



**Market Sector Briefing Notes  
Briefing Note Number 4**

**The Secondary Smelting Industry**

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## **Introduction**

This document is one of a series of market sector briefing notes, which have been produced as an information resource for PCME Distributors. The aim of these documents is to provide background information on the main types of industry in which PCME operates with a view to providing reference material to enable the identification of specific monitoring requirements.

Briefing Notes are available for the following industry sectors:

### **Metals Industries**

Steel and Foundry  
Secondary Smelting – Non-ferrous

### **Minerals Industries**

Cement  
Gypsum and Plaster

### **Chemical and Food Industries**

Carbon Black/Tyre Manufacture  
Chemical and Food Processing (including pigment, tobacco, starch, milk and coffee manufacture)  
Tobacco

## Industry Data

- BHP Bilton is the world's third largest producer of primary aluminium, with a total operating capacity in one million tonnes of aluminium, approximately 9.5 million tonne of bauxite and four million tonnes of alumina per annum.
- BHP Bilton is a shareholder in five successful primary aluminium smelters (brackets indicate percentage of ownership):

Alumar, Brazil (46%)  
Valesul, Brazil (41%)  
Hillside Aluminium, Africa (100%)  
Bayside Aluminium, Africa (100%)  
Mozal, Mozambique (47%)

- Alcoa World Alumina is one of the world's largest producers of bauxite, which is mined and then refined into alumina at Alcoa sites around the world.
- According to the Brazilian Associations of Aluminium (ABAL), Brazilian production of primary aluminium reached a volume of 124,7 thousand tons, in March(2004), presenting a 4.9% growth compared to the same month of 2003, when the production totalled 118,9 thousand tons product.

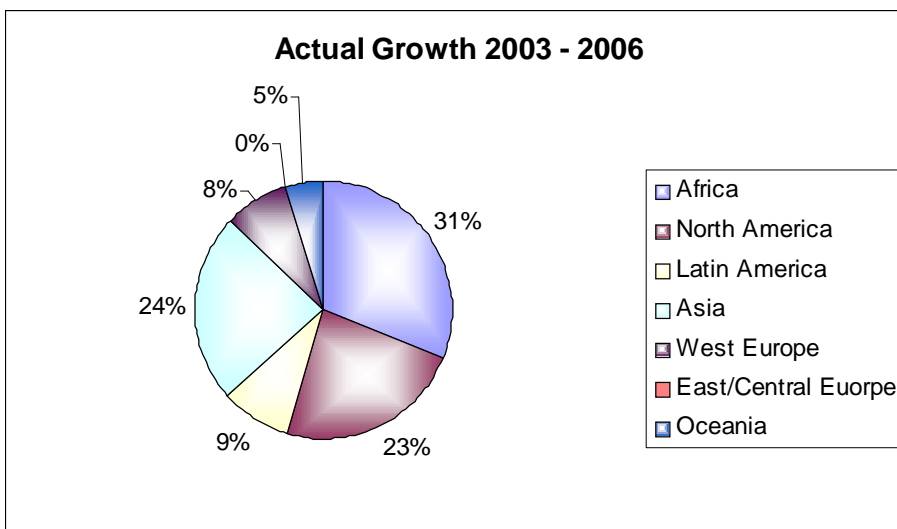
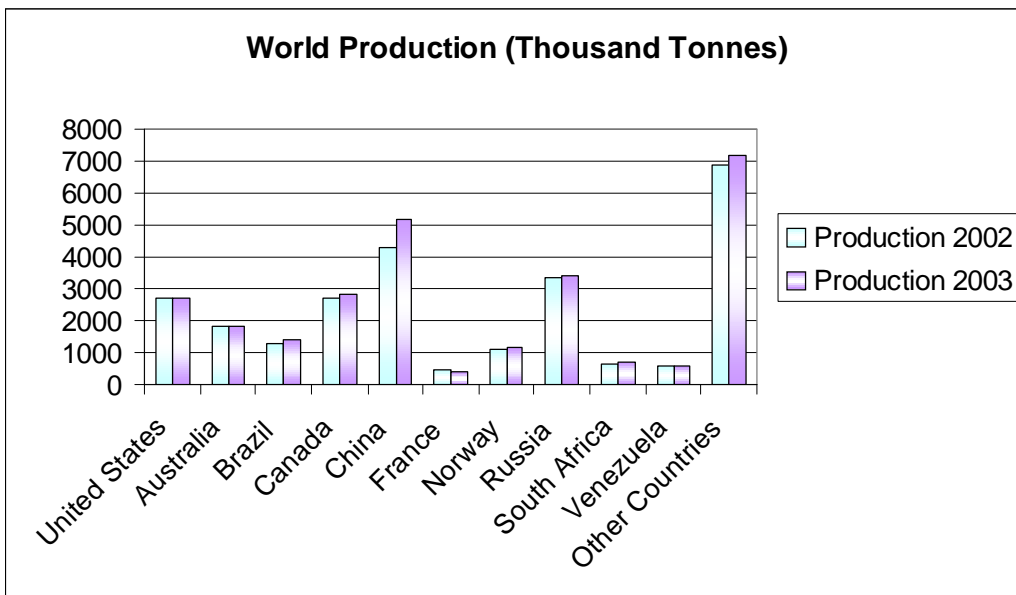
The forecast of the sector for 2004 is to produce 1.463 thousand tons, with a growth of 6.0% over previous year. (May 05 2004)

- China Minmetals Nonferrous Metals Co Ltd (CMN) announced the establishment of a new relationship with Sherwin Alumina Company, by acquiring an equity interest in the company. CMN and BPU Associates,LLC, will jointly own and operate Sherwin Alumina Company, the second largest refinery in North America. (May 05 2004)
- Century Aluminium Company has completed the acquisition of Nordural Aluminium hg from Columbia Ventures Corporation, Nordural owns a 90,000 metric-ton-per-year (mtpy) primary aluminium plant at Grundartangi, Iceland. An expansion is planned that will double the plant's capacity of 180,000 mtpy by 2006. Century assumed operating and management control of the facility today.

## Industry Data Table & Charts

Company/Group	Ranking	Total Aluminium Production capacity	No of Plants
Alcoa	1	-	27
Alcan	2	2,238 KT	41
BHP Billiton	3	1 million	7
Rio Tinto	4	30037.7 thousand tonnes	9

Alcoa total production since start up in 1886 is 690 million metric tonnes



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## Description of Main Processes Involved

### Introduction

Non-ferrous metals are defined to be metals or alloys that are free of iron or comparatively so. Non-ferrous metals have their own individual properties and applications. In several cases however, e.g. copper and aluminium, alloys are used in more applications than pure metals because they can be designed to have specific strength, toughness, etc., to meet the requirements of particular applications.

There are many similarities between primary and secondary production of non-ferrous metals and in some cases it is impossible to distinguish between the techniques used. Secondary production of non-ferrous metals includes the production of metal from secondary raw materials (including scrap) and the re-melting and alloying processes.

In order to deal with the complex area of the production of non-ferrous metals, an approach was adopted by the Technical Working Group (TWG) responsible for the production of the Integrated Pollution Prevention and Control Reference Document on Best Available Techniques in the Non Ferrous Metals Industries (BREF), to cover production of the metals from both primary and secondary raw materials together in one document.

The production of 42 non-ferrous metals and the production of ferro alloys were identified in countries that are obliged to implement IPPC. These metals were then grouped into 10 categories of metals with similar production methods. This Market Sector Briefing Note is structured on the basis adopted by the BREF Technical Working Group.

The groups of non-ferrous metals identified by the BREF TWG are:

- Copper (including Sn and Be) and its Alloys.
- Aluminium.
- Zinc, Lead and Cadmium, (+ Sb, Bi, In, Ge, Ga, As, Se, Te).
- Precious Metals.
- Mercury.
- Refractory Metals.
- Ferro Alloys.
- Alkali and Alkaline Earth Metals.
- Nickel and Cobalt.
- Carbon and graphite electrodes

There is an enormous range of processes used worldwide for the production of non-ferrous metals and alloys including pyrometallurgical and hydrometallurgical routes. This Market Sector Briefing Note does not aim to cover all processes involved, but instead concentrates on the most common methods for primary smelting of non-ferrous metals, which are the most likely processes to require continuous monitoring of particulate matter using PCME equipment.

Some of the above groups of non-ferrous metals are also excluded from this document, as they do not fall into the category of primary metals. For example, ferro alloys are compounds consisting of iron and other metals and are not designated as primary metals.

The production of carbon and graphite electrodes is included as a separate group, as many such processes are associated with primary aluminium smelters.

The most commonly used methods for the primary smelting of non-ferrous metals are discussed below:

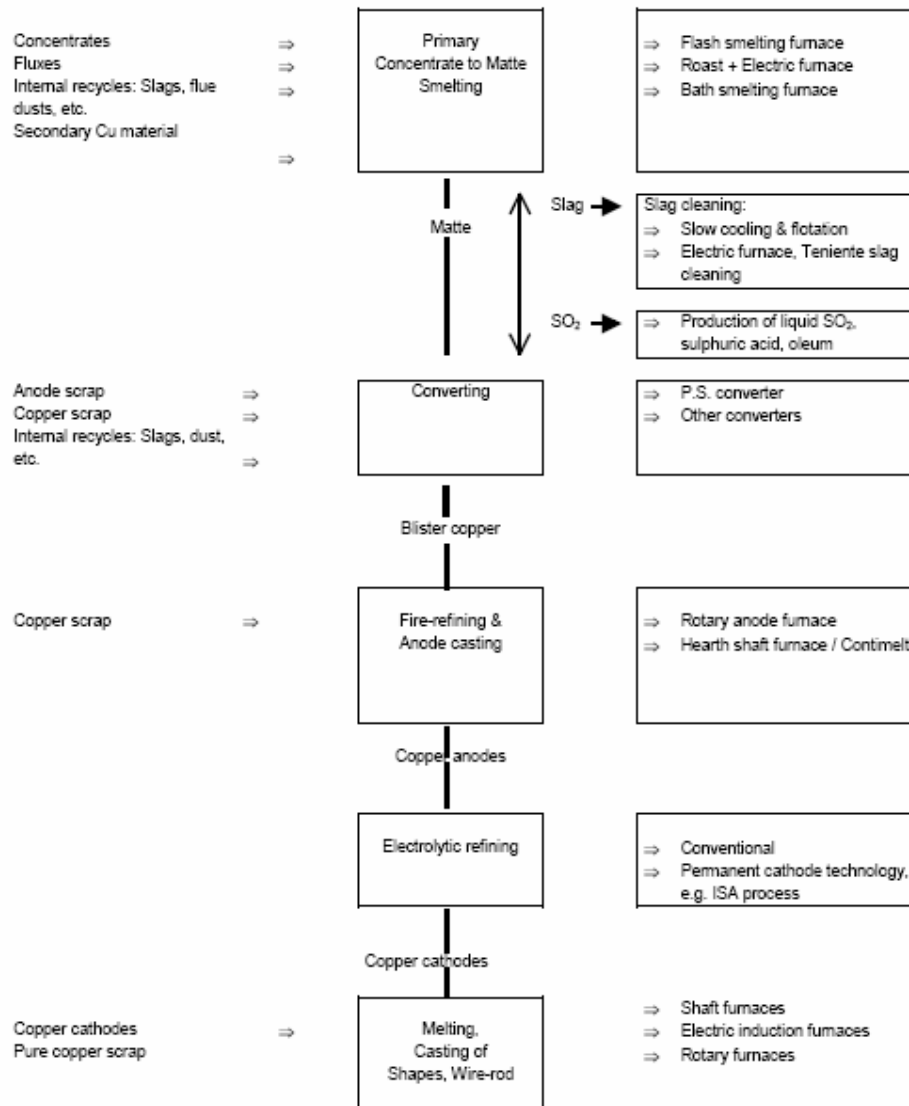
### **Copper and its Alloys**

Copper has been used for many centuries; it has a very high thermal and electrical conductivity and is relatively corrosion resistant. Used copper can be recycled without loss of quality. These properties mean that copper is used in diverse sectors such as electrical engineering, automobiles, construction, plumbing, machinery, shipbuilding, aircraft, and precision instruments. Copper is frequently alloyed with Zn, Sn, Ni, Al and other metals to make a range of brasses and bronzes.

Mining produces ores with less than 1% copper. Concentration is accomplished at the mine sites by crushing, grinding, and flotation purification, resulting in ore with 15% to 35% copper. A continuous process called floatation, which uses water, various floatation chemicals, and compressed air, separates the ore into fractions. Depending upon the chemicals used, some minerals float to the surface and are removed in a foam of air bubbles, while others sink and are reprocessed.

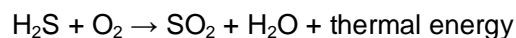
Pine oils, cresylic acid, and long-chain alcohols are used for the flotation of copper ores. The flotation concentrates are then dewatered by clarification and filtration, resulting in 10% to 15% water, 25% sulphur, 25% iron, and varying quantities of arsenic, antimony, bismuth, cadmium, lead, selenium, magnesium, aluminium, cobalt, tin, nickel, tellurium, silver, gold, and palladium.

A typical pyrometallurgical copper smelting process includes 4 steps: roasting, smelting, concentrating, and fire refining. Ore concentration is roasted to reduce impurities, including sulphur, antimony, arsenic, and lead. The roasted product, calcine, serves as a dried and heated charge for the smelting furnace. Smelting of roasted (calcine feed) or unroasted (green feed) ore concentrate produces matte, a molten mixture of copper sulphide ( $\text{Cu}_2\text{S}$ ), iron sulphide ( $\text{FeS}$ ), and some heavy metals. Converting the matte yields a high-grade "blister" copper, with 98.5% to 99.5% copper. Typically, blister copper is then fire-refined in an anode furnace, cast into "anodes", and sent to an electrolytic refinery for further impurity elimination.



### *Primary Copper Production Route*

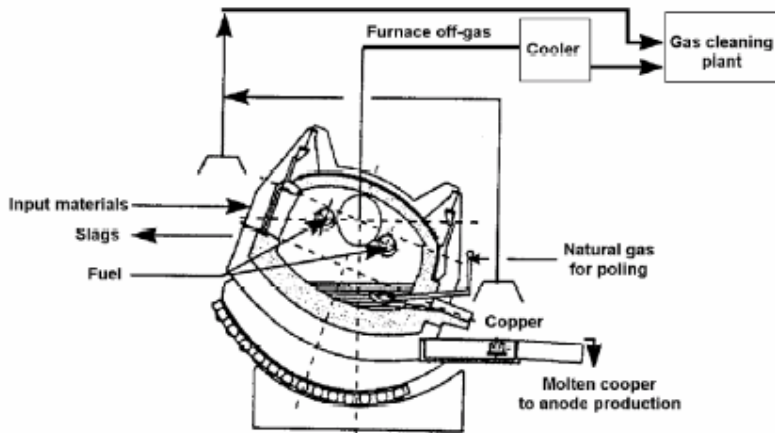
Roasting is performed in copper smelters prior to charging reverberatory furnaces. In roasting, charge material of copper concentrate mixed with a siliceous flux (often a low-grade copper ore) is heated in air to about 650°C, eliminating 20% to 50% of the sulphur as sulphur dioxide (SO<sub>2</sub>). Portions of impurities such as antimony, arsenic, and lead are driven off, and some iron is converted to iron oxide. Roasters are either multiple hearth or fluidised bed; multiple hearth roasters accept moist concentrate, whereas fluidised bed roasters are fed finely ground material. Both roaster types have self-generating energy by the exothermic oxidation of hydrogen sulphide, shown in the reaction below.



In the smelting process, either hot calcine from the roaster or raw unroasted concentrate is melted with siliceous flux in a smelting furnace to produce copper matte. The required heat comes from partial oxidation of the sulphide charge and from burning external fuel. Most of the iron and some of the impurities in the charge

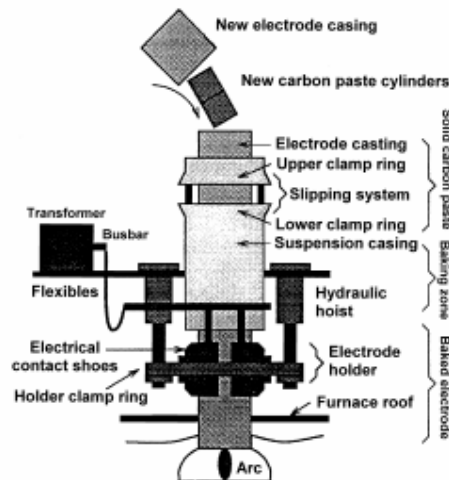
oxidize with the fluxes to form a slag on top of the molten bath, which is periodically removed and discarded. Copper matte remains in the furnace until tapped. Matte ranges from 35% to 65% copper, with 45% the most common. The copper content percentage is referred to as the matte grade. The four smelting furnace technologies mainly used are reverberatory, electric, Noranda, and flash.

