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OUTOTEC SMELTING SOLUTIONS FOR THE PGM INDUSTRY

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Abstract

The platinum group metals (PGMs), i.e. ruthenium, rhodium, palladium, osmium, iridium, and platinum, are typically found in association with each other, but also importantly, with nickel and copper. Typically Platinum and palladium have the greatest economic significance and other PGMs are typically produced as co-products of these. With recent increases in the value of nickel, cobalt, and the PGMs and an ever increasing focus on the sustainable use of metals, interest in the processing of secondary feed material sources and metal-bearing residues has also substantially increased.

As an efficient, proven, and environmentally sound technology Outotec Ausmelt Top Submerged Lance (TSL) Technology has gained commercial acceptance in the nickel industry, including PGM recovery.

For the processing of nickel- and PGM-bearing feed materials, five Outotec Ausmelt Furnaces at four sites are in operation. Two of these furnaces are located in Rustenburg, South Africa, which is by far the biggest mine-based producer of platinum.

Outotec also has hydrometallurgical processes available for further treatment and extraction of PGMs, which are also briefly discussed.

Introduction

The platinum group metals (PGMs) have exceptional physical and chemical properties that have made them indispensable to modern society. Platinum and palladium especially play an increasingly important role in the modern world through their application in autocatalysts, contributing to reduced emissions from motor vehicles. PGMs are also used in a variety of industrial catalyst applications, in the glass industry, and have become popular for use in jewellery.

South Africa and Zimbabwe, together account for approximately 80 per cent of the world's mined platinum production¹ as well as a significant proportion of the other PGMs. Other major PGM-producing regions are Russia, North America, and China.

While orebodies such as the Merensky and UG2 reefs are specifically targeted for their PGM content², the subsequent production process is influenced by the associated non-ferrous metals, most notably nickel and copper.

PGMs are generally associated with nickel-copper sulphides in magmatic rocks, and there are many similarities between PGM smelting and nickel sulphide smelting. Despite the heavy concentration of the platinum production, significant amounts of PGMs are also recovered as by-products during the production of copper and nickel from smelters predominantly targeting those metals.

Whether the PGMs are produced as a primary product or by-product, the extraction process typically involves a combination of pyrometallurgical and hydrometallurgical processes. Outotec has a long history as a process supplier of both pyro- and hydrometallurgical technologies that are applied commercially for the production of copper, nickel, cobalt, and PGMs. The principal focus of this paper is on the pyrometallurgical processes that are employed in the treatment of PGM-bearing concentrates and secondary feed materials.

Outotec technologies for treating sulphidic concentrates

Depending on the characteristics of the sulphidic concentrate, Outotec has a range of technologies suited to these materials, including pyro- and hydrometallurgical processes.

For the production of low- and high-grade mattes, three potential pyrometallurgical routes are available

- Outotec Direct Nickel Flash Smelting Process, which produces high-grade nickel matte directly from the concentrate
- Outotec Flash Smelting Process for nickel which produces low-grade nickel matte for converting
- Outotec Ausmelt Process for primary nickel concentrates smelting and matte converting.

All these processes produce a continuous off-gas stream with a high sulphur dioxide content to be treated at the acid plant.

High-grade nickel matte can be further processed hydrometallurgically using Outotec's atmospheric leaching process, solvent extraction, and electrowinning/reduction. These processes are discussed as well.

Outotec Flash Smelting Process

The Outotec Direct Nickel Flash Smelting Process was first implemented at Harjavalta Smelter in Finland. Simultaneously with the adoption of the new process, the nickel production was doubled. The entire target of the project was to improve the profitability, cut sulphur dioxide emissions, improve the working conditions in the plant, and increase the raw material flexibility.

In the same context, the nickel refinery was also thoroughly renovated. The project was completed in 1995 with all these requirements fulfilled. The second application was at Fortaleza de Minas Smelter in Brazil, which started operation in 1998. The flow sheet of the process is presented in Figure 1.

