

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, with time, extracts and deposits the ore 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; chemically bound water is removed by a reduction furnace, which also reduces the nickel oxide. Lateritic ores have no significant fuel value, and an electric furnace is needed to obtain the high temperatures required to accommodate the high magnesia content of the ore. Some laterite smelters add sulfur to the furnace to produce a matte for processing. Most laterite nickel processors run the furnaces so as to reduce the iron content sufficiently to produce ferronickel products. 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

Flash smelting is the most common process in modern technology, 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 before smelting 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 environmental concerns.

In flash smelting, dry sulfide ore containing less than 1% moisture is fed to the furnace along with preheated air, oxygen-enriched air (30–40% oxygen), or pure oxygen. Iron and sulfur are oxidized. The heat that results from exothermic reactions is adequate to smelt concentrate, producing a liquid matte (up to 45% nickel) and a fluid slag. Furnace matte still contains iron and sulfur, and these 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, and particulates are then removed by gas-cleaning devices.

Nickel Refining

Various processes are used to refine nickel matte. Fluid bed roasting and chlorine-hydrogen reduction produce high-grade nickel oxides (more than 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 that requires separate treatment. Use of electrical cells equipped with inert cathodes is the most common technology for nickel refining. Electro-winning, in which nickel is removed from solution in cells equipped with inert anodes, is the more common refining process. Sulfuric acid

solutions or, less commonly, chloride electrolytes are used.

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.) SO₂ releases can be as high as 4 metric tons (t) of sulfur dioxide per metric ton of nickel produced, before controls. Reverberatory furnaces and electric furnaces produce SO₂ concentrations of 0.5–2.0%, while flash furnaces produce SO₂ 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 occur at furnace openings, launders, casting molds, and ladles that carry 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 the resulting wastewater could have high metal concentrations. Process bleed streams may contain antimony, arsenic, or mercury. Large quantities of water are used for slag granulation, but most of this water should be recycled.

Solid Wastes and Sludges

The smelter contributes a slag that is a dense silicate. Sludges that require disposal will result when 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 of reducing pollution at source.

Sulfur dioxide emissions can be controlled by:

- Recovery as sulfuric acid
- Recovery as liquid sulfur dioxide (absorption of clean, dry off-gas in water or chemical absorption 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 broken down 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. Impervious clothing is used to protect workers against contact of liquid nickel carbonyl with skin.

Preventive 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. Stormwaters 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, 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 buildup 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 discharge to a municipal sewer.

Modern plants using good industrial practices are able to achieve the pollutant loads described below: 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%).

Emission Guidelines

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

The following guidelines present emissions levels normally acceptable to the World Bank

Group in making decisions regarding provision of World Bank Group assistance. Any deviations from these levels must be described in the World Bank Group project documentation. The emissions levels given here can be consistently achieved by well-designed, well-operated, and well-maintained pollution control systems.

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

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

Air Emissions

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

Liquid Effluents

The effluent emissions levels presented in Table 2 should be achieved.

Table 1. Air Emissions from Nickel Smelting

(milligrams per normal cubic meter, unless otherwise specified)

Parameter	Maximum value
PM	20
Nickel	1
Sulfur dioxide	2 kg/t sulfuric acid

Table 2. Effluents from Nickel Smelting

(milligrams per liter, except for pH)

Parameter	Maximum value
pH	6–9
TSS	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 levels given below or a maximum increase in background levels of 3 decibels (measured on the A scale) [dB(A)]. Measurements are to be taken at noise receptors located outside the project property boundary.

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

Key Issues

The key production and control practices that will lead to compliance with emission requirements can be summarized as follows:

- 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 sulfur dioxide as possible by producing sulfuric acid, liquid sulfur dioxide, or other sulfur products.
- Reuse process waters, recirculate cooling waters, and use stormwater for the process.
- Enclose processes and conveyors to minimize fugitive emissions; cover raw material storage.

Sources

- Bounicore, Anthony J., and Wayne T. Davis, eds. 1992. *Air Pollution Engineering Manual*. New York: Van Nostrand Reinhold.
- UNEP (United Nations Environment Programme). 1993. *Environmental Management of Nickel Production. A Technical Guide*. Technical Report 15. Paris.
- World Bank. 1995. "Industrial Pollution Prevention and Abatement: Nickel Smelting and Refining." Draft Technical Background Document. Environment Department, Washington, D.C.