The reverberatory furnace smelting operation is a continuous process, with frequent charging and periodic tapping of matte, as well as skimming slag. Heat is supplied by natural gas, with conversion to oil during gas restrictions. Furnace temperature may exceed 1500°C, with the heat being transmitted by radiation from the burner flame, furnace walls, and roof into the charge of roasted and unroasted materials mixed with flux. Stable copper sulphide ( $\text{Cu}_2\text{S}$ ) and stable FeS form the matte with excess sulphur leaving as sulphur dioxide.



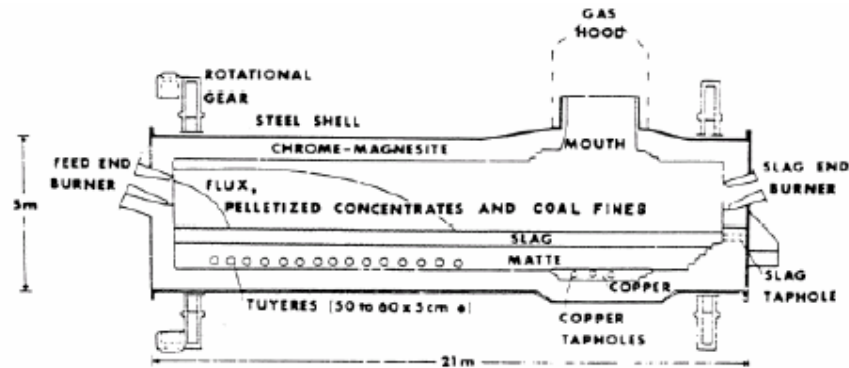
*An example of a Reverberatory Furnace*

Electric arc furnace smelters generate heat with carbon electrodes that are lowered through the furnace roof and submerged in the slag layer of the molten bath. The feed consists of dried concentrates or calcine. The chemical and physical changes occurring in the molten bath are similar to those occurring in the molten bath of a reverberatory furnace. The matte and slag tapping practices are also similar.



*An Electric Arc Furnace*

The Noranda process, as originally designed, allowed the continuous production of blister copper in a single vessel by effectively combining roasting, smelting, and converting into one operation. Metallurgical problems, however, led to the operation of these reactors for the production of copper matte. The Noranda process uses heat generated by the exothermic oxidation of hydrogen sulphide. Additional heat is supplied by oil burners or by coal mixed with the ore concentrates.

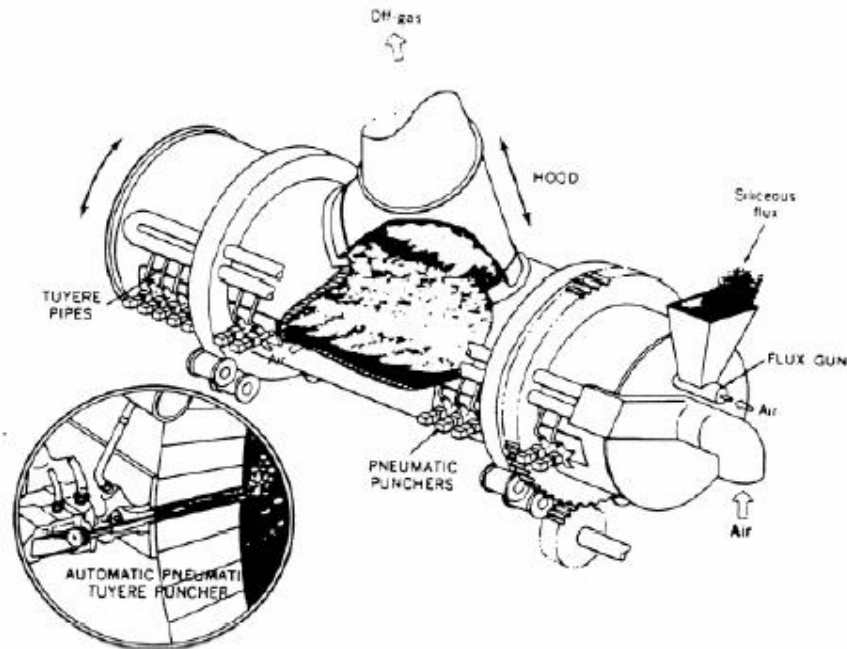


*The Noranda Process*

Flash furnace smelting combines the operations of roasting and smelting to produce a high-grade copper matte from concentrates and flux. In flash smelting, dried ore concentrates and finely ground fluxes are injected together with oxygen and preheated air (or a mixture of both), into a furnace maintained at approximately 1000°C. As with the Noranda process reactor, and in contrast to reverberatory and electric furnaces, flash furnaces use the heat generated from partial oxidation of their sulphide charge to provide much or all of the required heat.

Slag produced by flash furnace operations contains significantly higher amounts of copper than reverberatory or electric furnaces. Flash furnace slag is treated in a slag cleaning furnace with coke or iron sulphide. Because copper has a higher affinity for sulphur than oxygen, the copper in the slag (as copper oxide) is converted to copper sulphide. The copper sulphide is removed and the remaining slag is discarded.

Converting produces blister copper by eliminating the remaining iron and sulphur present in the matte. Pierce-Smith converters are commonly used, which are refractory-lined cylindrical steel shells mounted on trunnions at either end, and rotated about the major axis for charging and pouring. An opening in the centre of the converter functions as a mouth through which molten matte, siliceous flux, and scrap copper are charged and gaseous products are vented. Air, or oxygen-rich air, is blown through the molten matte. Iron sulphide is oxidized to form iron oxide (FeO) and SO<sub>2</sub>.



*The Pierce-Smith Converter*

Blowing and slag skimming continue until an adequate amount of relatively pure  $\text{Cu}_2\text{S}$ , called "white metal", accumulates in the bottom of the converter. A final air blast ("final blow") oxidizes the copper sulphide to  $\text{SO}_2$ , and blister copper forms, containing 98% to 99% copper. The blister copper is removed from the converter for subsequent refining. The  $\text{SO}_2$  produced throughout the operation is vented to pollution control devices.

Impurities in blister copper may include gold, silver, antimony, arsenic, bismuth, iron, lead, nickel, selenium, sulphur, tellurium, and zinc. Fire refining and electrolytic refining are used to purify blister copper even further. In fire refining, blister copper is usually mixed with flux and charged into the furnace, which is maintained at  $1100^\circ\text{C}$ . Air is blown through the molten mixture to oxidize the copper and any remaining impurities. The impurities are removed as slag. The remaining copper oxide is then subjected to a reducing atmosphere to form purer copper. The fire-refined copper is then cast into anodes for even further purification by electrolytic refining.

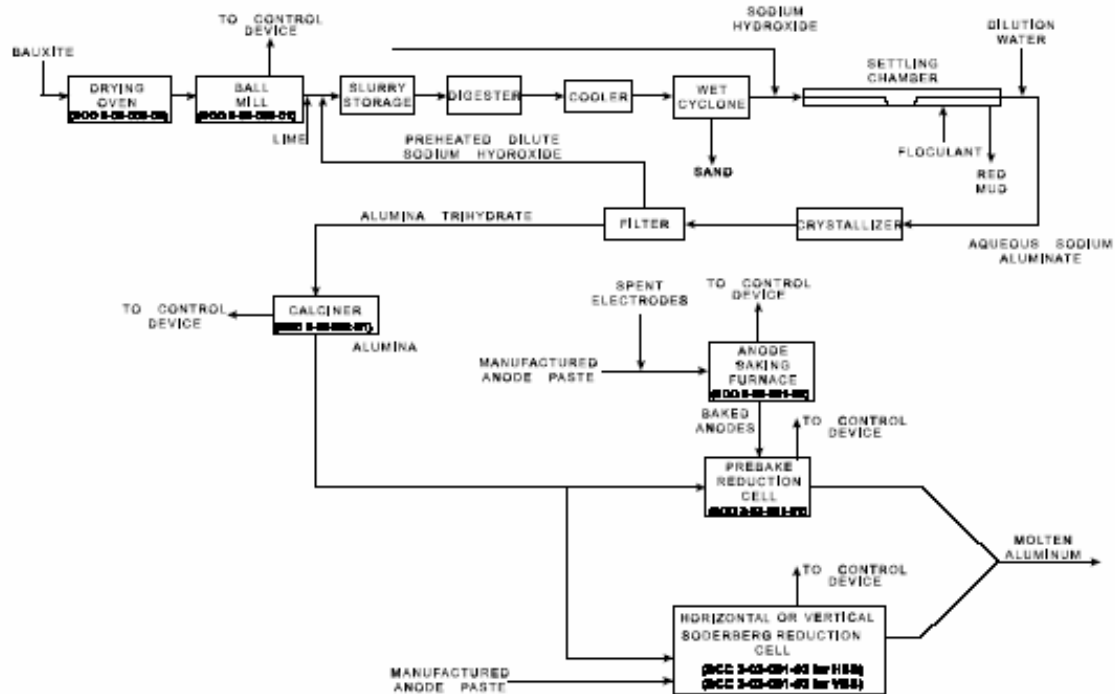
Electrolytic refining separates copper from impurities by electrolysis in a solution containing copper sulphate ( $\text{Cu}_2\text{SO}_4$ ) and sulphuric acid ( $\text{H}_2\text{SO}_4$ ). The copper anode is dissolved and deposited at the cathode. As the copper anode dissolves, metallic impurities precipitate and form a sludge. Cathode copper, 99.95% to 99.96% pure, is then cast into bars, ingots, or slabs.

### **Aluminium**

Aluminium is a material with a large range of applications in the transportation, construction and packaging industries, the electricity sector, in all high voltage electricity distribution systems, household appliances, and the mechanical and agricultural sectors. It is light, has good electrical conductivity and forms a surface oxide layer when exposed to air that prevents further corrosion. Aluminium is highly reactive particularly in the form of powder and is used in aluminothermic reactions to produce a variety of other metals.

Primary aluminium refers to aluminium produced directly from mined ore. The ore is refined and electrolytically reduced to elemental aluminium.

Primary aluminium production begins with the mining of bauxite ore, a hydrated oxide of aluminium consisting of 30% to 56% alumina ( $\text{Al}_2\text{O}_3$ ) and lesser amounts of iron, silicon, and titanium. The ore is refined into alumina by the Bayer process. The alumina is then shipped to a primary aluminium plant for electrolytic reduction to aluminium. The refining and reducing processes are seldom accomplished at the same facility.

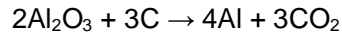


*Schematic Diagram of the Aluminium Production Process*

In the Bayer process, crude bauxite ore is dried, ground in ball mills, and mixed with a preheated spent leaching solution of sodium hydroxide ( $\text{NaOH}$ ). Lime ( $\text{CaO}$ ) is added to control phosphorus content and to improve the solubility of alumina. The resulting slurry is combined with sodium hydroxide and pumped into a pressurised digester operated at 105 to 290°C. After approximately 5 hours, the slurry of sodium aluminate ( $\text{NaAl}_2\text{OH}$ ) solution and insoluble red mud is cooled to 100°C and sent through either a gravity separator or a wet cyclone to remove coarse sand particles. A flocculent, such as starch, is added to increase the settling rate of the red mud. The overflow from the settling tank contains the alumina in solution, which is further clarified by filtration and then cooled. As the solution cools, it becomes supersaturated with sodium aluminate. Fine crystals of alumina trihydrate ( $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ) are seeded in the solution, causing the alumina to precipitate out as alumina trihydrate. After being washed and filtered, the alumina trihydrate is calcined to produce a crystalline form of alumina, which is advantageous for electrolysis. Crystalline  $\text{Al}_2\text{O}_3$  is used in the Hall-Heroult process to produce aluminium metal. Electrolytic reduction of alumina occurs in shallow rectangular cells, or "pots", which are steel shells lined with carbon.

Carbon electrodes extending into the pot serve as the anodes, and the carbon lining serves as the cathode.

Molten cryolite ( $\text{Na}_3\text{AlF}_6$ ) functions as both the electrolyte and the solvent for the alumina. The electrolytic reduction of  $\text{Al}_2\text{O}_3$  by the carbon from the electrode occurs as follows:



Aluminium is deposited at the cathode, where it remains as molten metal below the surface of the cryolite bath. The carbon anodes are continuously depleted by the reaction. The aluminium product is tapped every 24 to 48 hours beneath the cryolite cover, using a vacuum siphon. The aluminium is then transferred to a reverberatory holding furnace where it is alloyed, fluxed, and degassed to remove trace impurities. From the holding furnace, the aluminium is cast or transported to fabricating plants. Three types of aluminium reduction cells are now in use: prebaked anode cell (PB), horizontal stud.

Soderberg anode cell (HSS), and vertical stud Soderberg anode cell (VSS). All three aluminium cell configurations require a "paste" (petroleum coke mixed with a pitch binder).

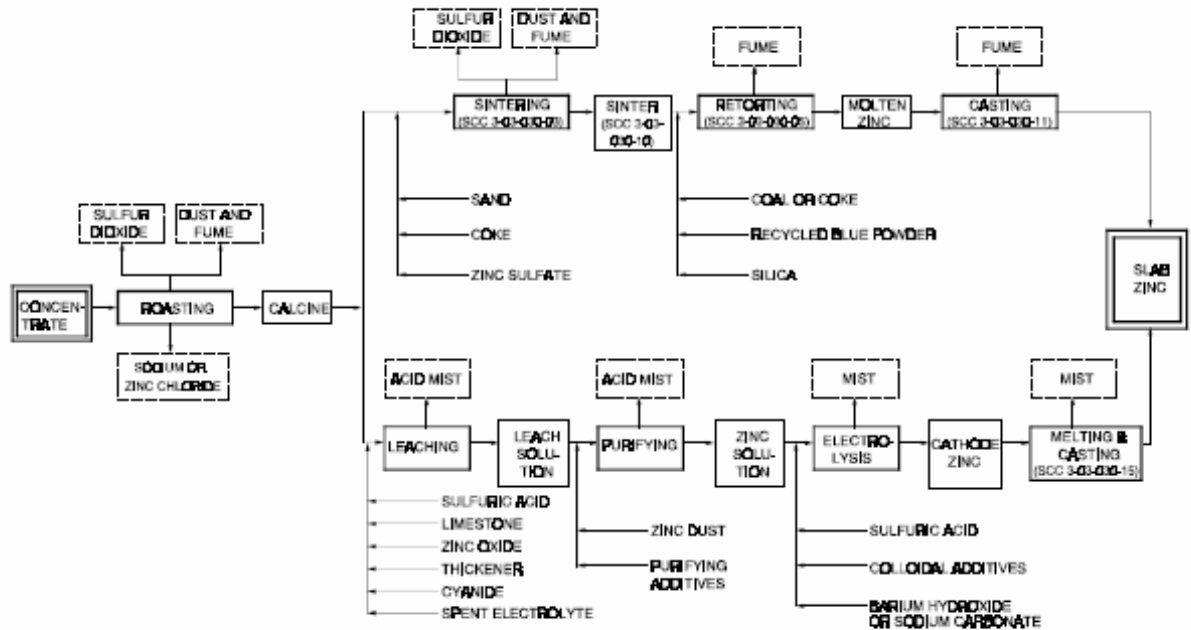
Paste preparation includes crushing, grinding, and screening of coke and blending with a pitch binder in a steam jacketed mixer. For Soderberg anodes, the thick paste mixture is added directly to the anode casings. In contrast, the prebaked ("green") anodes are produced as an ancillary operation at a reduction plant. In prebake anode preparation, the paste mixture is moulded into green anode blocks ("butts") that are baked in either a direct-fired ring furnace or a Reid Hammer furnace, which is indirectly heated. After baking, steel rods are inserted and sealed with molten iron. These rods become the electrical connections to the prebaked carbon anode. Prebaked cells are preferred over Soderberg cells because they are electrically more efficient and emit fewer organic compounds.

## **Zinc**

Zinc has the third highest usage of nonferrous metal, behind aluminium and copper. It has a relatively low melting point and is used in the production of a number of alloys such as brass. It can easily be applied to the surface of other metals such as steel (galvanising) and when it is used as a metal coating, zinc corrodes preferentially as a sacrificial coating. Zinc is also used in the pharmaceutical, nutrient, construction, battery and chemical industries.

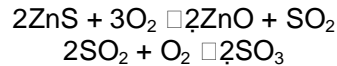
Zinc ores typically may contain from 3% to 11% zinc, along with cadmium, copper, lead, silver, and iron. Beneficiation, or the concentration of the zinc in the recovered ore, is accomplished at or near the mine by crushing, grinding, and flotation process. Once concentrated, the zinc ore is transferred to smelters for the production of zinc or zinc oxide. The primary product of most zinc companies is slab zinc, which is produced in 5 grades: special high grade, high grade, intermediate, brass special and prime western. Primary smelters also produce sulphuric acid as a by-product. Reduction of zinc sulphide concentrates to metallic zinc is accomplished through either electrolytic deposition from a sulphate solution or by distillation in retorts or furnaces. Both of these methods begin with the elimination of most of the sulphur in the concentrate through a roasting process, which is described below.