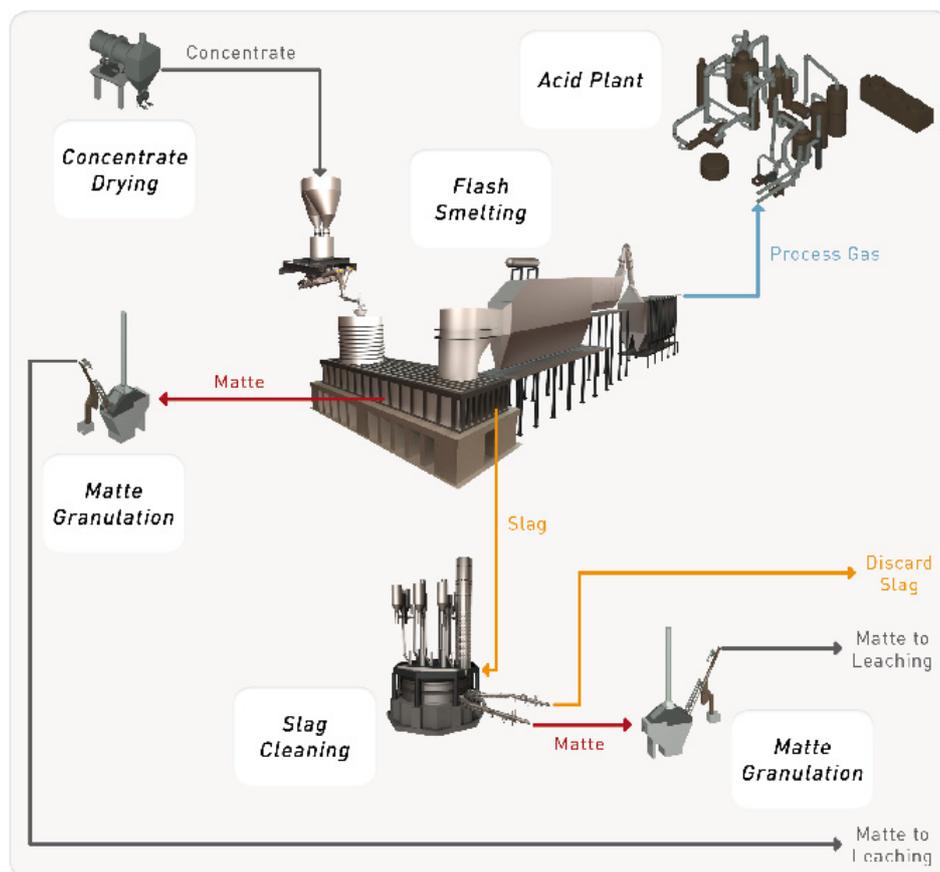


Figure 1-Flow diagram of the Direct Outotec Nickel Flash Smelting Process

The concentrate and flux are dried (typically by utilizing the steam produced by the process itself) before feeding to the flash smelting furnace. This energy is saved in the furnace operations and also results in smaller off-gas streams. The concentrate is then fed into a flash smelting furnace (FSF), where it is smelted and oxidized to produce high-grade matte, slag, and sulphur dioxide (SO₂)-containing off-gas. The process air is oxygen-enriched, in and thus no additional fuel is needed in the reaction shaft. Matte is periodically tapped from the furnace and granulated. Granulated matte is further refined by hydrometallurgical methods to recover copper, nickel, cobalt, and PGMs.

Process gas containing SO₂ from the FSF is cooled by a waste heat boiler (WHB) and an electrostatic precipitator (ESP) before being ducted to the sulphuric acid plant. Flue dust is re-circulated to the FSF.

Because the degree of oxidation in the FSF is high, some nickel, copper, and cobalt oxidize and report to the slag phase. Therefore the FSF slag is laundered to an electric furnace (EF), where the metals are recovered from the slag by coke reduction. To adjust the liquidus temperature of EF matte (increase S-level of matte), some concentrate is injected into the EF.

The EF process produces metallized matte, which is sent to granulation directly from the furnace. EF matte is also treated by hydrometallurgical methods. The slag from the EF is granulated, and it is clean enough to be discarded.

In the Direct Outotec Nickel Flash Smelting Process, converting is not needed, thus there is no ladle transportation of molten materials, bringing considerable advantage from the environmental, economic, and workplace hygiene and safety points of view.

The traditional Outotec Flash Smelting Process is used in Norilsk Nickel operations for nickel concentrate processing. Norilsk is the world's largest producer of nickel and palladium, and also a substantial producer of platinum.

Outotec Ausmelt Process

The Outotec Ausmelt Process employs a lance to inject fuel and oxygen-enriched air into the furnace bath. This causes intense mixing, promoting rapid reaction within the bath. The process is suited to a wide range of non-ferrous metals and waste materials, and is also in wide commercial use (over 60 references). Furnace designs will be specifically tailored to suit an individual application of processing capacity, tapping regimes, and off-gas configurations. Figure 2 shows a typical configuration of an Outotec Ausmelt Furnace.

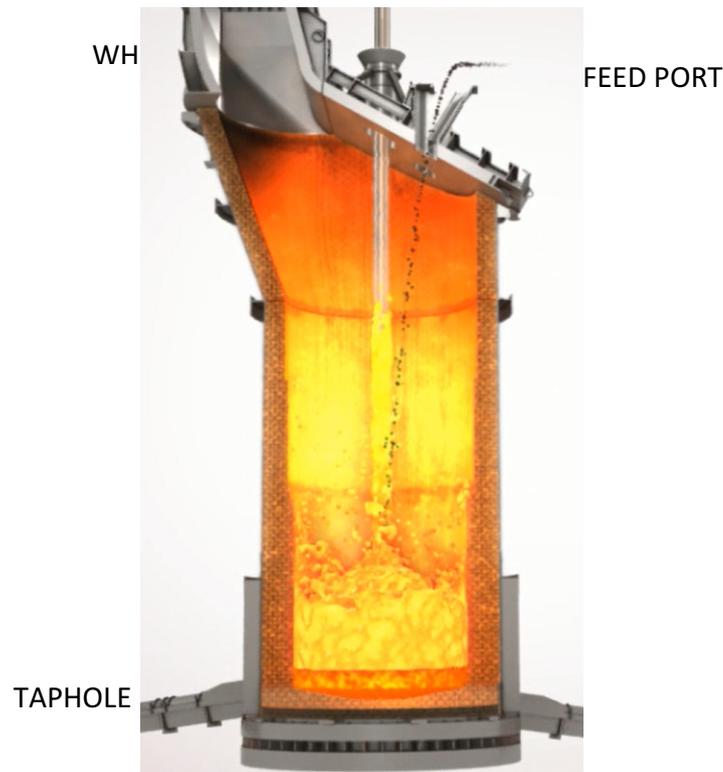


Figure 2-Schematic of a typical Outotec Ausmelt furnace

The application of the Outotec Ausmelt Process in the nickel industry has gained increased commercial acceptance for smelting of nickel sulphide concentrate, matte converting, and residues treatment (Table I).

