

Nickel Smelting and Refining

Industry Description and Practices

Primary nickel is produced from two very different ores – lateritic and sulfidic. Lateritic ores are normally found in tropical climates where weathering will, with time, extract and deposit it in layers at varying depths below the surface. Lateritic ores are excavated using large earth moving equipment and are screened to remove boulders. Sulfidic ores, often found in conjunction with copper bearing ores, are mined from underground. Following is a description of the processing steps used for the two types of ores.

Lateritic ore processing

Lateritic ores have a high percentage of free and combined moisture which must be removed. Drying removes free moisture and chemically bound water is removed by a reduction furnace which also reduces the nickel oxide. Lateritic ores have no significant fuel value and the electric furnace is required to obtain the high temperatures that are required to accommodate the high magnesia content of the ore. Some laterite smelters add sulfur to the furnace to produce a matte for processing. Other furnaces are operated to reduce iron content sufficiently to produce ferronickel products (the route adopted by most laterite nickel operators). Hydrometallurgical processes based on ammonia or sulfuric acid leach are also used. Ammonia leach is usually applied to the ore after the reduction roast step.

Sulfidic ore processing

Modern technology uses electric smelting or

flash smelting. Flash smelting is the most common process but electric smelting is used for more complex raw materials when increased flexibility is needed. Both processes use dried concentrates. Electric smelting requires a roasting step ahead of the smelter to reduce sulfur content and volatiles. Older nickel smelting processes, such as blast or reverberatory furnaces, are no longer acceptable because of low energy efficiencies and because of environmental concerns.

In flash smelting, dry sulfide ore containing less than 1% moisture, is fed to the furnace along with pre-heated air, oxygen-enriched air (30-40% oxygen), or pure oxygen. Iron and sulfur are oxidized, and the heat that results from exothermic reactions is adequate to smelt concentrate to produce a liquid matte (up to 45% nickel) and a fluid slag. Furnace matte still contains iron and sulfur that are oxidized in the converting step to sulfur dioxide and iron oxide by injecting air or oxygen into the molten bath. Oxides form a slag which is skimmed off. Slags are processed in an electric furnace prior to discard to recover nickel. Process gases are cooled followed by removal of particulates by gas cleaning devices.

Nickel refining

Various processes are used to refine nickel matte. Fluid bed roasting and a chlorine-hydrogen reduction will produce high grade nickel oxides (95%+ nickel). Vapor processes, such as the carbonyl process, can be used to produce high purity nickel pellets. In this process, copper and precious metals remain as a pyrophoric residue requiring separate treatment. Electrical cells equipped with inert

cathodes is the most common technology used for nickel refining. Electrowinning, where nickel is removed from solution in cells equipped with inert anodes is the more common refining

Waste Characteristics

Air emissions

Sulfur dioxide (SO₂) is a major air pollutant emitted in the roasting, smelting and converting of sulfide ores (nickel sulfide concentrates contain 6-20% nickel and up to 30% sulfur). Sulfur dioxide releases can be as high as 4 metric tons of sulfur dioxide per metric ton of nickel produced, before controls. Reverberatory furnaces and electric furnaces produce sulfur dioxide concentrations of 0.5-2.0% while flash furnaces produce sulfur dioxide concentrations of over 10% – a distinct advantage for the conversion of the sulfur dioxide to sulfuric acid. Particulate emission loads for various process steps include: 2.0-5.0 kilograms per metric ton (kg/t) for the multiple hearth roaster; 0.5-2.0 kg/t for the fluid bed roaster; 0.2-1.0 kg/t for the electric furnace; 1.0-2.0 kg/t for the Pierce-Smith converter; and 0.4 kg/t for the dryer upstream of the flash furnace. Ammonia and hydrogen sulfide are pollutants associated with the ammonia leach process; hydrogen sulfide emissions are associated with acid leaching processes. Highly toxic nickel carbonyl is a contaminant of concern in the carbonyl refining process. Various process off gases contain fine dust particles and volatilized impurities. Fugitive emissions will occur at furnace openings, launders, casting molds and ladles that are carrying molten product. The transport and handling of ores and concentrates produce wind borne dust.

Liquid effluents

Pyrometallurgical processes for processing sulfidic ores are generally dry and effluents are of minor importance although wet electrostatic precipitators (ESPs) are often used for gas treatment and a resulting wastewater could have high metal concentrations. Process bleed streams may contain antimony, arsenic or mercury. Large quantities of water are used for

process used for nickel. Chloride electrolytes are used although sulfuric acid solutions are used more often.

slag granulation, but the majority should be recycled.