*Generalised Process Flow for Primary Zinc Smelting*

Roasting is a high-temperature process that converts zinc sulphide concentrate to an impure zinc oxide called calcine. Roaster types include multiple-hearth, suspension, or fluidised bed. The following reactions occur during roasting:



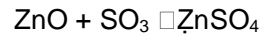
In a multiple-hearth roaster, the concentrate drops through a series of 9 or more hearths stacked inside a brick-lined cylindrical column. As the feed concentrate drops through the furnace, it is first dried by the hot gases passing through the hearths and then oxidized to produce calcine. The reactions are slow and can be sustained only by the addition of fuel. Multiple hearth roasters are unpressurised and operate at about 690°C. Operating time depends upon the composition of concentrate and the amount of the sulphur removal required. Multiple hearth roasters have the capability of producing a high-purity calcine.

In a suspension roaster, the concentrates are blown into a combustion chamber very similar to that of a pulverized coal furnace. The roaster consists of a refractory-lined cylindrical steel shell, with a large combustion space at the top and 2 to 4 hearths in the lower portion, similar to those of a multiple hearth furnace. Additional grinding, beyond that required for a multiple hearth furnace, is normally required to ensure that heat transfer to the material is sufficiently rapid for the desulphurization and oxidation reactions to occur in the furnace chamber. Suspension roasters are unpressurized and operate at about 980°C.

In a fluidised-bed roaster, finely ground sulphide concentrates are suspended and oxidized in a feedstock bed supported on an air column. As in the suspension roaster, the reaction rates for desulphurization are more rapid than in the older multiple-hearth processes. Fluidised-bed roasters operate under a pressure slightly lower than atmospheric and at temperatures averaging 1000°C. In the fluidised-bed

process, no additional fuel is required after ignition has been achieved. The major advantages of this roaster are greater throughput capacities and greater sulphur removal capabilities.

Electrolytic processing of desulphurized calcine consists of 3 basic steps, leaching, purification, and electrolysis. Leaching occurs in an aqueous solution of sulphuric acid, yielding a zinc sulphate solution as shown in the equation below.



In double leaching, the calcine is first leached in a neutral or slightly alkaline solution, then in an acidic solution, with the liquid passing counter current to the flow of calcine. In the neutral leaching solution, sulphates from the calcine dissolve, but only a portion of the zinc oxide enters into solution.

The acidic leaching solution dissolves the remainder of the zinc oxide, along with metallic impurities such as arsenic, antimony, cobalt, germanium, nickel, and thallium. Insoluble zinc ferrite, formed during concentrate roasting by the reaction of iron with zinc, remains in the leach residue, along with lead and silver. Lead and silver typically are shipped to a lead smelter for recovery, while the zinc is extracted from the zinc ferrite to increase recovery efficiency.

In the purification process, a number of various reagents are added to the zinc-laden electrolyte in a sequence of steps designed to precipitate the metallic impurities, which otherwise will interfere with deposition of zinc. After purification, concentrations of these impurities are limited to less than 0.05 milligram per litre. Purification is usually conducted in large agitated tanks. The process takes place at temperatures ranging from 40 to 85°C, and pressures ranging from atmospheric to 240 kiloPascals (kPa).

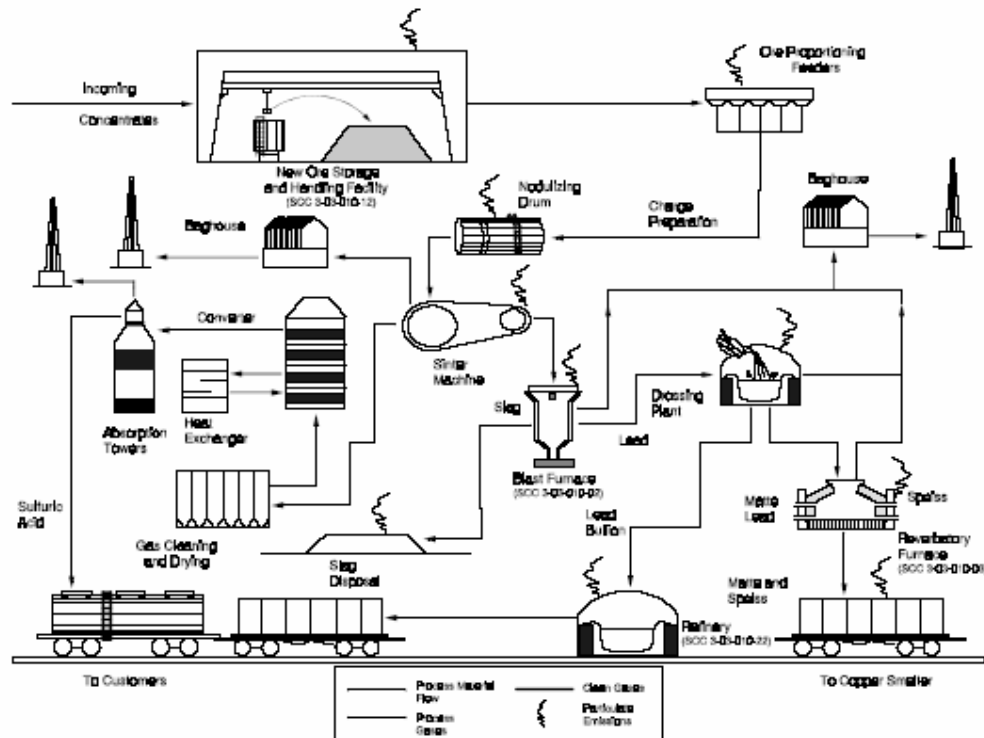
In electrolysis, metallic zinc is recovered from the purified solution by passing current through an electrolyte solution, causing zinc to deposit on an aluminium cathode. As the electrolyte is slowly circulated through the cells, water in the electrolyte dissociates, releasing oxygen gas at the anode. Zinc metal is deposited at the cathode and sulphuric acid is regenerated for recycle to the leach process. The sulphuric acid acts as a catalyst in the process as a whole.

Electrolytic zinc smelters contain as many as several hundred cells. A portion of the electrical energy is converted into heat, which increases the temperature of the electrolyte. Electrolytic cells operate at temperature ranges from 30 to 35°C and at atmospheric pressure. A portion of the electrolyte is continuously circulated through the cooling towers both to cool and concentrate the electrolyte through evaporation of water. The cooled and concentrated electrolyte is then recycled to the cells. Every 24 to 48 hours, each cell is shut down, the zinc-coated cathodes are removed and rinsed, and the zinc is mechanically stripped from the aluminium plates.

## Lead

Lead is the most abundant heavy metal in the earth's crust and has been used for many centuries. It is found in pure sulphide ores or nowadays more in mixed ores where it is associated with zinc and small amounts of silver and copper. Lead is a soft metal; it has a low melting point and is resistant to corrosion. These properties give it great functional value, both in its pure form and in as alloys or compounds.

The processing of lead concentrate into metallurgical lead involves 3 major steps: sintering, reduction, and refining.

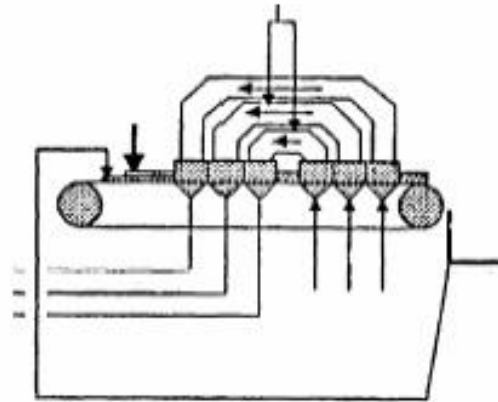


*A Typical Lead Smelting and Refining Process*

## Sintering

The primary purpose of the sinter machine is the reduction of sulphur content of the feed material. This feed material typically consists of the following:

1. Lead concentrates, including pyrite concentrates that are high in sulphur content, and concentrates that are high in impurities such as arsenic, antimony, and bismuth, as well as relatively pure high-lead-concentrates;
2. Lime rock and silica, incorporated in the feed to maintain desired sulphur content;
3. High-lead-content sludge byproducts from other facilities; and
4. Undersized sinter recycled from the roast exiting the sinter machine.



*A Sintering Furnace*

The undersized sinter return stream mixes with the other feed components, or green feed, as the 2 streams enter a rotary pelletising drum. A water spray into the drum enhances the formation of nodules in which the sinter returns form a core rich in lead oxide and the green feed forms a coating rich in lead sulphide. The smaller nodules are separated out and conveyed through an ignition furnace, then covered with the remaining nodules on a moving grate and conveyed through the sinter machine, which is essentially a large oven. Excess air is forced upward through the grate, facilitating combustion, releasing  $\text{SO}_2$  and oxidizing the lead sulphide to lead oxide. The "strong gas" from the front end of the sinter machine, containing 2.5% to 4%  $\text{SO}_2$ , is vented to gas cleaning equipment before possibly being piped to a sulphuric acid plant. Gases from the rear part of the sinter machine are recirculated up through the moving grate and are typically vented to a bag house. That portion of the product, which is undersized, usually due to insufficient desulphurization, is filtered out and recycled through the sinter; the remaining sinter roast is crushed before being transported to the blast furnace.

### **Reduction**

The sinter roast is then conveyed to the blast furnace in charge cars along with coke, ores containing high amounts of precious metals, slags and byproducts dusts from other smelters, and by-product dusts from bag houses and various other sources within the facility. Iron scrap is often added to the charge to aid heat distribution and to combine with the arsenic in the charge. The blast furnace process rate is controlled by the proportion of coke in the charge and by the air flow through the tuyeres in the floor of the furnace. The charge descends through the furnace shaft into the smelting zone, where it becomes molten, and is tapped into a series of settlers that allow the separation of lead from slag. The slag is allowed to cool before being stored, and the molten lead of roughly 85 % purity is transported in pots to the cross building.

### **Refining**

The drossing area consists of a variety of interconnected kettles, heated from below by natural gas combustion. The lead pots arriving from the blast furnace are poured into receiving kettles and allowed to cool to the point at which copper dross rises to the top of the top and can be skimmed off and transferred to a reverberatory furnace. The remaining lead dross is transferred to a finishing kettle where such materials as wood chips, coke fines, and sulphur are added and mixed to facilitate further separation, and this sulphur dross is also skimmed off and transferred to the reverberatory furnace. To the drosses in the reverberatory furnace are added tetrahedrite ore, which is high in silver content but low in lead and may have been

dried elsewhere within the facility, coke fines, and soda ash. When heated in the same fashion as the kettles, the dross in the reverberatory furnace separates into 3 layers: lead bullion settles to the bottom and is tapped back to the receiving kettles, and matte (copper sulphide and other metal sulphides), which rises to the top, and speiss (high in arsenic and antimony content) are both typically forwarded to copper smelters.

The third and final phase in the processing of lead ore to metallurgical lead, the refining of the bullion in cast iron kettles, occurs in 5 steps: (1) removal of antimony, tin, and arsenic; (2) removal of precious metals by Parke's Process, in which zinc combines with gold and silver to form an insoluble intermetallic at operating temperatures; (3) vacuum removal of zinc; (4) removal of bismuth by the Betterton Process, in which calcium and magnesium are added to form an insoluble compound with the bismuth that is skimmed from the kettle; and (5) removal of remaining traces of metal impurities through the adding of NaOH and NaNO<sub>3</sub>. The final refined lead, from 99.990% to 99.999% pure, is typically cast into 45 kilogram pigs for shipment.

### **Cadmium**

Cadmium belongs to the zinc subgroup of the periodic table and was discovered by Strohmeyer in 1817 during an investigation into ZnCO<sub>3</sub>. It is associated with zinc in minerals at a ratio of 1:200 Cd to Zn. It is physically similar to zinc but is denser, softer and can be polished. Unlike zinc it is also resistant to alkalis. Cadmium is also a good absorber of neutrons and is therefore often used in nuclear reactors. Cadmium is widely distributed worldwide with content between 0.1 and 1 ppm in the topsoil.

Cadmium is produced as a by-product from many of the metal recovery processes. The production of zinc and lead are the main sources.

In the Imperial Smelting Furnace (ISF), cadmium is recovered via two separate routes. Some cadmium follows zinc and is eventually recovered as condensate from the second stage distillation. The balance is recovered from the flue dust from the gas cleaning section that precedes the sulphuric acid plant. It is leached with sulphuric acid and is then stripped from this liquor.

### **Precious Metals**

Precious metals include such well-known metals as gold and silver as well as the six platinum group metals: platinum, palladium, rhodium, iridium, ruthenium and osmium. They are termed precious metals because of their rarity and corrosion resistance. The EU has the largest refining and fabricating capacity for precious metals in the world, even though its actual mineral resources of such metals are very limited. The recycling of precious metals from scrap and industrial residues has always been an important raw material source for the EU industry.

Consumption of gold is mainly for jewellery, with smaller amounts used in electronics and other industrial and decorative applications. The principal users of silver are the photographic and jewellery industries. The platinum group metals are used extensively as catalysts and the imposition of strict emissions limits on vehicles sold in the EU and elsewhere has stimulated demand for their use in catalytic converters.

### **Silver**

Anodes are refined in Moebius or Balbach-Thum electrolytic cells using titanium or stainless steel cathodes in an acidified silver nitrate electrolyte. A direct current applied between the electrodes causes silver ions dissolved from the anode to migrate and deposit as crystals of silver on the cathodes. The crystals are

continuously scraped off the cathodes, removed from the cells, filtered and washed. The slimes from the electrolytic cells are treated for their gold and platinum group metals content.

The silver crystals may be melted in a crucible furnace and batch cast into market ingots or grains for rolling down. They can be continuously cast into market bars for rolling down to sheet and strip. Silver is also cast into billet for extrusion into rod for subsequent drawing into wire.

Silver produced by smelting, and high-grade silver residues from manufacturing processes can be refined by dissolution in nitric acid. The resulting solution is purified either by recrystallisation as silver nitrate suitable for use in the photographic industry or by electrolysis to fine silver for melting and casting into bullion bars.

### **Gold**

The Miller process can be used to pre-treat the material. In this process the feed materials are melted in an indirectly heated crucible or electric induction furnace while chlorine gas is injected into the melt. At the operating temperature of about 1000°C, gold is the only metal present that does not react to form a stable molten or volatile chloride. Molten silver chloride rises to the surface of the melt. A borax flux is used to assist collection and skimming of the metal chlorides. Zinc in the feed is converted to zinc chloride which, together with volatile metal chlorides, is exhausted to a gas scrubbing system.

The Miller process is operated to produce either 98% gold, which is cast into anodes for electrorefining, or 99.5% gold that is cast into bullion bar.

### **Platinum Group Metals (PGMs)**

PGMs comprise platinum, palladium, rhodium, ruthenium, iridium and osmium. The principal raw materials are concentrates produced from ores, mattes and slimes from nickel and copper operations. Secondary materials such as spent chemical and auto exhaust catalysts, electronic and electrical component scrap are also significant sources. PGMs can be present in the anode slimes described above and are separated from the gold and silver by a variety of hydrometallurgical processes. Low-grade feedstock may be crushed and blended while metallic feed materials are generally melted to provide a homogeneous product for sampling.

The main stages in the recovery of PGMs are:

Pre-treatment of the feedstock, sampling and assay;

Dissolution, separation and purification of the PGMs e.g. by precipitation, liquid/liquid extraction or distillation of tetroxides;

Recovery of platinum, palladium, rhodium and iridium by reduction (hydrogen), liquid/liquid extraction or electrolytic processes;

Refining of PGMs for example by hydro-metallurgical techniques such as the use of ammonium-chloro compounds to produce pure metal sponge by pyrolysis.

Specific processes have been developed for carbon-based catalysts, using incineration prior to the dissolution stage. Powder based catalysts and sludges are treated in batches, often in box section furnaces. Direct flame heating is applied to dry and then ignite the catalyst that is allowed to burn naturally. The air ingress to the furnace is controlled to modify the combustion conditions and an afterburner is used.

Reforming or hydrogenation catalysts can be treated by dissolution of the ceramic base in sodium hydroxide or sulphuric acid. Prior to leaching, the excess carbon

and hydrocarbons are burnt off. PGMs from automotive catalysts can be collected separately in Cu or Ni in plasma, electric or converter furnaces. Small operators use open trays to burn off catalysts by self-ignition or roasting, these processes can be dangerous and fume collection and after burning can be used to treat the fume and gases.

PGM refining is complex and individual process stages may have to be repeated to achieve the required purity. The number and order of the stages also depends on the contaminants to be removed and the specific mix of PGMs to be separated from any one batch of feedstock. The processing of secondary materials such as spent chemical and auto catalysts, electrical and electronic scrap in base metal smelters or specific equipment finally produces PGM rich residues or precipitates.