The Outotec JAE Ni Smelting Process³ developed with Jinchuan Nickel and ENFI is used at the Jinchuan Nickel Smelter to process over 1.1 Mt/a of nickel sulphide feeds. The process is also used at Jilin Nickel in China to process 245 kt/a of nickel sulphide feeds.

The Outotec Ausmelt Nickel Converting Process is used for the converting of low-grade matte into high-grade matte and is used in the Anglo Platinum Converting Process (ACP) in Rustenburg, South Africa.

The variation in nickel sulphide concentrate properties presents challenges in the smelting of these materials. One of the main strengths of the Outotec Ausmelt Process is its flexibility to control the heat balance by the use of supplementary fuel and oxygen enrichment. This feature also makes the process very flexible regarding the feed material moisture content.

Table I-Outotec Ausmelt smelting and converting operations for Ni-containing materials

Client	Location	Year	Feed	Design	Product
Jilin	China	2009	Concentrate	275,000	LG Matte
Jinchuan	China	2008	Concentrate	1,100,000	LG Matte
Anglo Platinum	South Africa	2002	EF Matte	213,000	HG Matte
Bindura Nickel	Zimbabwe	1995	Residues	10,000	Blister Cu
RTZ	Zimbabwe	1992	Residues	7,700	HG Matte

The exothermic oxidation of FeS reduces the energy input requirements for the nickel sulphide smelting processes. The use of a waste heat boiler to cool the furnace off-gas allows the recovery of energy in the form of steam, which can be converted into electrical energy via the use of a steam turbine and generator system. The design of the Outotec Ausmelt Furnace can allow the waste heat boiler to extend down such that the upper section of the furnace is comprised of the waste heat boiler. This allows the recovery of energy to be maximized.

The well-sealed nature of the Outotec Ausmelt Furnace is well suited to deal with ever-tightening environmental regulations, minimizing fugitive emissions of SO₂ or fume to the atmosphere. The off-gas from nickel sulphide smelting is high in SO₂ and suitable for processing in an acid plant.

Outotec Ausmelt Process in PGM-bearing materials production

As in any extraction process, recovery of the metals is crucial. Fortunately there is little tendency for the PGMs to form species that can dissolve in the slag phases present during the various stages of the matte smelting of nickel. The PGMs therefore follow nickel into the matte phase during smelting and conversion procedures, and total recovery of PGMs exceeds 99 per cent. During matte separation by controlled cooling and solidification, gold and the PGMs are almost entirely concentrated in the 'metallics' fraction. Following nickel removal by either electrolysis, carbonylation, or leaching, a PGM concentrate comprising either the anode slimes, carbonylation residue, or leach residue is produced for treatment in a precious metal refinery⁴.

Flow sheet and chemistry

A general flow sheet incorporating an Ausmelt furnace to smelt and convert nickel sulphide concentrate is shown in Figure 3.

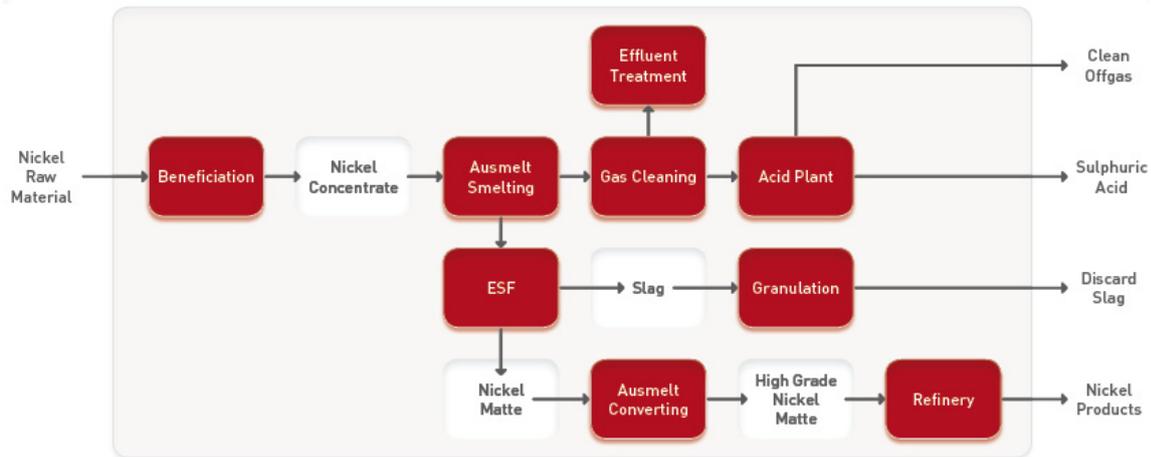
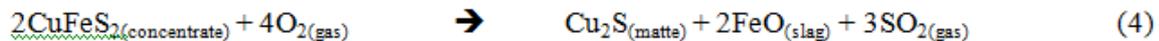
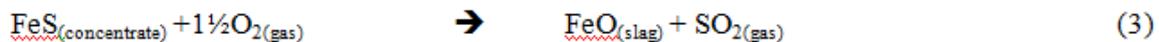
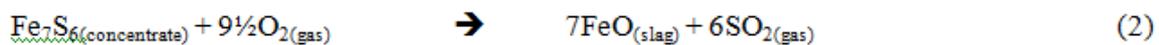
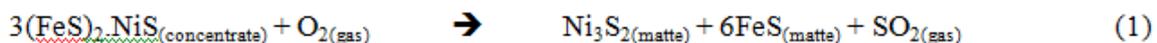