Solid wastes and sludges

The smelter contributes a slag that is a dense silicate. Sludges that require disposal will result where neutralized process effluents produce a precipitate.

Pollution Prevention and Control

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

The choice of flash smelting over older technologies is the most significant means to reduce pollution at source.

Sulfur dioxide emissions can be controlled by:

- recovery as sulfuric acid;
- recovery as liquid SO₂ (absorption of clean dry off gas in water or chemically absorbed by ammonium bisulfite or dimethyl aniline);
- recovery as elemental sulfur (using reductants such as hydrocarbons, carbon or hydrogen sulfide).

Toxic nickel carbonyl gas is normally not emitted from the refining process because it is decomposed in decomposer towers. However very strict precautions throughout the refining process are required to prevent the escape of the nickel carbonyl into the workplace. Continuous monitoring for the gas with automatic isolation of any area of the plant where the gas is detected is required. Worker protection against liquid nickel carbonyl contact with skin is afforded by impervious clothing.

Prevention measures for reducing emissions of particulate matter include encapsulation of furnaces and conveyors to avoid fugitive emissions. Covered storage of raw materials should be considered.

Wet scrubbing should be avoided and cooling waters should be recirculated. Storm waters should be collected and used in the process. Process water used to transport granulated slag should be recycled. To the extent possible, all process effluents should be returned to the process.

Treatment Technologies

The discharge of particulate matter emitted during drying, screening, roasting, smelting and converting is controlled by using cyclones followed by wet scrubbers, ESPs, or bag filters. Fabric filters may require reduction of gas temperatures by, for example, or dilution with low temperature gases from hoods used for fugitive dust control. Preference should be given to the use of fabric filters over wet scrubbers.

Liquid effluents are used to slurry tailings to the tailings ponds which act as a reservoir for the storage and recycle of plant process water. However, there may be a need to treat bleed streams of some process effluents to prevent a build-up of various impurities. Solid wastes from nickel sulfide ores often contain other metals such as copper, and precious metals, and consideration should be given to further processing for their recovery. Slag can be used as construction material after nickel recovery as appropriate (e.g. return of converter slag to the furnace). Sanitary sewage effluents require treatment in a separate facility or discharged to a municipal sewer.

Modern plants using good industrial practices are able to achieve the following in terms of pollutant loads: The double contact double absorption plant should emit no more than 0.2 kg of sulfur dioxide per metric ton of sulfuric acid produced (based on a conversion efficiency of 99.7 percent).

Emission Guidelines

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

must be justified in the EA and acceptable to MIGA.

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

The guidelines are expressed as concentrations to facilitate monitoring. Dilution of air emissions or effluents to achieve these guidelines is unacceptable.

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

Air Emissions

For nickel smelters the following air emissions levels should be achieved:

Air Emissions from Nickel Smelting

<i>Parameter</i>	<i>Maximum value milligrams per normal cubic meter (mg/Nm³)</i>
Particulates	20
Nickel	1
Sulfur dioxide	2 kg/t sulfuric acid

Liquid Effluents

For nickel smelters the following effluent emissions levels should be achieved:

Effluents from Nickel Smelting

<i>Parameter</i>	<i>Maximum value milligrams per liter (mg/L)</i>
PH	6-9
Total suspended solids	50
Nickel	0.5
Iron	3.5
Total metals	10

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

Ambient Noise

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

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

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

Monitoring and Reporting

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

Air emissions (filters and stacks) should be monitored continuously for SO₂ and particulate matter.

Liquid effluents should be monitored daily for pH and total suspended solids and at least weekly for all other parameters.

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

Key Issues

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

- Use flash smelting for sulfidic ores; electric furnaces should only be used where regenerative energy is available.
- Choose oxygen enrichment processes that allow higher SO₂ concentrations in smelter gases to assist in sulfur recovery.
- Recover as much SO₂ as possible by producing sulfuric acid, liquid sulfur dioxide or other sulfur products.
- Reuse process waters, recirculate cooling waters and use storm water for the process.
- Enclose processes and conveyors to minimize fugitive emissions, and cover raw material storage.

Further Information

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

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

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

United Nations Environment Programme. 1993. "Environmental Management of Nickel Production. A technical Guide." Technical Report No. 15