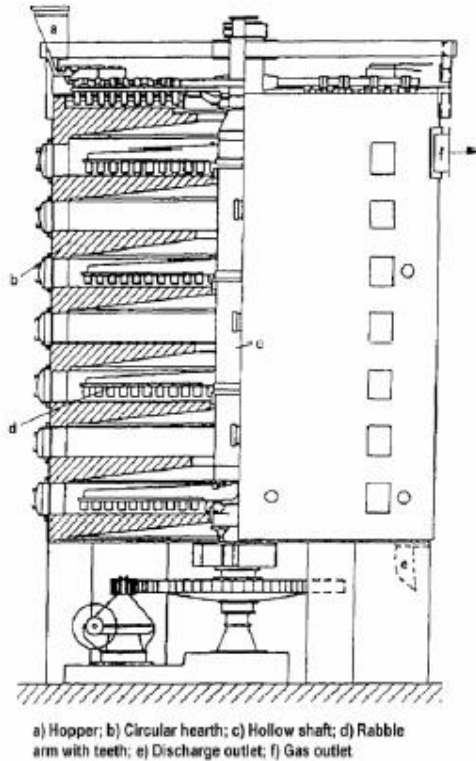
### **Mercury**

Mercury is the only metal that is liquid at room temperature and has the lowest fusion and boiling points of all metals. It also has a high electrical conductivity and these features are used in a variety of applications such as electrical switch-gear and battery production. Mercury forms alloys easily with a number of other metals and these are known as Amalgams, which were extensively used in dentistry. Due to the toxicity of mercury however, dental amalgams are currently being phased-out and are being replaced with ceramic and plastic materials. The major use of mercury is as a flowing cathode in the Chlor-Alkali process. This process exploits mercury's high conductivity and the formation of an amalgam with sodium.

Mercury is characterised by the toxicity of the metal and its' vapour and the extreme toxicity of some of its' compounds. The result is that mercury is being replaced by alternative materials in many of its' uses and so the demand and production of mercury has declined rapidly. There are implications in the future as it is likely that some existing inventories of mercury will come on the market or may even become wastes.

There is only one producer of mercury from Cinnabar ore in Europe but the process is similar to other worldwide producers. The main difference is the higher mercury content of the European Ore, which means that the ore does not have to be concentrated.

Rock containing cinnabar (HgS) is crushed in 2 stages to – 25 mm, an extraction system and bag filters are used to treat dust from the crushers and conveyors. The crushed rock is heated to 750 °C in Herreschoff furnaces, which have 8 hearths and use propane fuel.



*A Herreschoff Furnace*

Cinnabar is oxidised and mercury and sulphur dioxide is driven off in the gas stream. Mercury is condensed in a system comprising 32 water-cooled steel condensers and is collected. Gases are discharged via a stack after passing through a water scrubber, which absorbs some sulphur dioxide. The roasted rock is discharged from the bottom of the furnace and cooled in air; the rock is mercury free and is sold for road building.

The condensed mercury is washed with caustic soda and sodium sulphide and the material pressed in a filter. Mercury is then distilled to give 99.9% purity. The residues from distillation contain 5% mercury and are pelletised with cement and returned to the furnace for recovery.

Cooling water and scrubber water is re-circulated. There is a bleed from the system, which is neutralised with caustic soda and treated with sodium sulphide to precipitate mercury sulphide.

The effluent passes through a carbon filter before discharging to the river.

The other significant source of primary mercury is the mercury recovered during the production of other non-ferrous metals. It has been reported that the mercury content ranges from 0.02 to 0.8 kg per tonne of metal (Cu, Zn or Pb). These processes remove mercury from the roaster or smelter gas streams prior to the production of sulphuric acid. It should be noted that any mercury that is not captured by the removal stage will be found in the sulphuric acid that is produced, most processes achieve < 0.1 ppm of mercury in sulphuric acid. Mercury is normally recovered from the residues produced from the various scrubbing processes.



## **Refractory Metals**

The term refractory metals refers to a group of metals (in some cases rare earth metals) that can mostly be characterised by the same physical properties. These properties are for the majority of refractory metals, a high melting point, high density, special electrical properties, and inertness and in particular, the ability to confer in small additions to steel and other metals exceptional increases in physical performance.

Refractory metals and hard metal powders are used for a wide range of industrial applications. Chromium metal is important in steel alloying and as a metal coating in the galvanic industry. Among a variety of other uses like steel alloying, manganese is the key component of certain widely used aluminium alloys and is used in oxide form in dry cell batteries. The largest use of tungsten is as cemented carbides, which are also called hard metals. Cemented carbides are wear resistant materials used by the metalworking, mining and construction industry. Tungsten metal wires, electrodes, and /or contacts are used in lighting electronic, heating and welding applications. Molybdenum finds significant usage as a refractory metal in numerous chemical applications, including catalysts, lubricants, and pigments. Tantalum and its twin element niobium as used as tantalum and niobium powder and carbides. Tantalum powder is mainly used for the production of tantalum capacitors.

## **Chromium**

Besides the use of chromium as an alloying element in the steel industry, chromium metal is also widely used in other industrial sectors. In the chemical industry for instance chromium is needed in large quantities to manufacture pigments that are used to produce paints and inks. Another considerable amount of chromium is consumed as an electroplated protective coating, because chromium is corrosion resistant to a variety of corrosive materials at room temperature.

Chromium metal can either be made from chromite ore and concentrates by carbo- and metallo-thermic reductions or by electrolysis from chromic acid. In order to get chromic acid the chromite ore is roasted with sodium carbonate followed by a leaching process with sulphuric acid to produce sodium chromate that can further be transformed to chromic acid.

The thermic process uses carbon, silicon or aluminium as a reducing agent. The charge is automatically weighed and loaded into a bin at a computerised weighing station. The station utilises various abatement techniques to prevent airborne emissions. Once the charge is complete, the bin is taken to an enclosed room to mix the contents. To minimise dust in the workplace, a negative pressure is maintained by the ventilation fan within the blender room, which feeds through a filter unit to atmosphere. The bin is finally located on an automatic feed platform at the firing station.

The firing pot is prepared by ramming refractory sand around a central former. Sand is fed from a storage hopper via a "sand slinger" and mixed with water. The pot is then vibrated in order to compact the sand. The feed hopper is fitted with an integral dust extraction and filter unit.

After ramming the firing pot, the inner surface is coated with a weak binder solution and dried under a gas fired hood before being transferred to the firing station. Combustion fumes from the drying hood are fed via a stack to atmosphere using natural convection.

The firing pot is located inside a firing chamber, which has a travelling fume hood, and integral feed chute above it. The raw material mix is automatically fed at a

controlled rate into the firing pot, where the exothermic reaction takes place. Fume generated by the reaction is ducted to the main bag filter plant. After the evolution of fume has subsided, a reduced volume of extraction is provided to the firing chamber. When the metal has solidified following the reaction, the firing pot is removed and transferred by crane to a cooling conveyor. This is partially enclosed by a hood and is ventilated by a number of extraction fans, which discharge to atmosphere outside the building. Disposable fibreglass filter panels protect the fan inlets.

On removal from the cooling conveyor (by crane), the firing pot is placed on a stripping bogie for transferral to a stripping booth. Inside the closed booth, the pot casing is hoisted off the solidified metal/slag. Debris from the pot lining falls into a hopper and is transferred to a vibratory sieve. Cartridge filter extraction units control emissions during these operations. The stripped metal/slag and firing pot casing are retrieved by means of the stripping bogie.

The firing pot casing is removed and returned to the pot preparation station for reuse. The slag is separated from the Chromium metal 'button' and sent to a despatch storage area. The button is lifted by crane from the stripping bogie and transferred to a bosh tank where water is used to reduce button temperature to below 100°C. Extraction of the steam generated is by means of a fan and ductwork which discharges to atmosphere outside the building.

After cooling the metal button is transferred to other departments on site for cleaning, breaking, crushing and grinding to achieve the desired product size. Packaging of the material is carried out in accordance with customer requirements and may utilise FIBC's, drums and plastic bags.

The silico-thermic reduction is not sufficiently exothermic to be self-sustaining and must therefore be performed in an electric arc furnace. If the carbo-thermic process is used, the chromium oxide will be reduced by carbon in an electric arc furnace. The chromium metal produced by this process contains high amounts of carbon.

### **Manganese**

The electrothermal process is the second important process to produce manganese metal on an industrial scale after the production of manganese metal by the electrolysis of aqueous manganese salts. The electrothermal process takes place as a multistage process. In the first stage manganese ore is smelted with only a small amount of reductant in order to reduce mostly the iron oxide. This produces a low-grade ferro-manganese and a slag that is rich in Mn-oxide. The slag is then smelted in the second stage with silicon to produce silicomanganese.

The molten silico-manganese can be treated with liquid slag from the first stage to obtain relatively pure manganese metal. For the last step a ladle or shaking ladle can be used. The manganese metal produced by the electrothermal process contains up to 98% of Mn.

### **Tungsten**

The first step for the production of tungsten, which is normally carried out directly at the mining site, is crushing and milling of the raw material in order to liberate the tungsten mineral from the gangue material. The next stage is the production of ammonium paratungstate (APT) by hydrometallurgical methods.

The Scheelite and Wolframite concentrates that are mostly used are dissolved by pressure leaching to produce a sodium-tungsten solution. The leaching process dissolves also other elements such as silicates, thiomolybdate as well as elements like As, Sb, Bi, Pb and Co that need to be removed from the solution by purification. Thiomolybdate can further be used for molybdenum production. The purified sodium tungstate solution is then converted into ammonium tungstate solution. The conversion of the sodium tungstate solution can be carried out either by a solvent extraction or an ion exchange process. In the subsequent crystallisation step, the water and ammonia are distilled. At the same time as the distillation takes place the pH-value decreases and the APT crystallises out of the solution. The solid APT is then calcined commonly in a rotary kiln in order to obtain tungsten oxides.

The two oxidic forms utilised for tungsten powder production are yellow and blue oxides ( $\text{WO}_3$  and  $\text{W}_4\text{O}_{11}$ ). Yellow oxide is produced by heating APT in air at temperatures above  $250^\circ\text{C}$ . Blue oxide can be produced if the calcining step is carried out with exclusion of air at temperatures from  $400$  to  $800^\circ\text{C}$ . The production of blue oxide is usually preferred, because a smaller amount of reducing agent is then required in the subsequent reduction stage.

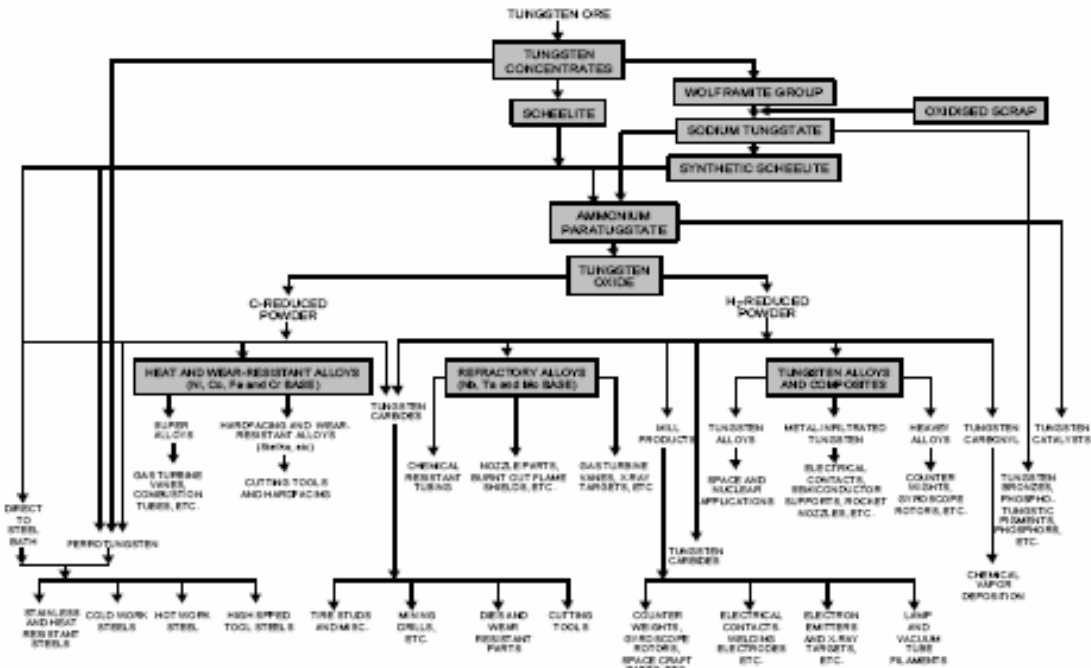
The reduction of tungsten oxides (blue or yellow tungsten oxide) to tungsten metal powder is today normally carried out by hydrogen reduction. For the reduction either a rotary furnace or a pusher furnace is used, in the latter case the powder passes through the furnace in boats. Today also modern automated band furnaces are used for the production of tungsten powder.

Hydrogen passes counter-currently to the oxides through the furnace; water vapour is formed in the reduction process in the furnace. The hydrogen is partly recirculated. Possible occurring dust is recovered by e.g. bag filter, wet scrubber or similar equipment. The important process parameters are the furnace temperature, the amount of oxides charged to the furnace per unit time, the rate of hydrogen circulation and the depth and the porosity of the bed or boat.

Most of the tungsten powder is converted to tungsten carbide. The tungsten powder is mixed with black carbon in a ratio giving the monocarbide after the reaction. Pusher or batch furnaces can be used for the carburisation.

Pusher furnace: The mixture of W and C is charged into graphite boats or crucibles and passes through the furnace continuously. Hydrogen is used as a protective atmosphere and passes through the furnace counter-currently and is flared off after exit using a propane flare as ignition control. The furnaces are electrically heated and operate in the temperature range of  $1100 - 2000^\circ\text{C}$ .

Batch furnace: The mixture of W and C is loaded into paper cylinders or other suitable containers and densified by tapping. The material is heated by induction in a water-cooled coil with hydrogen as protective atmosphere. Hydrogen is flared off when leaving the furnace. The process takes place at a temperature range of  $1800 - 2000^\circ\text{C}$ .



*Tungsten Flow Sheet*

## Vanadium

The majority of vanadium metal used today is produced from vanadium slag, which is obtained from a pre-reducing process of titanomagnetite ore in an electric arc furnace. The electric arc furnace produces pig iron that is oxidised further in an oxygen blown converter in order to transfer the vanadium into the slag. The vanadium containing slag is then used as the world's major raw material source to produce vanadium oxide, which can further be transformed by reduction to vanadium metal, especially vanadium containing alloys.

In the first step of the process the vanadium slag is ground and liberated from the iron granulates. After grinding, commonly alkali metal salts are blended and fed to a multiple hearth furnace or rotary kiln where roasting, a disintegration of the slag under oxidising conditions, takes place at about 700 – 850°C. Thus, both the oxidation of vanadium to V(V) and the formation of a water-soluble salt, can be achieved. Afterwards, the roasted vanadium slag is leached to form high concentrated vanadium containing liquid phase. The separation and purification of the vanadium from the liquid phase can be usually done by precipitation of an ammonium-containing vanadate by controlling pH-value and temperature. The achieved precipitate is filtered, dried and can be alternatively transformed in several process steps to high purity vanadium oxides, such as vanadium pentoxide, vanadium tetroxide or vanadium trioxide as function of temperature and reduction/oxidation conditions.

In order to gain vanadium metal, the vanadium oxides can either be treated by carbo or metallo-thermic reduction. The carbo-thermic reduction forms vanadium metal with high oxygen and carbon contents, which is the reason for the rare use of this process. The more common method is the metallo-thermic process using calcium or aluminium as the reducing agent. By using calcium as a reductant the reaction takes place in a closed pressure furnace that is lined with pure magnesium oxide. The alumino-thermic process of exclusively vanadium pentoxide is a self-sustaining process without additional requirements of energy.

The process is carried out in temperature resistant equipment where a mixture of high purity vanadium pentoxide is reduced by aluminium powder. Melting in an electron beam furnace allows both the direct purification of the vanadium metal and the use of reduced vanadium oxides by the aluminothermic process.

### **Molybdenum**

Molybdenum in its pure stage is a lustrous grey metal that can be used for a wide range of industrial applications. The use of molybdenum starts with its demand as an alloying element in the steel production process, combines the use of molybdenum compounds in the chemical industry and ends with a product used by lubricant manufacturers.

Molybdenum can be obtained from primary ore sources or from secondary ores. Molybdenum is also produced as a by-product of copper mining. The molybdenum containing mineral is first ground and floated in order to separate the molybdenite from the host rock. The molybdenite ore is then roasted to remove the sulphur and change the sulphide to oxide. Besides the use of technical grade molybdenum trioxide in the production of ferro-alloys, it is also the starting compound for all other molybdenum containing products such as ammonium dimolybdate, sodium molybdate and molybdenum metal. The conversion of concentrated molybdenite ore (molybdenum sulphide) into technical grade molybdenum trioxide ( $\text{MoO}_3$ ) for the metallurgical or chemical industry is performed by calcination and roasting.