Figure 3-Outotec Ausmelt Process for nickel/PGM smelting

During smelting, nickel sulphide concentrates are fed into the Ausmelt Smelting furnace along with dusts recycled from the Ausmelt furnace and downstream furnaces to maximize recovery of nickel. Fuel and enriched air are injected through the lance into the bath to maintain the bath at the target temperature, to react the nickel sulphide with oxygen to form a matte rich in Ni_3S_2 , a discard slag, and an off-gas rich in SO_2 (Equations 1 to 4). The gas injected through the lance into the bath also provides agitation to the bath, promoting rapid reaction⁵.



Fluxes are added with the feed to achieve the desired slag chemistry, the choice of which will be optimized for the specific chemical composition of the feed. An $\text{MgO-SiO}_2\text{-FeO}$ phase diagram constructed using Factsage is presented in Figure 4. The target region has been highlighted.

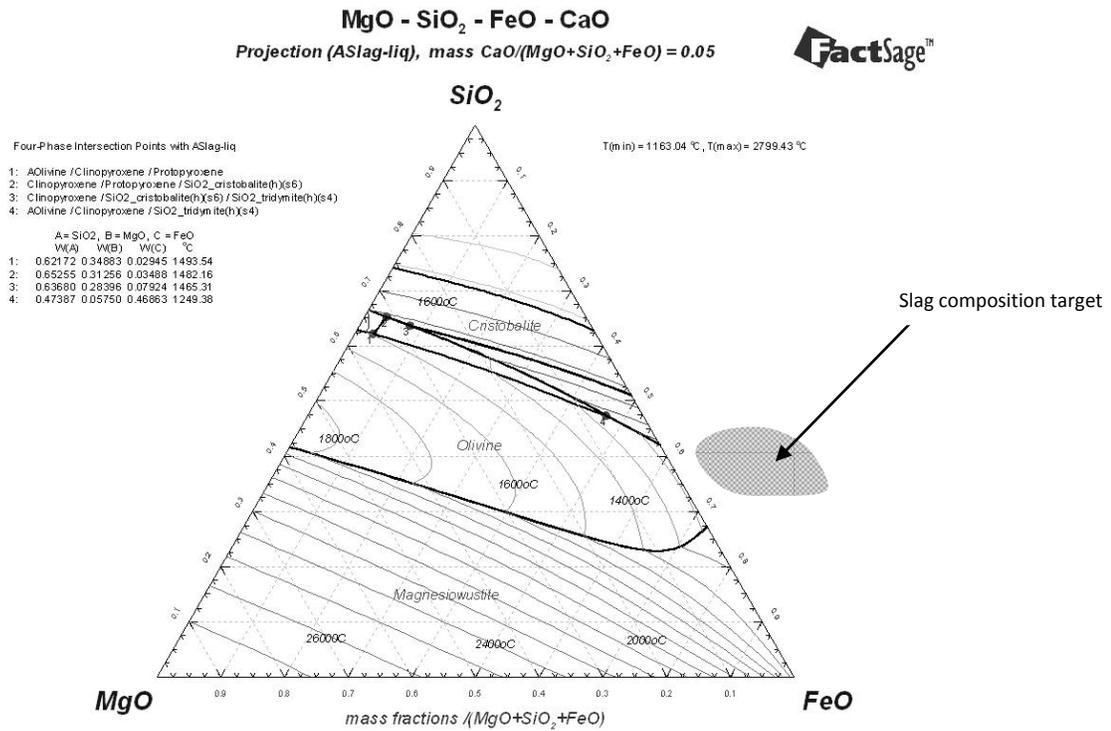


Figure 4-Nickel smelting slag target chemistry

The smelt slag target chemistry will be located in the shaded region. The exact location of the target chemistry will depend on feed composition. It can be seen that as the MgO content increases, so too does the liquidus temperature and hence the required operating temperature. These high temperatures can be easily achieved by the Ausmelt Process, as the energy input to the furnace can be controlled efficiently via the lance.

Converting of Cu/Ni/PGM matte

Low-grade nickel matte has been traditionally treated in Peirce–Smith (PS) converters to produce a high-grade matte (or so-called Bessemer matte that is low in iron), which can be further hydrometallurgically refined into nickel metal, as described later.

