement measures should achieve either the following levels or a maximum increase in background levels of 3 dB(A). Measurements are to be taken at noise receptors located outside the project property boundary.

Ambient Noise

Receptor	Maximum Allowable L _{eq} (hourly), in dB(A)	
	Daytime 07:00 – 22:00	Nighttime 22:00 – 07:00
Residential	55	45
; institutional		
; educational		
Industrial;	70	70
commercial		

The emission requirements given here can be consistently achieved by well-designed, well-operated and well-maintained pollution control systems.

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 above should be as detailed 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. These should be reported to the responsible authorities and relevant parties, as required, and provided to MIGA if requested.

Key Issues

The following box summarizes the key production and control practices that will lead to compliance with emission requirements:

Bauxite production

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

Alumina plant

- Thicken and concentrate red mud in the alumina plant through high efficiency thickeners and then dispose 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 absorbant for control of emissions from reduction cells and from anode bake ovens.
- Maximize the reuse of spent pot linings (SPL).
- Dispose of SPL that cannot be reused in engineered landfills.

Secondary aluminum production

- Processes for reusing salt slag are available and should be used

Further Information

The following are suggested as sources of additional information (these sources are provided for guidance and are not intended to be comprehensive):

Bounicore, A.J. and W.T. Davis. 1992. *Air Pollution Engineering Manual*. New York: Van Nostrand Reinhold.

World Bank, Environment Department. 1995. "Industrial Pollution Prevention and Abatement: Aluminum Smelting." Draft document.

PARCOM. 1992. *Industrial Sectors: Best Available Technology – Primary Aluminium Industry*.