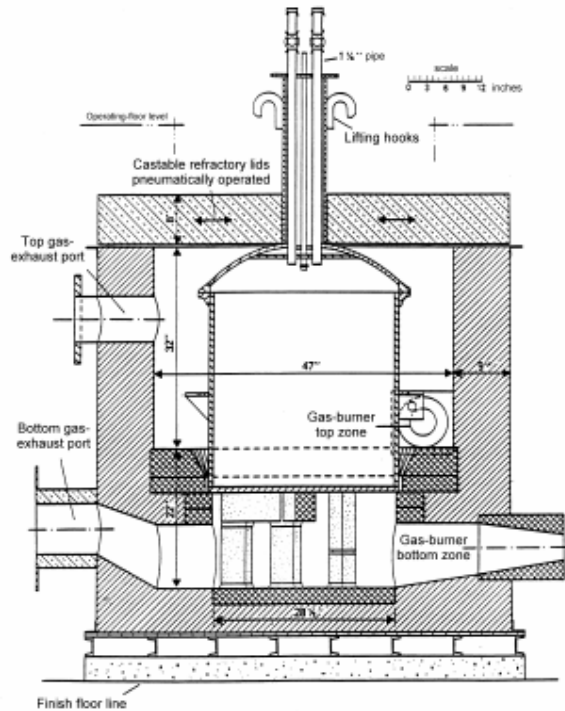
Molybdenum metal powder can be produced in a two-stage process by reducing molybdenum trioxide with hydrogen. Besides molybdenum trioxide compounds like ammonium hexamolybdate and ammonium dimolybdate may also be used for the powder production. In the first step of the process  $\text{MoO}_3$  is reduced at about 600 °C in an exothermic process to molybdenum dioxide ( $\text{MoO}_2$ ). The second reduction stage, in which the metal powder is produced, takes place at ca. 1050°C. The process can be carried out either in a pusher furnace, a walking beam furnace or a rotary kiln where the hydrogen is led in a counter current flow.

Pressing and sintering in order to get compact molybdenum metal can then be used to process the powder. Melting of molybdenum in a vacuum arc furnace or an electron beam furnace is another way to produce compact molybdenum metal.

### **Titanium**

Titanium is consumed by the industry mostly as titanium dioxide ( $\text{TiO}_2$ ) that is used as pigments in the paint, plastic and paper industry, and as titanium metal. Titanium metal either as a pure metal or alloys is used in applications where the relatively high cost of the metal is justified by its outstanding characteristics. Due to the high strength-to-weight ratio of its alloys and their corrosion resistance, titanium is important and widely used for high performance aircraft engines and airframes. There are commonly two applied processes established for the production of titanium metal.

The Kroll-process, where titanium-tetrachloride (TTC) is reduced with molten magnesium to produce pure titanium metal as well as titanium sponge and the Hunter-process, which uses molten sodium for the reduction of TTC. Due to the reactivity of molten titanium the production of titanium ingots is then carried out in special vacuum furnaces.



*Reaction Vessel of the Kroll Process*

Titanium-tetrachloride can be manufactured from titanium oxide containing ore and from titanium rich slag that is generated by the metallurgical treatment of ilmenite ore. The chlorination is today exclusively carried out by a fluidised-bed process. The choice of a fluidised bed reactor is due to its higher reaction rate and the improved heat-transfer and therefore the higher achievable reaction temperatures. After the chlorination a subsequent separation and purification process is normally necessary in order to obtain a titanium tetrachloride of a purity of about 99.9%.

As already mentioned above the production of titanium metal sponge can be carried out either by the Kroll or the Hunter process. In the Kroll-process, pure titanium-tetrachloride (TTC a colourless, fuming liquid) is reduced by reaction with molten magnesium under an inert gas atmosphere. The reaction takes place in a reaction vessel that is constructed of stainless or carbon steel, sometimes with titanium coated interior.

The reactor is first charged with oxide free magnesium and argon gas. When the magnesium is molten by using external heating, TTC is carefully charged to the reactor. Due to the exothermic nature of the reaction, the process can be operated and controlled by the rate of adding TTC to the reactor. The temperature range goes from 850 to 950°C, where the lower temperatures give longer reaction times but purer titanium sponge. The process produces titanium metal sponge intimately mixed with magnesium chloride and other impurities such as unreacted magnesium, TTC and some sub chlorides of titanium. These impurities can be removed by using the following techniques:

- Acid leaching with dilute nitric or hydrochloric acid
- Purging the reaction vessel and its contents with argon at 1000 °C, thus volatilising and removing the impurities.

- Vacuum distillation at a pressure of 0.2 mm mercury and a temperature of about 960-1020 °C for 30 – 60 hours.

The Hunter-process, in which TTC is reduced with metallic sodium has lost its importance and is now mostly replaced by the Kroll-process. The titanium sponge can be melted in order to obtain titanium ingots by using the consumable electrode vacuum arc melting process.

### **Tantalum**

The production of metallic tantalum can be based on both tantalum-containing minerals or tantalum rich slag that arises from smelting of tin concentrates. The recovery of tantalum from tin slag has increased in recent years and today represents about 30% (worldwide) of the total tantalum production.

The tantalum-containing mineral is first crushed and treated by flotation and subsequent leaching and concentrated by flotation or other beneficiation processes. The concentrate is digested in hydrofluoric acid. Ta and Nb subsequently is extracted by organic solvents in order to obtain potassium heptafluorotantalate as an intermediate product. The potassium heptafluorotantalate is then reduced by sodium to tantalum powder. To produce a pure metal powder normally two processes can be used. The first process is carried out by de-oxidation of the tantalum powder with magnesium or a vacuum thermal treatment under protective gas.

The second process takes place by melting the powder in an electron beam furnace (EBM). Due to the high melting point of tantalum, most of the impurities presented in the powder are volatilised and captured by the furnace off-gas. The purified powder can then further be used for the production of semi-finished products or the fabrication of tantalum capacitors.

### **Niobium**

In primary raw material like columbite and tantalite niobium always occurs together with tantalum and other elements. In order to separate both metals the production of niobium needs the same separation process as it is used by the production of tantalum. After a series of different unit operations the pre-treatment process ends up with niobium pentoxide as an intermediate product. Niobium pentoxide can be used in the chemical industry or further be reduced to niobium metal powder and niobium carbide.

The production of niobium metal can be carried out by carbo-thermic or metallo-thermic reduction of niobium pentoxide, whereas the most important process is the reduction of niobium pentoxide with aluminium. The alumino-thermic process today produces almost 90% of niobium metal. The process is carried out under vacuum in an electric arc furnace and produces a low-oxygen and carbon free niobium metal. For the carbo-thermic reduction, niobium pentoxide is mixed with carbon, pelletised and reduced in a vacuum furnace. The process that takes place at about 1950°C and produces a niobium metal with a high carbon and oxygen content that needs a further refining step.

The refining step is necessary in order to remove the impurities, which are carried into the process by the raw material or introduced during the process. The refining takes place at high temperatures using an electric arc or electron beam furnace. Due to the high melting point of niobium most of the impurities are removed from the melt by vaporisation. To obtain a sufficient refining result the crude niobium needs a second refining cycle. The refining and electron beam melting process generates a highly purified niobium metal that can be used for high-frequency superconductors.

## **Rhenium**

Rhenium, the refractory metal with the third highest melting point has only recently been exploited for commercial use. Less than one quarter of the consumption of rhenium is in the form of alloys in which rhenium is a very small but important constituent. The biggest application is in platinum-rhenium catalysts used to produce lead free petrol. Other uses include thermocouples, reforming catalysts and a variety of electrical applications.

Rhenium metal is exclusively produced as a by-product from the molybdenite roasting process, where rhenium is volatilised and exits with the roaster off-gas. The rhenium can then be recovered from the off-gas steam by high-energy scrubbers.

The roasting process of molybdenite ore generates large amounts of dust and sulphur dioxide and also vaporised rhenium in the form of rhenium heptoxide ( $\text{Re}_2\text{O}_7$ ). The rhenium escapes with the roaster off-gas because of its high vapour pressure. Rhenium heptoxide and selenium oxide present in the off-gas can be removed from the waste gas stream by using a wet scrubbing operation.

Because of the ability of rhenium heptoxide to dissolve in water it is transferred easily into the scrubbing liquor. The scrubbing water is recirculated to the scrubber in order to get a higher rhenium concentration. The concentrated scrubbing liquor that contains about 0.2 to 1.5 g/l of rhenium can then be treated by chemical precipitation or preferably by the use of ion exchangers in order to obtain rhenium metal.

After removal of the rhenium content from the roaster off-gas it can be recovered from the scrubbing liquor by precipitation as its sparingly soluble sulphide or the use of ion exchangers. Further treatment with strong mineral acids leads to the intermediate product ammonium per-rhenate. Ammonium per-rhenate can then be reduced with hydrogen in order to obtain rhenium metal powder. The reduction process occurs as a two-stage process. In the first stage that takes place at about 300 – 350°C rhenium dioxide will be produced. The second stage reduces the rhenium dioxide at 800 °C to rhenium metal that can be obtained from the process as pure metal powder. The metal powder can then further be compressed and sintered in order to get pellets or large workpieces.

## **Zirconium and Hafnium**

The sister metals zirconium and hafnium both have an important role in the nuclear industry because of their excellent metallurgical and corrosion resistant properties in the extreme environment of the nuclear core. Besides this zirconium is also used in the chemical industry, and Zircon bricks are used as furnace linings.

The production of zirconium and hafnium metal starts with mixing together zircon concentrates and carbon. The mixture can then be chlorinated in a fluidised bed reactor. The zirconium-chloride can be removed from the reactor off-gas by condensation that is controlled by the temperature. Dissolution in a low melting fused salt eutectic followed by vaporisation of a zirconium-hafnium-chloride. Separation of zirconium and hafnium is carried out by solvent extraction where zirconium or hafnium can selectively be extracted depending on the extractant that is used. Metal production uses the Kroll-process, where the zirconium/hafnium tetrachloride is sublimed and reduced with magnesium and magnesium chloride. The product of this process step can then be treated by vacuum arc refining to the final metal.



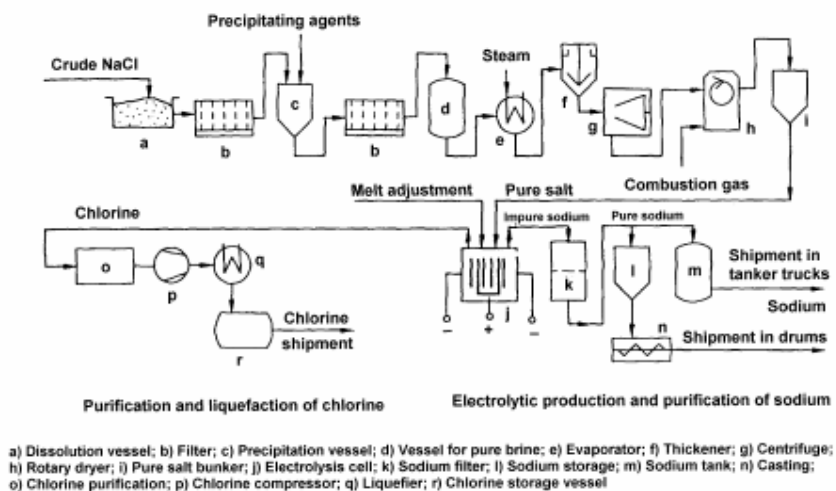
## Alkali and Alkaline Earth Metals

Alkali metals, which belong chemically to the first group of the periodic table of the elements includes metals such as lithium, sodium, potassium, as well as the extremely rare radioactive substance - francium. Alkali metals are characterised by their low melting point and density. They have a silvery-white colour and are softer than other metals. Alkali metals have only one single, highly mobile electron in the outermost shell. Due to this fact alkali metals are highly reactive especially with oxygen or water where they also can react violently by producing gaseous hydrogen and heat.

Alkaline-earth metals resemble alkali metals in several ways but they react less vigorously with water. Alkaline metals are elements in the second group of the periodic table. In order of their increasing atomic number and their metallurgical and technical importance, they are magnesium, calcium and strontium.

## Sodium

Sodium metal is produced by the electrolysis of fused sodium chloride (NaCl). Calcium and barium chlorides ( $\text{CaCl}_2$  and  $\text{BaCl}_2$ ) are added to the NaCl to form a eutectic mixture, which melts at  $580^\circ\text{C}$ .



### *Flow Sheet of Sodium Production*

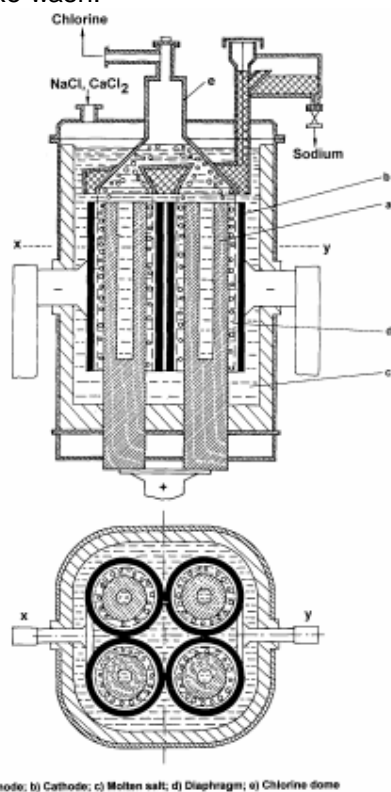
Downs Cells are used and have a special cylindrical anode and a circular concentric cathode separated from the anode by a steel mesh diaphragm. Each cell normally has 4 pairs of electrodes. Energy from electrolysis is sufficient to keep the electrolyte molten and no additional heating is needed. The cell voltage is 6.2 to 7 V and this is used to monitor and control the process. Raw materials are received as crystals and are dried in a rotary drier before use; dust is extracted and scrubbed. The sodium chloride concentration in the cell bath is held in the desired range by continuously feeding salt to the cells at the same rate as it is electrolysed to form sodium and chlorine, thus maintaining a constant cell bath level. Sodium and chlorine are collected, under the surface of the cell bath, in separate compartments of a collector assembly.

The chlorine is drawn off continuously under a very slight vacuum, to a Chlorine Plant, where it is normally liquefied and passed to the liquid chlorine storage tanks. The sodium is forced, by the weight of the bath above the collector assembly, up a

finned riser-pipe where it continuously overflows across a weir into receivers. These are tapped every two hours into larger, portable 24-hour receivers.

A small amount of the calcium chloride in the cells is also electrolysed, along with the sodium chloride, forming calcium and chlorine. A portion of this metallic calcium is carried out of the cells as an impurity in the sodium and separates as the metal cools. This calcium chloride in the cell bath is replaced by adding dry granular calcium chloride to the cells daily. The barium chloride is not electrolysed. Filters remove by-product calcium from the sodium and the purified sodium from the filters is transferred by vacuum to the intermediate storage tanks and thence under gravity to final storage tanks.

Filter cake from the sodium cleaning stage is pressed to remove sodium and is then washed, dissolving it away as an alkaline effluent. This is used as a reagent to treat other site effluents. Other solid wastes arise from sediment in storage tanks, these are burnt on an open hearth and fumes are collected and scrubbed in a 2-stage water scrubber, this scrubber discharges into a third stage using HCl which also treats fumes from the filter cake wash.



a) Anode; b) Cathode; c) Molten salt; d) Diaphragm; e) Chlorine dome

### *The Downs Cell*

#### **Lithium Metal**

This is produced by the electrolysis of a molten, eutectic mixture of lithium chloride (LiCl) and potassium chloride (KCl) at 450°C. Lithium carbonate is received in IBC's and is converted into LiCl; the solution is concentrated and crystallised. Waste lithium hydroxide can also be converted. LiCl crystals are dried before they are drummed for manual feeding into the cells. There is some local dust extraction at handling points. KCl is not electrolysed at the voltage used (4 to 5 V) and only LiCl is added to the cells during operation.

Cells are rectangular baths each containing 5 pairs of electrodes (a cylindrical carbon anode and a concentric circular steel cathode). There is no membrane in this process and this is likely to reduce the efficiency of electrolysis, as a portion of the Lithium liberated (from the inside surface of the cathode) will react with chlorine to reform LiCl. Cells can be heated by gas burners for start up and winter use but normally sufficient heat is generated by electrolysis to keep the bath molten. Cell life is ~7 years and is prompted by wear of the weir plate

Molten lithium is produced and accumulates at the front of the cell and is skimmed off manually using a fine mesh skimmer into a hand-held ladle. The metal is then immediately cast into small moulds (~350mm x 50mm x 50mm), no metal fume is produced but the filled moulds are immediately covered by a mineral oil to prevent oxidation. This causes an oil fume, which is extracted into a vertical lip captor and emitted untreated through a stack along with other fume extracted from the cell room that contains alkali, dust and chlorine. Lithium bar can also produced in small quantities using a hand-operated hydraulic press.

Chlorine produced by the cell room is collected by partial vacuum and is absorbed in caustic soda to produce sodium hypochlorite, which is sold. Two absorption columns are used, one on standby for emergency use.

The applied current and voltage control the process. Rectifier trips are easily handled and only cause a problem during skimming when current induced stirring of the electrolyte stops. Other problems arise from the presence of sodium as an impurity in the electrolyte as it is electrolysed and separates from Li as it cools. Na forms small “mushrooms” on the metal surface and these ignite and may cause the ingot to burn, the sodium content of the raw material is controlled to prevent this.