However, there are a number of well-known operating difficulties inherent in PS converters. PS converters operate in a batch-wise manner; consequently the off-gas from these converters varies in composition and volumetric flow rate, increasing the difficulty of off-gas treatment. The converters are poorly sealed, leading to fugitive SO₂ and fume emissions causing hygiene and environmental issues.

PS converters are limited in their ability to control temperature. Hot matte transfer is a requirement for the converters and they are limited in their ability to process cold revert material. Problems also relate to blockage of tuyeres, short refractory life, and poor control of the end-point for the converter blow.

An attractive alternative to PS converting is to perform the matte converting in an Ausmelt furnace. This is done commercially at Anglo Platinum's Rustenburg site in South Africa, where an Ausmelt furnace is used to convert a Ni/Cu/PGM electric furnace matte⁶. Converting of a range of other nickel mattes has also been successfully carried out on a pilot plant scale⁷.

For the converting of nickel matte, the nickel matte is fed to the furnace together with flux to achieve the targeted slag chemistry. Dust from the converter is recycled back as a feed to either the smelter or converter to maximize nickel recovery.

Oxygen-enriched air and fuel are injected into the converter bath via the Ausmelt lance. This serves to control the temperature of the matte and reduce the iron levels in the matte by oxidizing the FeS, as shown in Equation 5. Oxidation of the bath will also lead to magnetite formation in the slag and oxidation of the Ni₃S₂ from the matte to NiO, which reports to the slag (Equations 6 and 7). The iron level in the final matte may be customized to suit downstream requirements. A downstream requirement for low iron in matte must be balanced against nickel losses to the slag, for the lower the iron level achieved in the final matte, the higher the resulting nickel level will be in the discard slag.



Nickel matte may be converted continuously in an Ausmelt furnace, which yields many benefits:

- Improved control of bath chemistry and temperature
- Off-gas composition and flow rate is steady
- Continuous operation allows an increased furnace throughput to be achieved
- Continuous operation enables easier plant operation and coordination generally.

A single Ausmelt furnace may be capable of treating the same tonnage of matte as a series of PS converters.

Anglo Platinum Waterval smelter operations

Anglo Platinum Limited utilizes the Outotec Ausmelt Ni Converting Process at their Waterval Smelter operations in Rustenburg, South Africa, which has been previously described in detail by Jacobs⁶ and is summarized below. The smelter objective is to process wet concentrate to produce crushed, slow-cooled, sulphur-deficient nickel-copper matte rich in PGMs, gold, and base metals for dispatching to the magnetic concentration plant at the Base Metals Refinery.

Wet concentrate is fed through a flash drying process utilizing coal-fired, fluidized-bed hot-gas generators to produce dry feed material for the electric furnaces and slag-cleaning furnace. For primary smelting at the Waterval smelter, two electric furnaces are used, each with a rated capacity of 34 MW.

Furnace matte, containing the bulk of the base metal sulphides and PGMs, is tapped periodically into refractory-lined ladles and granulated using high-pressure water jets, then dried through electrically powered pneumo-driers to become the main feed to the Anglo Platinum Converting Process (ACP) for removal of excess iron sulphides. Slag is tapped semi-continuously, granulated, and treated through the slag mill to recover entrained matte containing valuable PGMs and base metal sulphides.

The ACP treats the combined matte output of the Waterval, Polokwane, and Mortimer smelters. Matte is fed continuously through the lance, which is submerged in the slag layer. Air and oxygen are also injected into the slag via the lance, where they react with the furnace matte at high temperature. The bath temperature in the converter is controlled at 1300°C, with most of the energy supplied by the reactions. Additional energy can be supplied by burning coal, which is added via the lance or a feed port in the roof. Oxidation of iron sulphide converts the matte from 40 per cent Fe to approximately 3.5 per cent Fe. Silica flux is injected through the lance to encourage the formation of a fayalitic slag.

Converter matte is tapped in batches into matte ladles and slow-cooled, which allows enough time to elapse in the critical temperature ranges for fractional crystallization to take place. During the process, metal alloy crystallizes out as a distinct phase, forming magnetic platelets that contain the bulk of the PGMs, ready for dispatch to refineries. Slag is granulated and dried for recycling to the slag-cleaning furnace. A flow sheet of operations is shown in Figure 6.