### **Potassium metal**

At the time of writing, potassium metal is produced on an industrial scale only by the reduction of potassium chloride with sodium metal. In the continuous production a fractional distillation is incorporated into a reaction column packed with molten potassium chloride. By feeding sodium into the column a vapour mixture of sodium and potassium is fractionated. Potassium metal is then obtained by distillation of the vapour mixture using air as a coolant.

### **Calcium and Strontium Metal**

Calcium and strontium metal are used for a variety of purposes. Calcium as an alloying element improves the quality of steels especially the mechanical properties like formability, drawing and machinability. Because of its strong ability to form oxides and sulphites calcium is important in the production of ultraclean steel. Calcium metal may also be used for lead de-bismuthation. Strontium metal is needed in aluminium refining as well as for the refinement of steel slag.

Calcium metal can be produced by electrolysis or metallo-thermic reduction, but at present the only process used in the European Union is the high temperature vacuum reduction of calcium oxide with aluminium using the metallo-thermic process. The production of calcium metal depends on a small finite equilibrium of calcium vapour in the range of 1000–1200°C. The calcium vapour is then transferred with a vacuum pump to a cooled region of the reactor where condensation takes place. This shifts the equilibrium at the reaction site and allows more calcium vapour to be formed.

Lime is ground in order to get a small particle size material that is then dry blended with the desired amount of aluminium. The mixture of both is then compacted into

briquettes to ensure good contact of reactants. The briquettes are then heated in the furnace, which is electrically heated by resistance, up to about 1300°C. Due to the vacuum in the furnace a condensed block containing more than 95% of calcium metal is formed in the cooled part of the furnace. These blocks of calcium metal and calcium aluminate residue are then removed from the furnace. For some applications calcium metal needs to be reduced in size, which can be done by using special grinders adapted to the characteristics of calcium.

### **Strontium Metal**

Strontium metal is produced by thermal reduction of strontium oxide with aluminium as a reducing agent. The reaction is conducted in a similar way to the production of calcium metal in a vacuum furnace. The vaporised metal is condensed in a cooler part of the furnace. The blocks of strontium metal and strontium aluminate residue are removed from the furnace. Strontium metal then is sold as such without any additional grinding.

### **Magnesium Metal**

Magnesium metal and magnesium containing alloys have widespread use in different industrial sectors, for instance as an alloying element in aluminium as well as in automotive, telecommunication or electrical applications. Magnesium can also be used for cathodic protection of pipelines, tanks and bridges.

Magnesium can be produced either by electrolysis or a thermal reduction process. The raw materials used are dolomite, magnesite, carnalite, brines or seawater depending on the process. Magnesium will as well be recovered and produced from a variety of magnesium containing secondary raw materials.

In the thermal reduction process calcined dolomite is reacted with ferro-silicon sometimes together with aluminium in a furnace or retort vessel. The calcination process takes place by decarbonisation and de-hydration of dolomite limestone. For the calcination process for dolomite, a rotary or vertical furnace can be used.

The metallo-thermic process is operated under vacuum and produces magnesium vapour, which is subsequently condensed into liquid or solid form. This operation is carried out in a furnace electrically heated by Joule effect where the liquid slag acts as a resistor between the electrode and a carbonaceous bottom lining. The reduction is carried out at 1700°C and 6 kPa pressure. Reductants and oxides are introduced continuously over the slag. Argon is also introduced to form an inert atmosphere. The magnesium is condensed in a condenser cooled by water (crucible). This crucible is taken apart when it is full, and then transported to the foundry to produce magnesium ingots.

### **Nickel and Cobalt**

Nickel is produced from oxidic (laterite and saprolite) or sulphidic ore, about 60% of the nickel comes from sulphide deposits and 40% from oxide deposits. There are several variations in the processes used to produce nickel from these ores and these variations are dependent on the grade of the concentrate and also on the other metals that are present in the material. Cobalt is usually present in nickel and copper ores and is recovered during their production.

Refining of the recovered Co containing by-product is performed by a combination of processes governed by the composition of the concentrate and the physical and chemical characteristics of the final product. Cobalt arsenide ores are also sources of cobalt. These ores are roasted to remove the majority of arsenic as arsenic oxide.

Secondary nickel and cobalt are consumed directly in the form of remelted scrap and other recycled products generally in the production of ferro-nickel and stainless steel. Other secondary materials such as catalysts and precipitator dusts are recovered in the primary smelting processes, usually in the slag furnace. Because these metals are so closely associated their production processes are dealt with together as far as possible.

In laterite ores nickel is bound with iron oxide or silica compounds and is difficult to upgrade to a concentrate. Smelting of these ores with a source of carbon in an electric furnace can be used. Ferronickel is produced or a nickel matte can be made after the addition of sulphur. Prior to smelting the ore is usually pre-heated or calcined in a rotary kiln. An electric furnace is then usually used for smelting.

Saprolite ores can be smelted with sulphur so that the nickel oxide is converted to a nickel sulphide matte and iron is removed as a slag. The matte is treated in the same manner as matte produced from sulphide ores. Smelting to ferronickel accounts for a large proportion of nickel production from laterite ores. Leaching of laterite with ammonia is also used to extract nickel and this process is becoming more important. Although conversion of nickel oxide to impure nickel and then to nickel carbonyl, which is volatile, is used to produce refined nickel, the nickel oxide is produced from the smelting of a sulphidic ore. The laterite ores generally have a maximum nickel content of 3% and are therefore not used directly in this process.

The pressure leaching of laterites with sulphuric acid is principally a simple and straightforward process. The temperature, pressure and other parameters may vary from case to case to achieve the best possible metallurgical conditions depending on the ore and products in question and other objectives. The temperature of the leaching autoclaves is usually between 230 and 260°C and pressures up to 43 bar are used. Oxygen can also be used in the process.

The resultant solution is purified either by modern solvent extraction methods or by traditional precipitation methods. For example hydrogen sulphide is used to selectively precipitate nickel and cobalt sulphides which are sent for further metal recovery. The solution can be neutralised so that iron precipitates. Nickel and cobalt will be precipitated and re-leached with ammonia.

Solvent extraction is used to separate nickel and cobalt chlorides or sulphates. Metallic nickel can be produced by electro-winning and cobalt can be precipitated as cobalt sulphide.

Alternatively nickel and cobalt can be recovered as metal powders using hydrogen reduction.

Nickel-bearing sulphide ores can be concentrated e.g. by flotation to upgrade the nickel content.

Nickel concentrates, generally containing 7 - 25% Ni, are produced which makes further processing easier. The nickel concentrates are usually smelted under oxidising conditions to oxidise the iron sulphides, which with other gangue materials forms an iron silicate slag. The Outokumpu flash furnace is used in Europe; the Outokumpu and INCO Flash Furnaces and electric or shaft furnaces are used elsewhere in the World.

The nickel is recovered into a sulphide matte containing 35 - 70% Ni, Co and Cu. The matte can be treated in a Pierce Smith Converter or alternatively it can be granulated or cooled slowly before a hydrometallurgical recovery stage. The converter stage is not used in Europe at the time of writing.

Important components of the nickel mattes are cobalt, copper and precious metals. The slag produced during smelting also contains recoverable metal and is treated in

an electric furnace to produce more nickel matte. This can be granulated and treated separately. Secondary materials are sometimes recovered in the electric furnace. Conventional smelting processes are used to remove iron and other gangue materials from sulphide concentrates to produce nickel matte. In Europe only the Outokumpu Flash Smelting furnace is used.

Worldwide there are five other smelters, which use this process. Two of these use a flash smelting furnace designed by Western Mining Corporation, where the smelting and slag cleaning furnaces have been built together to form one larger unit. There are differences in operations between the smelters. The most visible difference is the matte grade but variations in the raw material composition also cause some differences.

More recent process developments have exploited the concept of separate treatment of the mattes that are produced during smelting and slag treatment stages.

The Direct Outokumpu Nickel process (DON process) uses an Outokumpu flash furnace with oxygen enriched air and produces a copper- nickel matte with a metal content of ~75% Cu+Ni and 2 - 6% iron. The matte is granulated and ground before passing to the leaching stage. The slag passes by launder to an electric slag-cleaning furnace where it is treated with coke to produce more nickel matte and a cleaned slag for disposal. The two mattes have different compositions and are treated separately.

The mattes produced by the smelting processes must be treated further in order to recover and refine the metal content. Nickel matte must go through a multi-stage refining process to reject iron and recover copper, cobalt and precious metals. Matte can be treated pyro-metallurgically but hydro-metallurgical processes are more commonly used. A variety of electro-refining, leaching-reduction and precipitation processes are carried out. Nickel is recovered from purified solutions by electro-winning or by hydrogen reduction.

### **Carbon and Graphite Electrodes**

There are a number of processes that are used to produce a wide range of carbon and graphite products. Carbon or graphite electrodes (anodes and cathodes) and furnace linings are produced for a variety of ferrous and non-ferrous metal production processes in particular primary aluminium smelting, ferro-alloy and steel production. More than 2000 products of varying sizes, shapes and properties are produced for other applications.

All of the process use coke or carbon and other raw materials such as pitch to produce pastes, electrodes and shapes. Raw material storage and handling stages use enclosed coke delivery and handling systems and integral dust filters. Coal tar pitch and tar delivery and storage systems use tank back venting and condensers for tank breathing.

Processes to produce electrodes.

Søderberg paste, Søderberg electrodes, prebaked anodes and graphite electrodes are made either in dedicated installations or in processes associated with primary aluminium smelting.

Green paste, Søderberg paste, Søderberg electrodes and green shapes

Green paste production is the starting point for the production of all carbon and graphite products. All green pastes are manufactured from a mixture of calcined petroleum coke and up to 28% coal tar pitch, which acts as a binder. The petroleum cokes are a residue from the distillation of crude oils and can therefore be contaminated with substances like metals (e.g. nickel) and sulphur compounds.

Highly annealed metallurgical and lignite cokes are used as auxiliaries for packing. Calcined and annealed cokes by themselves are free of hydrocarbon and PAH. Coke is normally transferred by sealed conveyor or dense phase pneumatic systems and is stored in silos. Pitch is transported in the molten state and is transferred by pumping and is stored in heated tanks, the tank ventilation gases contain hydrocarbon fume and are usually cleaned. Condensers or oil scrubbers are used and back venting of the tank gases is also used. Petroleum coke is ground and then mixed with pitch in heated mixers. The ratio of coke and pitch is adjusted according to the application and to allow the paste to be handled.

In the case of Søderberg paste the blend is produced to allow it to be added to the electrode shell. Dry electrode paste (low pitch content) is preferred to minimise the amount of hydrocarbon released during use. Dry paste also improves electrical conductivity but a stud hole paste is required for the electrical connections and this paste uses up to 40% pitch. Søderberg paste is normally used for electrodes in the primary aluminium industry but the paste can be made into electrodes by pressing and forming for use in other applications for example in electric furnaces for the production of ferro-alloys.

Søderberg electrodes are also produced from the paste by a forming process. In this case the green electrodes are formed into the size and shape required and sold. These electrodes are commonly used in submerged arc electric furnaces. A number of variants exist, for example hollow electrodes can be made to allow furnace feeding through the electrode and composite electrodes can be made to overcome production problems.

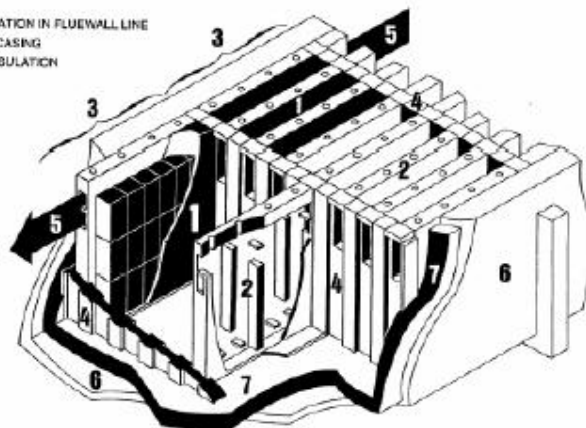
#### Prebaked anodes, electrodes and carbon shapes

The primary aluminium prebake process uses prebaked anodes, which are manufactured by anode production plants. These anode production plants can be associated within the site of the aluminium smelter and several of these plants produce anodes that are sold to other plants and processes. Other dedicated production sites produce a range of electrodes including cathodes and furnace linings. These electrodes are also manufactured from a mixture of petroleum coke and 14 to 18% coal tar pitch and residual material from old anodes.

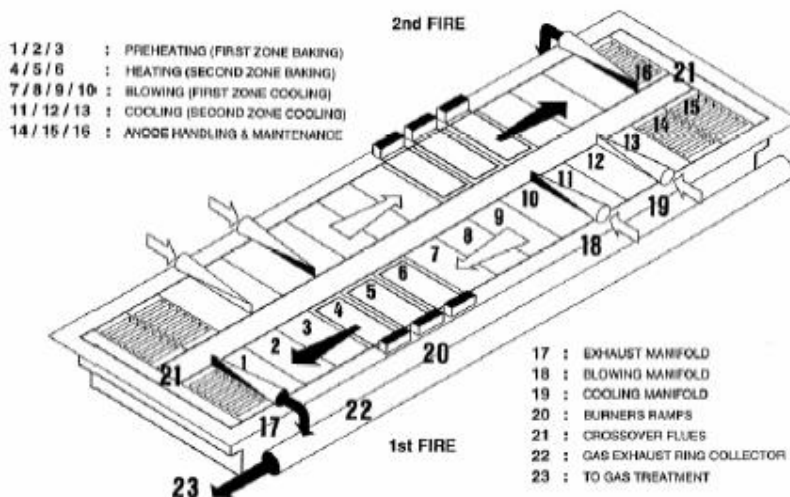
Electrode production involves crushing, grinding and mixing of the raw materials. The mixed materials are then formed into green electrodes. The green electrodes are then baked in ring furnaces comprising a large number of pits, which contain the electrodes. Refractory brick walls separate the pits and ducts are formed for the flue gases. Green electrodes are stacked in the anode furnace in rows and the heating ducts are formed. Layers of packing coke separate the anodes and prevent oxidation. This coke is consumed during the heating and cooling cycle at a rate of 12 to 18 kg per tonne of electrodes, the remaining coke is re-used. At any one time, pits in separate sections of the furnace are being filled, heated, cooled or emptied. Hot air is passed through the ducts using movable gas fired burners and the electrodes are baked at 1100°C in the absence of air. The ducts are kept under negative pressure to contain the fumes. At the end of the heating cycle the ducts are then connected to blowers to cool the section. Hot air passing from the furnace section being cooled is then recycled through the burners or through other furnace sections to preheat that part of the system.

### VIEW OF SECTIONS OF AN OPEN TYPE BAKING FURNACE

- 1 : PIT (ANODE + PACHING COKE)
- 2 : FLUEWALL
- 3 : SECTION
- 4 : HEADWALL
- 5 : GAS CIRCULATION IN FLUEWALL LINE
- 6 : CONCRETE CASING
- 7 : THERMAL INSULATION



### VIEW OF AN OPEN TYPE BAKING FURNACE



Two types of furnace are used for anode baking; open and closed ring furnaces. Open furnaces use a horizontal duct and closed furnaces use a vertical flue. Open furnaces account for 60% of capacity. The horizontal ducts of the open furnace are separate and parallel; this allows the heating cycle to be optimised for each duct and so reduces fuel consumption. The use of multiple chambers in the furnace allows heat from one section to be used in other sections.

During the baking process the coal tar pitch is converted into coke, making the material electrically conductive. There is a 5% loss in weight during baking; the baking process takes approximately 18 to 21 days. In the aluminium industry the prebaked anodes are connected to the anode studs using rods.

These are fixed into the anode in a rodding plant allowing the anodes to be placed in the top of the electrolysis pot using hangers. The anodes are consumed during the electrolysis and have to be replaced after about 80% of the anode is consumed. The



anode residues (20% of original anode weight) are re-used for anode production after residual electrolyte has been removed. The steel rods are reconditioned for further use although a small proportion is scrapped if corroded.

### **Graphite Electrodes**

The production process for graphite electrodes (anodes and cathodes) is very similar to the production of the pre-bake electrodes; normally no residual anode material is used in the blend. Green shapes are first of all baked, the baking temperature used is ~ 1000 °C and the loss in weight during baking is increased to 15%. Single chamber furnaces or pit furnaces are used as well as closed ring furnaces for the baking stage during graphite electrode production. Tunnel furnaces are used for small-scale production of speciality carbon. Baked electrode material is then subject to impregnation with pitch, re-baking and graphitising.

Machining and finishing stages follow to produce graphite electrodes. Graphite is formed when prebaked carbon is heated to approximately 2800 °C. Graphitising of electrodes is usually carried out in Acheson or Castner furnaces. In some cases no hoods are used where there are only minor fugitive dust emissions and the carbon oxides are well dispersed at the roofline.

The Acheson furnace is used for carbon shapes with irregular dimensions and cross sections and the Castner furnace is used for shapes with parallel faces and equal cross sections. Both furnaces are electric resistance furnaces constructed from refractory material. They differ in the way the current is applied to the furnace. In the Acheson furnace shapes are placed inside the furnace body and the interstices filled with a carbon/graphite mixture (resistor packing), the current is passed through the resistor packing and the shapes. In the Castner furnace the shapes form the entire current path and can lead to gains in the current efficiency.

In the Acheson furnace thermal insulation is provided by a mixture of silicon carbide, coke, sawdust and sand. In the Castner furnace only coke is used. Heating cycles vary from 2 to 7 days and the cooling cycle takes up to 14 days. At the end of the cycle the insulation and resistor packing are processed and re-used.

The graphitised shapes are finished by turning, drilling, milling and similar processes to customers' requirements. The resultant final shapes are then polished. Dusts produced by these processes are collected and re-used as far as possible. The specific process depends on the final product.

These electrodes are used in electric arc furnaces in a variety of processes. Furnace linings are also produced in the same process and may be used in aluminium cells as cathodes (cathode blocks can be made from pre-baked, graphite or mixed prebake/graphite material). Carbon cathodes are also used in electric arc furnaces.

### **Processes to produce other carbon and graphite products**

Other graphite products such as seals, brushes, crucibles and similar products are produced in a similar way to graphite electrodes. There are differences in the size and complexity of the products and this affects the processes that are used. Other additives such as sulphur and metals can be added to the blend of raw materials to give the desired physical properties to the product. Sometimes resins are used instead of pitch.

## **Particulate Releases to Atmosphere Potential Sources/Levels and Key Issues**

This section of the briefing note focuses on the potential particulate emission sources from the most commonly used processes:

### **Copper and its Alloys**

Emissions from primary copper smelters are principally particulate matter and sulphur oxides (SO<sub>x</sub>). Emissions are generated from the roasters, smelting furnaces, and converters. Fugitive emissions are generated during material handling operations.

Roasters, smelting furnaces, and converters are sources of both particulate matter and SO<sub>x</sub>. Copper and iron oxides are the primary constituents of the particulate matter, but other oxides, such as arsenic, antimony, cadmium, lead, mercury, and zinc, may also be present, along with metallic sulphates and sulphuric acid mist. Fuel combustion products also contribute to the particulate emissions from multiple hearth roasters and reverberatory furnaces.

Gas effluents from roasters usually are sent to an electrostatic precipitator (ESP) or spray chamber/ESP system or are combined with smelter furnace gas effluent before particulate collection.

Overall, the hot ESPs remove only 20 to 80 % of the total particulate (condensed and vapor) present in the gas. Cold ESPs may remove more than 95 % of the total particulate present in the gas. Particulate collection systems for smelting furnaces are similar to those for roasters.

Reverberatory furnace off-gases are usually routed through waste heat boilers and low-velocity balloon flues to recover large particles and heat, then are routed through an ESP or spray chamber/ESP system.

In the standard Pierce-Smith converter, flue gases are captured during the blowing phase by the primary hood over the converter mouth. To prevent the hood from binding to the converter with splashing molten metal, a gap exists between the hood and the vessel. During charging and pouring operations, significant fugitives may be emitted when the hood is removed to allow crane access.

Converter off-gases are treated in ESPs to remove particulate matter, and in sulphuric acid plants to remove SO<sub>2</sub>.

Remaining smelter operations process material containing very little sulphur, resulting in insignificant SO<sub>2</sub> emissions. Particulate may be emitted from fire refining operations. Electrolytic refining does not produce emissions unless the associated sulphuric acid tanks are open to the atmosphere. Crushing and grinding systems used in ore, flux, and slag processing also contribute to fugitive dust problems.

Particular emissions vary depending upon configuration of the smelting equipment. Roasting, smelting, converting, fire refining, and slag cleaning are potential fugitive emission sources. The actual quantities of emissions from these sources depend on the type and condition of the equipment and on the smelter operating techniques. Fugitive emissions are generated during the discharge and transfer of hot calcine from multiple hearth roasters. Fluid bed roasting is a closed loop operation, and has negligible fugitive emissions.

Matte tapping and slag skimming operations are sources of fugitive emissions from smelting furnaces.

Fugitive emissions can also result from charging of a smelting furnace or from leaks, depending upon the furnace type and condition.

Each of the various converter stages (charging, blowing, slag skimming, blister pouring, and holding) is a potential source of fugitive emissions. During blowing, the converter mouth is in the stack (a close-fitting primary hood is over the mouth to capture offgases). Fugitive emissions escape from the hood. During charging, skimming, and pouring, the converter mouth is out of the stack (the converter mouth is rolled out of its vertical position, and the primary hood is isolated). Fugitive emissions are discharged during roll out.

Occasionally slag or blister copper may not be transferred immediately to the converters from the smelting furnace. This holding stage may occur for several reasons, including insufficient matte in the smelting furnace, unavailability of a crane, and others. Under these conditions, the converter is rolled out of its vertical position and remains in a holding position and fugitive emissions may result.

At primary copper smelters, both process emissions and fugitive particulate from various pieces of equipment contain oxides of many inorganic elements, including lead. The lead content of particulate emissions depends upon both the lead content of the smelter feed and the process off gas temperature. Lead emissions are effectively removed in particulate control systems operating at low temperatures, about 120°C.

Fugitive emissions from primary copper smelters are captured by applying either local ventilation or general ventilation techniques. Once captured, fugitive emissions may be vented directly to a collection device or can be combined with process off-gases before collection. Close-fitting exhaust hood capture systems are used for multiple hearth roasters and hood ventilation systems for smelt matte tapping and slag skimming operations. For converters, secondary hood systems or building evacuation systems are used.

### **Aluminium**

In bauxite grinding, hydrated aluminium oxide calcining, and materials handling operations, various dry dust collection devices (centrifugal collectors, multiple cyclones, or electrostatic precipitators (ESPs) and/or wet scrubbers) have been used. Large amounts of particulate are generated during the calcining of hydrated aluminium oxide, but the economic value of this dust leads to the use of extensive controls which reduce emissions to relatively small quantities.

Emissions from aluminium reduction processes are primarily gaseous hydrogen fluoride and particulate fluorides, alumina, carbon monoxide, carbon dioxide (CO<sub>2</sub>), volatile organics, and sulphur dioxide from the reduction cells. The source of fluoride emissions from reduction cells is the fluoride electrolyte, which contains cryolite, aluminium fluoride, and fluorospar. The dissociation of the molten cryolite is the source of the perfluorinated carbons (PFCs) tetrafluoromethane and hexafluoroethane which are formed during anode effects.

Particulate emissions from reduction cells include alumina and carbon from anode dusting, and cryolite, aluminium fluoride, calcium fluoride, chiolite, and ferric oxide. Emissions from anode bake ovens include the products of fuel combustion; high boiling organics from the cracking, distillation, and oxidation of paste binder pitch;

sulphur dioxide from the sulphur in carbon paste, primarily from the petroleum coke; fluorides from recycled anode butts; and other particulate matter.

A variety of control devices has been used to abate emissions from reduction cells and anode baking furnaces. To control gaseous and particulate fluorides and particulate emissions, one or more types of wet scrubbers (spray tower and chambers, quench towers, floating beds, packed beds, venturis) have been applied to all 3 types of reduction cells and to anode baking furnaces. In addition, particulate control methods such as wet and dry electrostatic precipitators (ESPs), multiple cyclones, and dry alumina scrubbers (fluid bed, injected, and coated filter types) are used on all 3 cell types and with anode baking furnaces.

The fluoride adsorption system is becoming more prevalent and is used on all 3 cell types. This system uses a fluidised bed of alumina, which has a high affinity for fluoride, to capture gaseous and particulate fluorides. The pot off gases are passed through the crystalline form of alumina, which was generated using the Bayer process. A fabric filter is operated downstream from the fluidised bed to capture the alumina dust entrained in the exhaust gases passing through the fluidised bed. Both the alumina used in the fluidised bed and that captured by the fabric filter are used as feedstock for the reduction cells, thus effectively recycling the fluorides. This system has an overall control efficiency of 99 % for both gaseous and particulate fluorides. Wet ESPs approach adsorption in particulate removal efficiency, but they must be coupled to a wet scrubber or coated baghouse to catch hydrogen fluoride.

Scrubber systems also remove a portion of the SO<sub>2</sub> emissions. These emissions could be reduced by wet scrubbing or by reducing the quantity of sulphur in the anode coke and pitch (ie calcining the coke).

Total dust generation varies and depends on the type of process applied and the type of alumina, but ranges from 0.6 to 10 kg per tonne Al. Typical dust concentrations for pot room ventilation are 0.5 to 5 mg.Nm<sup>3</sup> whereas the dust concentration in the process air ranges from 150 – 500 mg.Nm<sup>3</sup> before abatement and from 1 - 20 mg.Nm<sup>3</sup> after abatement.

Casting is another source of dust (and metals) and cast-house fume is usually collected and treated in a fabric filter.

Potential sources of fugitive particulate emissions in the primary aluminium industry are bauxite grinding, materials handling, anode baking, and the 3 types of reduction cells.

## **Zinc**

Each of the 2 smelting processes generates emissions along the various process steps. The roasting process in a zinc smelter is typically responsible for more than 90% of the potential SO<sub>2</sub> emissions. About 93 to 97% of the sulphur in the feed is emitted as sulphur oxides.

Concentrations of SO<sub>2</sub> in the offgas vary with the type of roaster operation. Typical SO<sub>2</sub> concentrations for multiple hearth, suspension, and fluidised bed roasters are 4.5 to 6.5%, 10 to 13%, and 7 to 12%, respectively. Much of the particulate matter emitted from primary zinc processing facilities is also attributable to the concentrate roasters. The amount and composition of particulate varies with operating parameters, such as air flow rate and equipment configuration. Various combinations of control devices such as cyclones, electrostatic precipitators (ESPs),

and bag houses can be used on roasters and on sintering machines, achieving 94 to 99 % emission reduction.

Dust carry over from the roasting and smelting processes are potential sources direct and fugitive emissions of dust and metals. The gases are collected and treated in the gas cleaning processes of the sulphuric acid plant. Dust is removed and returned to the process.

The gases leaving splash condensers in the ISF, from distillation columns and from the tapping points are also potential sources. Good extraction and abatement is needed at these points to prevent fugitive emissions. Slag treatment and quenching also gives rise to dust. The range of dust emissions from these captured sources is <1 to 20mg.Nm<sup>3</sup>.

### **Lead**

Emissions of lead and particulate occur in varying amounts from nearly every process and process component within primary lead smelter/refineries, and SO<sub>2</sub> is also emitted from several sources. The lead and particulate emissions point, volume, and area sources may include:

1. The milling, dividing, and fire assaying of samples of incoming concentrates and highgrade ores;
2. Fugitive emissions within the crushing mill area, including the loading and unloading of ores and concentrates from rail cars onto conveyors;
3. The ore crushers and associated transfer points, which may be controlled by bag houses;
4. Fugitive emissions from the unloading, storage, and transfer of byproduct dusts, highgrade ores, residues, coke, lime, silica, and any other materials stored in outdoor piles
5. Strong gases from the front end of the sinter machine, which are typically vented to an electrostatic precipitator (ESP), one or more scrubbers and a wet ESP for sulphuric acid mist elimination but during shutdowns of the acid plant may bypass the ESP;
6. Weak gases from the back end of the sinter machine, which are high in lead dust content but typically pass through cyclones and a bag house;
7. Fugitive emissions from the sinter building, including leaks in the sinter machine and the sinter cake crusher;
8. Gases exiting the top of the blast furnace, which are typically controlled with a bag house;
9. Fugitive emissions from the blast furnace, including leaks from the furnace covers and the bottoms of charge cars, dust from the charge car bottom dump during normal operation, and escaping gases when blow holes develop in the shaft and must be "shot" with explosives;
10. Lead fumes from the molten lead and slag leaving the blast furnace area;
11. Fugitive leaks from the tapping of the kettles and settlers;
12. The hauling and dumping of slag, at both the handling and cooling area and the slag storage pile;
13. The combustion of natural gas, as well as the creation of lead-containing fumes at the kettles and reverberatory furnace, all of which are typically vented to a bag house at the dressing building;
14. Fugitive emissions from the various pouring, pumping, skimming, cooling, and tapping operations within the dressing building;
15. The transporting, breaking, granulating, and storage of speiss and matte;
16. The loading, transferring, and drying of tetrahedrite ore, which is typically controlled with cyclones and a bag house;

17. The periodic cleanout of the blast and reverberatory furnaces; and
18. Dust caused by wind erosion and plant vehicular traffic.

### **Cadmium**

As cadmium is produced mainly as a by-product of the zinc and lead manufacturing processes, emission points and typical emissions levels are similar to those described in the previous two sections.

### **Precious Metals**

Particulate emissions to air can generally be emitted from incinerators, furnaces and cupels as fugitive or collected and abated emissions. Furnace sealing and secondary collection from launders is an important factor in preventing fugitive emissions; some electric furnaces use hollow electrodes for material additions to allow improved furnace sealing. Ash from incinerators is usually quenched and the maintenance of the water seal is an important factor in reducing fugitive emissions. Batch incinerators using open trays or boxes present dust and ash containment problems. Collected emissions are usually treated in ceramic or fabric filters, EPs or wet scrubbers. Due to the valuable nature of the products involved, particulate releases are generally extremely low, usually below  $5\text{mg.Nm}^3$ .

### **Mercury**

Mercury is volatile at the temperatures encountered in most abatement processes and different techniques from the usual bag filtration or ESP arrestment systems are therefore used to remove it. It has been reported that mercury in the condenser gases from the production of mercury from cinnabar is in the form of fine particulate and may not be removed efficiently by some processes.

### **Refractory Metals**

According to the raw material that is needed and the unit operations used, e.g. crushing, drying, smelting firing, metal and slag separation, calcining, hydrogen reduction, carburisation and product handling one of the most important sources of environmental input are dust and fume emissions. The dust emissions either as stack or fugitive emissions are important because harmful metal compounds, such as manganese and cobalt may be part of the dust.

Unloading and storage of raw material can generate dust when the material is feed from packaging containment's such as drums, plastic bags or Flexible Intermediate Bulk Containers (FIBC) into bins.

The dust and fume that is generated by smelting or melting for instance chromium or titanium metal or from the production of hard metal powder, is collected by hoods and transferred to an abatement system and de-dusted (e.g. by a fabric filter or a wet scrubber). Stack emissions are normally monitored continuously or periodically and reported by on-site staff or off-site consultants to the competent authorities.

Heavy metals are carried into the process as trace elements in the primary or secondary raw material. The metals with boiling points below the process temperature will escape as gases in the form of metal vapour, which partly condenses and oxidises to form part of the dust and fume from the firing chamber. The metal vapour and off-gases generated by melting or refining of refractory metals in an electron beam furnace are collected by a vacuum system and then condensed by intensive cooling.

Another environmental impact of the production of refractory metals such as tantalum, zirconium and hafnium are the radioactive levels of some raw materials. Also the toxicology of some refractory metals for instance chromium, manganese and

vanadium should be taken into account. This is as well the case if cobalt takes part of the hard metal powder, where then the occurrence of "hard metal disease" has been found.

### **Alkali and Alkaline Earth Metals**

The main environmental input to the atmosphere by producing calcium and strontium metal are dust emissions. Dust may be generated by unloading and crushing the calcined lime, by mixing and compacting lime and aluminium and by grinding and screening the produced metal. Due to the baking operation that is necessary to produce strontium oxide for the production of strontium metal about 420 kg of CO<sub>2</sub> is generated to the atmosphere for each tonne of strontium oxide produced.

The production of magnesium metal is related to the emission of dust, SO<sub>2</sub>, NO<sub>x</sub>, Cl<sub>2</sub>, HCl, dioxin and in several cases the emission of sulphur hexafluoride (SF<sub>6</sub>). Dust is mainly emitted from the calcination of dolomite. Dioxin is generated from the chlorination furnace where magnesium oxide is converted into magnesium chloride. The emission of sulphur hexafluoride (SF<sub>6</sub>) is due to the need to prevent the magnesium metal from re-oxidation. It should be noted that SF<sub>6</sub> has a very high global warming potential (23900 times the effect of CO<sub>2</sub>) and is therefore a controlled substance under the Kyoto protocol.

Typical particulate emission levels from the various processes are:

From dolomite calcination 100mg.Nm<sup>3</sup>  
From MgO calcination 16mg.Nm<sup>3</sup>  
From pellet drying 40mg.Nm<sup>3</sup>  
From chlorination off-gas treatment 3mg.Nm<sup>3</sup>  
From chlorination (vent. gas) 16mg.Nm<sup>3</sup>

### **Nickel and Cobalt**

Dust carry over from the roasting, smelting and converting processes are potential sources of direct and fugitive emissions of dust and metals. In some processes the gases are collected and treated in the gas cleaning processes of a sulphuric acid plant. Dust is removed and returned to the leaching process.