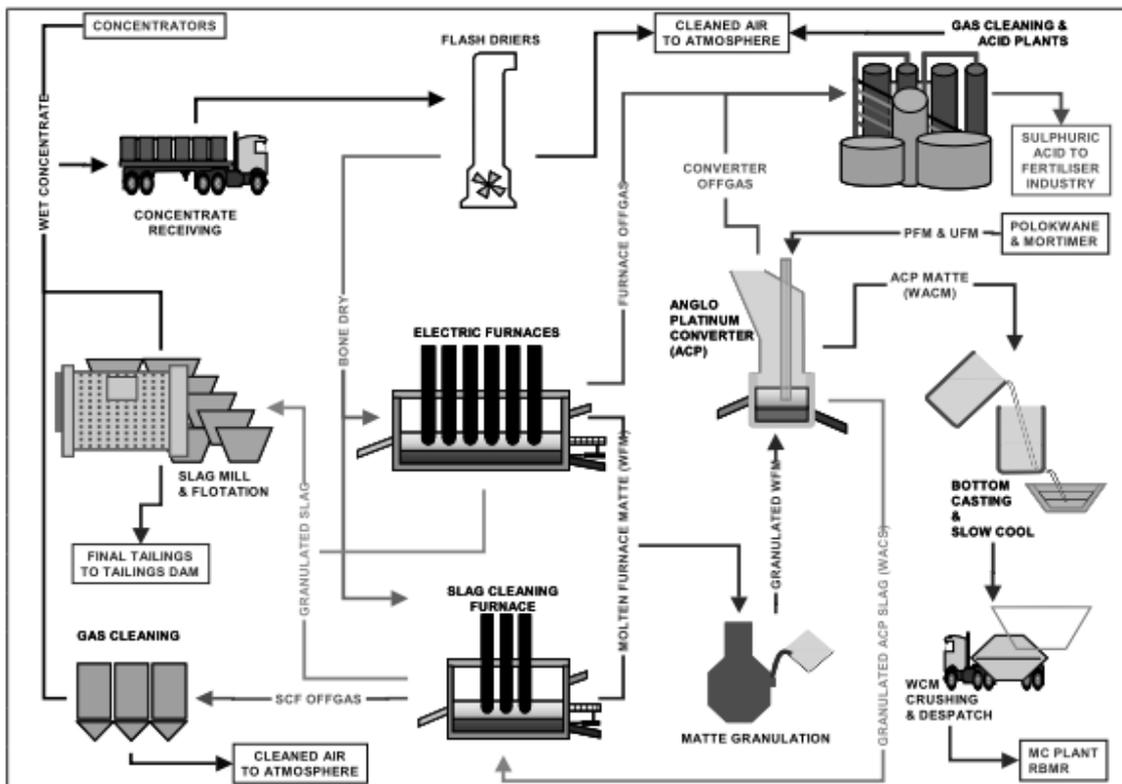


Figure 5-Anglo Platinum Waterval smelter flow sheet showing the ACP (Jacobs⁶)

Furnace and converter off-gas are treated through the tower and contact acid plants for production of sulphuric acid, which is further used by the fertilizer industry.

Outotec high-grade nickel matte refining process

Outotec has a strong reference list and experience in engineering and delivering the high-grade nickel matte leaching processes. These processes have been delivered, for example, to the southern Africa region, South America, and Finland.

The main objective of the traditional high-grade matte refining process is to leach nickel in a sulphate environment and to recover nickel in a metallic phase using hydrogen reduction or electrowinning. Typically present are cobalt and copper, which can also be recovered in metallic, precipitate, or chemical form. The process is presented in a block diagram in Figure 6.

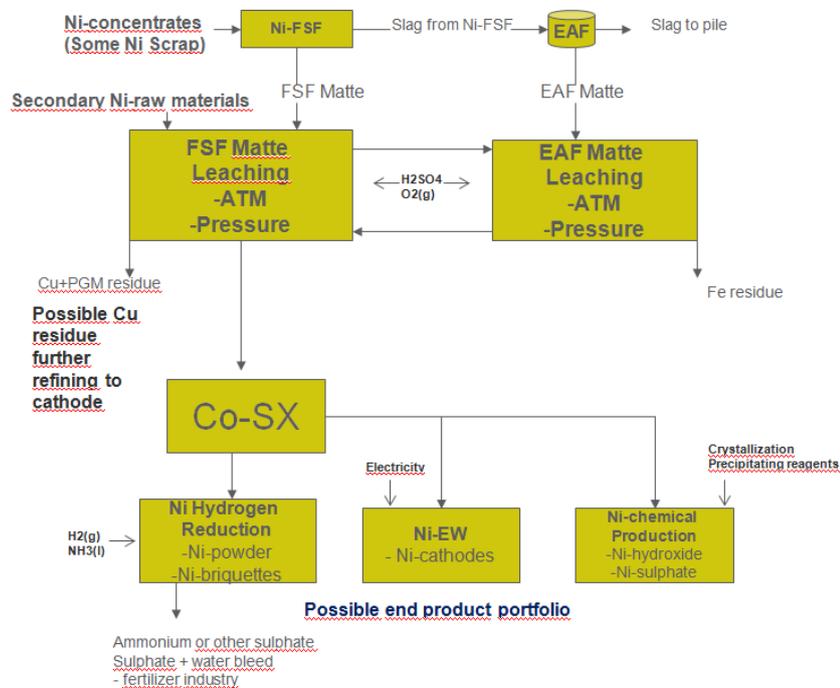


Figure 6-High-grade matte leaching and refining process

The leaching takes place in two leaching lines - one line for leaching of matte from the FSF matte and another line for leaching of matte from the EF matte. Excess copper is precipitated in the FSF matte-leaching circuit. This precipitate (CuS, Cu_{1.8}S) can then be totally leached in autoclave and the copper removed from the solution by electrowinning. The PGMs from the total leaching of copper precipitate report to the leach residue. The other possibility is to sell or recycle the (CuS, Cu_{1.8}S) residue to a copper smelter.

In the first stage of atmospheric leaching of FSF matte, part of the nickel is leached while copper is cemented. The rest of the nickel is leached selectively in the second atmospheric stage and nickel pressure leach.

EF matte is leached first in an atmospheric stage and then in a pressure leach stage. Iron is simultaneously leached and precipitated as a haematite/goethite mixture. The iron-containing filter cake from the EF matte leach is dumped to a pond or can also be recirculated to the smelter, if needed.

Cobalt/nickel separation is done by solvent extraction. The extractant is diluted with kerosene. Cobalt can be separately recovered from the cobalt solution by hydrogen reduction.

After the cobalt removal, the $\text{NiSO}_{4(\text{aq})}$ solution can be diverted to the selected end product line. Metallic nickel can be produced using either Ni electrowinning (the product is Ni cathodes) or hydrogen reduction. The product of hydrogen reduction line is nickel briquettes. The hydrogen reduction process is the Outotec Low Temperature and Pressure process (LTP), which produces 99 per cent pure nickel metal. This product is used as a raw material in the stainless steel industry. The reduction is continuous and is typically operated at 7.5 bar pressure and a temperature of 130°C, giving feasible process conditions compared to those of the conventional hydrogen reduction process and electrowinning.

Ammonia is used as neutralizing agent, and an equivalent amount of ammonium sulphate is crystallized. Ammonium sulphate is the outlet for the sulphur introduced to the process. The outlet for bleed water is also from the crystallization process area.

Modified sulphate-based high-grade nickel matte refining

Nowadays, when designing a greenfield plant and process for high-grade nickel matte refining, it has become more popular to use a slightly simplified flowsheet compared to that shown in Figure 6. This modified Outotec process with combined input feed is presented in Figure 7.

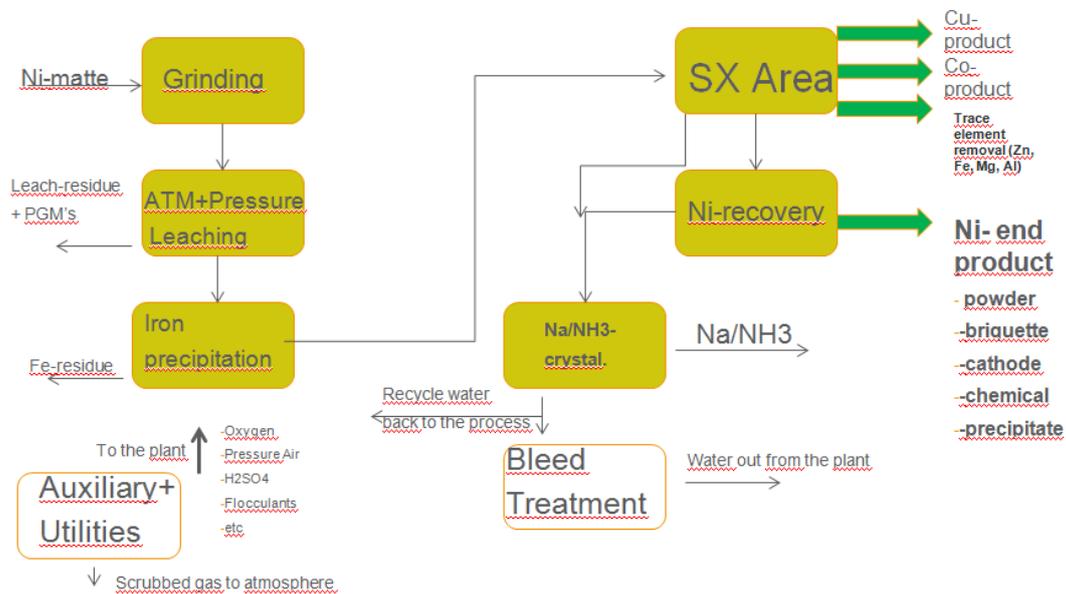


Figure 7-Modified Outotec high-grade nickel matte leaching and refining process

The main differences compared with the traditional Outotec high-grade nickel matte refining process are that both the FSF and EF mattes are fed to the same short atmospheric leaching chain, which is then followed by total leaching in an autoclave. The other difference is that all precious metals besides nickel (Cu, Co) are removed by solvent extraction. Outotec has recently made a lot of progress in designing and delivering cost-efficient solvent extraction technology for feasible recovery of even small amounts of metal. One advantage of this flow sheet is that it is very straight forward compared to the traditional flow sheet. There is less need for solid/liquid separation and settling phases, which reduces the investment cost. The removal of copper and cobalt from the pregnant leach solution by solvent extraction improves the recovery compared to the previous flow sheet, where, for example, copper was precipitated. In copper precipitation there is almost invariably also a little side-precipitation of nickel, leading to lower nickel recovery.

Outotec Nickel Chloride Leaching Process (ONCL) for high-grade nickel matte

Outotec has done extensive R&D work and pilot testing over the years in the area of chloride hydrometallurgy. This process development is ongoing continually, to secure the commercially viable high-grade nickel matte refining process. This patented process is called the Outotec Nickel Chloride Leaching Process. The main features of Outotec Chloride Leaching are inherited from Outotec HydroCopper® technology.