Besides process emissions, fugitive emissions occur. The major fugitive emission sources are:

Dust from storage and handling of concentrates  
Leakage from roasters, smelters and converters;  
Dust from the exhaust gases of leaching and purification vessels;  
Exhaust gases ( including HCl, Cl<sub>2</sub> and VOCs) from the solvent extraction and electrowinning units;  
Dust from the exhaust gases of casting furnaces;  
Miscellaneous including building ventilation air.

### **Carbon and Graphite Electrodes**

During production dust emissions occur during all process stages (storage, transfer, mixing, grinding, baking, graphitising and shaping). The emission is mainly caused by dust generated during the grinding and screening and shaping processes and from the carbonisation gases. The mechanical handling and treatment stages are usually enclosed and extracted. The source of dust and its characteristics influence the abatement method used to remove it, carbon dust can be very fine and abrasive. In some cases of manufacturing special carbon and graphite products, absolute filters are used to remove it; the cleaned air is then used in the workplace.

### *Bibliography*

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3. United States Environmental Protection Agency. Emission Factors – Primary Copper Smelting
4. United States Environmental Protection Agency. Emission Factors – Zinc Smelting
5. United States Environmental Protection Agency. Emission Factors – Primary Lead Smelting and Refining.

### *Glossary of Terms*

BREF	Best Available Technology Reference
Cinnabar ore	Naturally occurring ore from which mercury metal is extracted
Co	Chemical symbol for cobalt
EBM	Electron Beam Furnace
ESP	Electrostatic Precipitator
Eutectic	Of maximum fusibility; said of an alloy or mixture which has the lowest melting point which it is possible to obtain by the combination of the given components.
FIBC	Flexible Intermediate Bulk Container
IBC	Intermediate Bulk Container
IPPC	Integrated Pollution Prevention and Control
PAH	Polycyclic Aromatic Hydrocarbon
PGM	Platinum Group Metals
Sublimed	Having been subjected to the process of sublimation; hence, also, purified.
TTC	Titanium tetrachloride

### *Emissions to air*

Mass of emitted substances related to the volume of waste gas under standard conditions (273K, 1013 mbar), after deduction of water vapour content, expressed in the units mg.Nm<sup>-3</sup>.



## How PCME Instruments Satisfy Monitoring Requirements

### Phase One Grinding

During the process of bauxite grinding, hydrated aluminum oxide calcining, and materials handling operations, various dry dust collection devices (centrifugal collectors, cyclones, Bagfilter, Multiple cyclones, or Electrostatic precipitators and/or wet scrubbers) have been used. Depending on the dust collector chosen, it does require the correct choice of instrument for reliable and reportable information. Typically nowadays a Bagfilter would be used to collect the fine particulate after grinding of the bauxite.

Because of the amount of bauxite required to produce the Aluminum i.e. two to three tones of bauxite are required to produce one tonne of Alumina and two tones of alumina to produce one tonne of Aluminium. The economic value of bauxite is greatly increased and therefore monitoring for emissions has a greater appeal. The Electrodynamic sensors can monitor very low levels of particulate emissions, sensitive to  $0.01\text{mg}/\text{m}^3$  and assist in prediction of 'Broken Bag Detection' which not only saves time but can also extend the working life of expensive replacement bags or filter media.

### Bayer Process

Cleaning and screening of the ground Bauxite to remove the Alumina, this part of the process does not have an environmental impact to the atmosphere. Apart from the alkalinity that is imparted by liquors in the process, the residue is chemically stable and non-toxic.

### Phase Two Calcining

Large amounts of particulate are generated during the calcining of hydrated aluminum oxide, but yet again the economic value of this dust leads to the use of extensive controls to reduce emissions to relatively small quantities.

Bagfilters are becoming a more common method of filtration after furnace installations because of their ability to absorb fume and new bag filtration media can now work at higher temperatures than in the past. Typical bag filter emission molecule sizes are in the region of 0.5 microns. The downside to this ability is that replacement bags can be expensive. Again the Electrodynamic instruments are capable of measuring particulate at 0.1-micron sizes and dust levels below  $0.1\text{mg}/\text{m}^3$ . Because of the Electrodynamic technology employed, the instruments are unaffected by build up on the sensor so therefore give reliable results for much longer periods compared to DC based Triboelectric systems.

The use of software can again assist in the maintenance of the filtration system to pinpoint filter failure and ensure the correct remedial work for repair has been undertaken.

### **Anode Baking Ovens/Electrolytic Reduction**

Emissions from anode baking ovens include the products of fuel combustion; high boiling temperature organics from the cracking, distillation, and oxidation of paste binder pitch; sulphur dioxide from the sulfur in carbon paste, primarily from the petroleum coke; fluorides from recycled anode butts; and other particulate matter.

High molecular weight organics and other emissions from the anode paste are released from HSS and VSS cells. These emissions can be ducted to gas burners to be oxidized, or they can be collected and recycled or sold. If the heavy tars are not properly collected, they can cause plugging of exhaust ducts, fans and emission control equipment.

A variety of control devices have been used to remove emissions from reduction cells and anode baking furnaces. To control gaseous and particulate fluorides and particulate emissions, one or more types of wet scrubbers (spray tower and chambers, quench towers, floating beds, packed beds, venturi) have been applied to all three types of reduction cells and to anode baking furnaces.

In addition, particulate control methods such as *wet and dry electrostatic precipitators (ESP), multiple cyclones and dry alumina scrubbers (fluid bed, injected, and coated filter types)* are used on all three cell types and with anode baking furnaces.

The Electrodynamic technology works very well even at elevated temperatures, 800°C. If the filtration system has water introduced as in a wet scrubber there is potential for carryover of the moisture. This would normally cause the system to fail due to short circuit on the sensor rod but with the use of the Electrodynamic technology supplied by PCME Ltd it is possible to completely insulate the sensor reducing this very common fault on standard sensors.

Where the exhaust diameter exceeds 3000mm the Dynamic Opacity monitor takes over where its counterpart left off. The Dynamic Opacity instrument can be used on stacks up to a diameter of 10 meters. Contamination again is not a major issue for this instrument as it can operate with the optical lenses 90% coated without any loss in accuracy.

### **Electrolytic Reduction**

Emissions from aluminum reduction processes are primarily gaseous hydrogen fluoride and particulate fluorides, alumina, carbon monoxide, carbon dioxide, volatile organics, and sulfur-dioxide from the reduction cells. The source of fluoride emissions from reduction cells is the fluoride electrolyte, which contains cryolite, aluminum fluoride, and fluorospar.

Particulate emissions from reduction cells include alumina and carbon from anode dusting, aluminum fluoride, calcium fluoride, cryolite and ferric oxide. In addition, emissions from reduction cells also include organics, carbon monoxide and sulfur oxides.

Poor combustion within the Electrolytic cell can cause dark plumes to be emitted from the stack and poor quality aluminium and as a result carry over lots of coke and pitch, hence the dark plume.

The Electrodynamic technology is very well suited to this type of application giving a rugged and reliable instrument operation.

Recovery of fluorides is important as even small amounts of fluorides in the air can severely damage vegetation. Ingestion by animals causes severe health problems.

The pot off-gases are passed through the crystalline form of alumina, which was generated using the Bayer process. A fabric filter is operated downstream from the fluidized bed to capture the alumina dust entrained in the exhaust gases passing through the fluidized bed. Both the alumina used in the fluidized bed and that captured by the fabric filter are used as feedstock for the reduction cells, thus effectively recycling the fluorides.

Wet ESP's approach adsorption in particulate removal efficiency, but they must be coupled to a wet scrubber or coated bag house to catch hydrogen fluoride. Scrubber systems also remove a portion of the SO<sub>2</sub> emissions. These emissions could be reduced by wet scrubbing or by reducing the original quantity of sulfur in the coke and pitch by calcining the coke prior to manufacturing anodes.

The moisture again in this application can lead to high maintenance intervals due to the moisture levels being carried over. This would normally cause the system to fail due to short circuit on the sensor rod but with the use of the Electrodynamic technology supplied by PCME Ltd it is possible to completely insulate the sensor reducing this very common fault on standard sensors.

#### **Reliable operation even when contaminated**

Due to the manufacturing process the temperatures, the pitch and the fume can be quite severe. Dependable emissions' monitoring operation and data collection is critical due to environmental sensitivity. Versions of the Electrodynamic instrumentation are certified by TUV in Germany not only for qualitative monitoring of bag filter condition (BlmschV 27), but also the more demanding requirement to measure mg/m<sup>3</sup> within defined limits (BlmschV 17 & 13).

The Electrodynamic instruments are specifically certified for these bag filter measurement requirements.

Due to the batch nature of the furnace operation and the climate change levy, where a reduction in power consumption is required, fan speeds, which affect flow rates, will vary. The Electrodynamic instrumentation maintains its calibration in spite of velocity changes in the order of 5 to 18 m/s

## PCME References in the Industry

Extract from PCME Reference List (refer to CD for complete listing)

Country	Customer	Location	Industry Group	Specific Industry	Process	Arrestment
Argentina	Aluar Aluminio	Chubut, Argentina	Metal	Aluminium		
Australia	Queensland Alumina	Queensland	Metal	Aluminium	Kiln	ESP
Australia	Glucina Smelters	New Zealand	Metal	Aluminium	Furnace	Bag
Australia	Alcoa	Kwinana	Metal	Aluminium	Smelting	Wet Scrubber
Australia	Comalco KAAL	Sydney	Metal	Aluminium	Smelting	Bag
Canada	Les Elevateurs	Quebec	Metal	Aluminium	Ship	Fabric Filter
Canada	Alcoa	Quebec	Chemical	Aluminium	Crusher	Bag
Denmark	Simatek A/S		Metal	Aluminium		Cart Filter
France	Aluminium Pechiney		Metal	Aluminium	Furnace	ESP
France	Trisource		Metal	Aluminium	Scrubber	Bag
France	Procedair	France	Metal	Aluminium	Furnace	Bag
France	Hydro Aluminium	France	Metal	Aluminium	Furnace	Bag
Germany	Gottschol Alucom		Metal	Aluminium		Bag
Germany	Eckart Werke	Wackersdorf	Metal	Aluminium	Mats.Transfer	Bag
United Kingdom	Alcan Smelting	Lynemouth	Metal	Aluminium	Smelting	
United Kingdom	Allgroup Alusuisse		Metal	Aluminium		Fabric Filter
United Kingdom	AluSuisse		Metal	Aluminium		
United Kingdom	Icelandic Aluminium	Iceland	Metal	Aluminium	HF Removal	Bag
United Kingdom	Alcan Iceland	Iceland	Metal	Aluminium	Recovery	Cartridge
United Kingdom			Metal	Aluminium	Furnace	Fabric/Ceramic filt
United Kingdom	Toyo Aluminium Co	Hino Plant	Metal	Aluminium		Bag
United Kingdom	Hydro Aluminium	Holmestrand	Metal	Aluminium	Furnace	Fabric Filter
United Kingdom	Alfsen og Gunderson	Oslo	Metal	Aluminium	Furnace	Fabric Filter
United Kingdom	Elkem		Metal	Aluminium	Furnace	Bag
South Africa	Mozal S.A.R.L.	Mozambique	Metal	Aluminium	Other	Bag
Sweden	Stena Aluminium	Almhalt	Metal	Aluminium	Casting	Bag
United Kingdom	Deeside Aluminium	Wrexham	Metal	Aluminium		
United Kingdom	Alcan	Ashington	Metals	Aluminium	Furnace	Baghouse
United Kingdom	Calder Industrial	Newcastle Upon Tyne	Metals	Aluminium	Furnace	Baghouse
United Kingdom	Alloy Wheels	Rochester	Metal	Aluminium	Swarf-Recovery	
United Kingdom	Anglo Blackwells	Widnes	Metal	Aluminium	Furnace	Baghouse
United Kingdom	Alcan	Fort William	Metals	Aluminium	Furnace	Baghouse
United Kingdom	Icelandic Aluminium	Iceland	Metal	Aluminium	Recycling	Fabric Filter
United Kingdom	Anglo Blackwells	Widnes	Metals	Aluminium	Furnace	Baghouse
United Kingdom	British Aluminium	Workington	Metals	Aluminium	Animal Feed	DSU
United Kingdom	Castle Alloys	Whitchurch	Metal	Aluminium	Recovery	Bag
USA	Commonwealth Alumin	Lewisport	Metal	Aluminium	Shredding	Bag
USA	IMCO, Eli Lilly, OMG	USA	Metal	Aluminium	Beading Process	Bag
USA	Alcan Ingot	Kty	Metal	Aluminium		Bag
USA	IMCO Recycling	Chicago	Metal	Aluminium		Bag
USA	Alcoa	Indiana	Metal	Aluminium	Aluminium Smelter	Bag
USA	Nichols Aluminium	Davenport Iowa	Metal	Aluminium	Recycling	Bag
USA	IMCO of Illinois	Chicago Heights	Metal	Aluminium	Recycling	Bag
USA	Commonwealth Alumin	Lewisport, Kentucky	Metal	Aluminium	Recycling	Bag

## **Associated Industries**

Recycling:

Cans  
Car Components  
Window Frames  
Aerospace  
Rail  
Marine  
Electrical  
Construction  
Medicine  
Foil  
Food and Beverage  
Cookware  
Packaging  
Overhead Lines

## Trade Associations

Aluminium Association of Canada

[www.aia.aluminium.gc.ca](http://www.aia.aluminium.gc.ca)

Aluminium Association of Greece

[www.aluminium.org.gr](http://www.aluminium.org.gr)

Aluminium Association of India

[www.aluminium.india.org](http://www.aluminium.india.org)

Aluminium Federation Ltd (UK)

[www.alfed.org.uk](http://www.alfed.org.uk)

Aluminium Federation of South Africa

[www.afsa.co.za](http://www.afsa.co.za)

Aluminiumindustriens Miljøsekretariat

[www.ams-aluminium.no](http://www.ams-aluminium.no)

Aluminium Packaging Recycling Organisation (UK)

[www.alupro.org.uk](http://www.alupro.org.uk)

Aluminium Verband Schweiz

[www.alu.ch](http://www.alu.ch)

Associação Brasileira do Alumínio

[www.abal.org.br](http://www.abal.org.br)

Asociación para el Reciclado de Productos de Aluminio (ARPAL)

[www.aluminio.org](http://www.aluminio.org)

Associazione Nazionale Industrie Metalli non Ferrosi (ASSOMET)

[www.assomet.it](http://www.assomet.it)

Industrie Metalli non Ferrosi (ASSOMET)

[www.aluminium.org.au](http://www.aluminium.org.au)

Australian Aluminium Council

[www.aluminium.org.au](http://www.aluminium.org.au)

Cámara Argentina de la Industria del Aluminio y Metales Afines

[www.uia.org.ar](http://www.uia.org.ar)

China Nonferrous Metals Industry Association

(no website)

Eurometaux

[www.eurometaux.org](http://www.eurometaux.org)

European Aluminium Association

[www.aluminium.org](http://www.aluminium.org)

European Aluminium Foil Association

[www.alufoil.org](http://www.alufoil.org)

Fabrimetal (Belgium)  
[www.fabrimetal.be](http://www.fabrimetal.be)

Genossenschaft Aluminium Recycling (Switzerland)  
[www.igora.ch](http://www.igora.ch)

Gesamtverband der Aluminiumindustrie e.V.  
[www.aluinfo.de](http://www.aluinfo.de)

Instituto Mexicano del Aluminio A.C.  
[www.imedal.com.mx](http://www.imedal.com.mx)

Japan Aluminium Association  
[www.aluminium.or.jp](http://www.aluminium.or.jp)

Organisation of European Aluminium Refiners and Remelters  
[www.oea-alurecycle.org](http://www.oea-alurecycle.org)

Stichting Aluminium Centrum (Netherlands)  
[www.aluminium.info.nl](http://www.aluminium.info.nl)

The Aluminium Association (USA)  
[www.aluminium.org](http://www.aluminium.org)

### **Associated Exhibitions/Conferences**

Eight International Aluminium Extrusion Technology Seminar and Exposition  
Orlando, Florida USA 18-21 May 2004

BATIMAT EXPO VIVIENDA  
Buenos Aires, Argentina 1-5 June 2004

9<sup>th</sup> World Aluminium Conference  
New York, USA 13-15 Jun 2004

ALUMINIUM 2004  
Essen, Germany 22-24 September 2004

CastTec 2004  
Sindelfingen, Germany 5-7 October 2004

Equip' Baie  
Paris, France 16-19 November 2004

ALUMEX Conference 2005  
Dubai 27-29 March 2005

ALUMINIUM  
Essen, Germany 22-24 September 2006

## **Bibliography**

[www.world-aluminium.org](http://www.world-aluminium.org)

[www.alcan.com](http://www.alcan.com)

[www.bhpbilliton.com](http://www.bhpbilliton.com)

[www.alcoa.com](http://www.alcoa.com)

[www.nalcoindia.com](http://www.nalcoindia.com)

[www.alunet.net](http://www.alunet.net)

[www.dubal.ae](http://www.dubal.ae)

[www.tomgo.com.au](http://www.tomgo.com.au)

[www.eaa.net](http://www.eaa.net)

[www.riotinto.com](http://www.riotinto.com)