A few of the main benefits of chloride-based leaching are listed below:

- Shorter retention time in leaching than in sulphate-based process, resulting in a decreased amount of equipment and lower investment cost compared to the sulphate process
- Leaching kinetics allow all the reactions to take place at atmospheric pressure. Eliminating the need for pressure leaching in autoclaves results in decreased investment cost, together with easier process operation and maintenance of equipment
- Chloride leaching can be selective for impurities such as SiO₂, Mg, Al, and Mn, which do not dissolve to the same extent as in the sulphate-based process. This reduces the reagent consumption and the scale of the impurity removal phases, thus reducing investment cost and operating cost compared to the sulphate-based process
- Process chemicals can be regenerated to a great extent, decreasing chemical consumption and operating costs
- The process is very flexible process and can accommodate very different raw material feeds.

The block diagram of the process is presented in Figure 8.

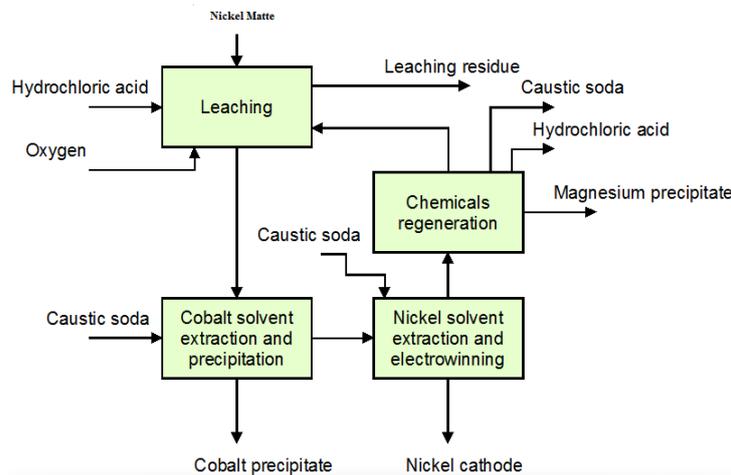


Figure 8-Outotec Nickel Chloride Leaching Process

The leaching is carried out in a two-stage leaching process. The first stage is non-oxidative and the second comprises oxidative leaching. The reactions are based on the dissolution of nickel-containing sulphides to dissolve by CuCl₂. Leaching is done in agitated atmospheric leaching reactors, at temperatures of 80-95°C. Retention time with matte is normally 6-9 hours. The recoveries of Ni and Co are usually >98 per cent.

Cobalt removal is carried out by solvent extraction. The pH adjusting chemical is caustic soda (NaOH). Cobalt metal can then be precipitated or refined. Nickel is also removed from the main stream with solvent extraction, and it is then refined by electrowinning, to produce LME-grade nickel cathodes.

In the chemicals regeneration step, magnesium is removed by NaOH precipitation and brine is purified with chlor-alkali electrolysis before being recycled back to the process.

Secondary processing for high-PGM bearing materials

PGMs and precious metals are commonly associated with secondary nickel- and copper-bearing materials, and in many cases the efficient recovery of the contained PGMs and precious metals is usually critical to the economics of the overall process. Processing of these secondary feed materials can be challenging due to the presence of species such as alumina and a range of problematic minor elements. Secondary materials that are commonly associated with high levels of PGMs include nickel plant residues and secondary materials such as spent catalysts. The Outotec Ausmelt Process is ideally suited for treating these materials due to its ability to operate over a wide range of process conditions.

Secondary nickel- and PGM-bearing materials may be smelted with nickel/copper sulphide concentrates to produce a matte product that acts as a collector phase to recover the PGMs. This matte product would be typically further upgraded in a converting process before being refined to recover nickel and PGMs. Alternatively, a specifically customized process can be employed, as has been the cases where the Outotec Ausmelt Process has been applied at the Eiffel Flats⁸ and Bindura⁹ smelters in Zimbabwe.

Conclusions

Based on extensive R&D over the years on a range of different materials, including a variety of base metal mattes and secondary feeds, Outotec continues to advance the application and commercial implementation of its technologies.

This work has led to industry-leading developments in commercial-scale smelting, converting, and refining such as:

- Nickel smelting at large scales (>1 Mt/a) accepting feeds with high MgO content (as at JNMC, China)
- Nickel converting for the continuous production of high-grade matte, which has been in operation now for almost a decade (as at the Anglo Platinum ACP in South Africa)
- The Outotec® Ausmelt C3 (Continuous Copper Converting) Process, which has been trialed commercially and a plant is currently in start-up phase (as at YTCL's new copper facility in China)
- The Outotec Direct Nickel Flash Smelting Process with improved feed systems, including Outotec feeding system, air slide, and concentrate burner
- New monitoring systems for process performance with the Sentinel and Process Advisor
- Simplified leaching processes for high-Ni matte treatment
- Development of chloride-based hydrometallurgy (ONCL).

Outotec's technologies cover a range of processes used widely in primary and secondary PGM production, and Outotec continues developing these technologies as means to support producers in achieving their demanding economic, environmental, and safety targets.

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