PILOT PLANT PRODUCTION OF FERRONICKEL FROM NICKEL OXIDE ORES AND DUSTS IN A DC ARC FURNACE

I.J Kotzé (Pyrometallurgy Division, Mintek, South Africa)
E-mail for correspondence: isabelk@mintek.co.za

Abstract

Laterites and other oxidized nickel ores constitute a very important part of world-wide nickel reserves. The development of nickel oxide ore smelting has drawn heavily on iron and steel metallurgy. In ferronickel production, the nickel oxide and part of the iron oxide are reduced to metal in an electric furnace to form immiscible layers of slag and metal. The crude ferronickel is tapped from the furnace and refined to saleable ferronickel by conventional techniques.

Because of the high moisture content (free and chemically bound water) and because water requires so much energy to evaporate and heat up, it is clear that dehydration is required before smelting the ore in an electric furnace. Due to the physical properties of the ores, a large fraction of fines is generated during the pre-treatment stages. In the conventional production of ferronickel from these ores, much fine material is produced which cannot readily be accommodated directly in existing three-electrode or six-in-line AC furnaces. DC-arc furnace technology allows ore particles less than 1 mm in size to be treated directly thereby improving the overall recovery of nickel without the need for expensive agglomeration techniques.
Keywords: Pyrometallurgy, Reduction, Oxide ores,

Introduction

Nickel laterites and other nickel oxide ores constitute a very important part of world reserves of nickel. Oxidic ores of nickel are primarily a product of a chemical concentration process that occurs as a result of lateritic weathering of magnesium iron silicate rock. The type of weathering which dissolves silica and metallic elements from rock to produce limonitic and silicate nickel ores, occurs most frequently in tropical climates with high rainfall and where decomposing vegetation provide organic acids and carbon dioxide in the groundwater.

Nickel laterite ores have high moisture contents (typically up to 40%) as well as chemically bonded water in the hydroxide form. Dehydration as a minimum, and some pre-reduction of the ore in a rotary kiln is used to optimize the utilization of electric energy for smelting operations in the conventional submerged-arc furnace process. During the dehydration of the ore, a large fraction of fines is generated. Dust generated during the pretreatment phases (screening, drying and calcining) is unsuitable for smelting in a conventional electric-arc furnace. Utilizing the fines generated involves agglomeration of the dust at considerable expense to the process economics. Dusty materials can be treated directly in a direct-current (DC) arc furnace, without the adverse process problems associated with feeding dust to conventional electric-arc furnaces. Processing lateritic ores using the DC arc furnace process resolves the dust issues, thereby improving the overall recovery of nickel without the need for expensive agglomeration techniques.

The chemical and metallurgical diversity of laterite deposits adds to the difficulty of processing the material. Conventional electric-furnace smelting usually operates with a covered or partially covered bath and operation of the furnace is generally limited by the SiO_2/MgO ratio or iron content. Operation in the conventional electric furnace generally requires a SiO_2/MgO ratio not greater than 2 and an iron content of not more than 20% to limit slag foaming and operational instability leading to decreased power and production levels.

DC-arc ferronickel process development

Mintek has been working on the production of unrefined ferronickel from nickel-containing lateritic ores and dust in DC-arc furnaces since 1993. The development and various advantages of the DC-arc furnace technology developed at Mintek has previously been described in detail (Jones *et al*, 1993 and Lagendijk *et al*, 1994). In essence, nickel-containing lateritic material, together with a carbonaceous reducing agent is fed onto the uncovered molten bath of a typical DC-arc furnace. The feed material is preferably pre-treated i.e. dehydrated (drying and calcining) with optional pre-reduction options effecting the optimisation of electrical energy requirements.

Small to medium scale testwork, up to a power level of 750kW has been well described previously (Lagendijk *et al*, 1997). However, since 1997, additional testwork demonstrating the flexibility of the DC-arc ferronickel process was conducted. The aim of this paper is to summarise results from the latest testwork completed at Mintek.

Furnace Configuration

The DC-arc furnace essentially consists of a cylindrical refractory-lined vessel with water-cooled sidewalls and roof. The refractory lined roof locates the electrode via a single entry port with a dust seal. The electrode is connected to the cathode via a water-cooled clamp connection. The electrode and clamp forms part of a moveable electrode arm. The mechanical arm is electrically isolated from the cathode connection (electrode and clamp) and is used to control the current and voltage ratio by adjusting the arc length i.e. moving the arm up or down.

The single graphite electrode (cathode) is positioned above the molten bath, and a multiple-pin anode located in the hearth essentially completes the circuit. The plasma arc forms a conducting path between the graphite cathode and the molten bath. The standard multiple-pin anode design utilised for testwork at Mintek, comprises of multiple steel rods embedded into the hearth refractories. The rods are connected to a steel plate installed in the hearth in contact with the molten bath by means of the pins. The steel plate is connected to the anode bus bars, via radially extended arms to complete the electrical circuit.

The furnace is fed through feed ports located in the roof. The feed materials, pre-treated ore and reductant, are fed to the furnace using standard weigh feeder technology and control strategies. Energy and feed ratios are controlled to adhere to specific target temperature for slag and alloy and operational parameters.

The gas-cleaning system consists of a water-cooled off-gas pipe, a refractory-lined combustion chamber, water-cooled ducting, a forced-draft gas cooler, a reverse-pulse bag filter, a fan, and a stack. In general approximately 1 to 3% dust and fines could be carried over through the off-gas system depending on the configuration of feed and extraction system. Any dust and fume accumulates in the lower conical section of the bag plant, and is collected and weighed to estimate the dust carry-over. The dust would be recycled back to the furnace in an industrial application.

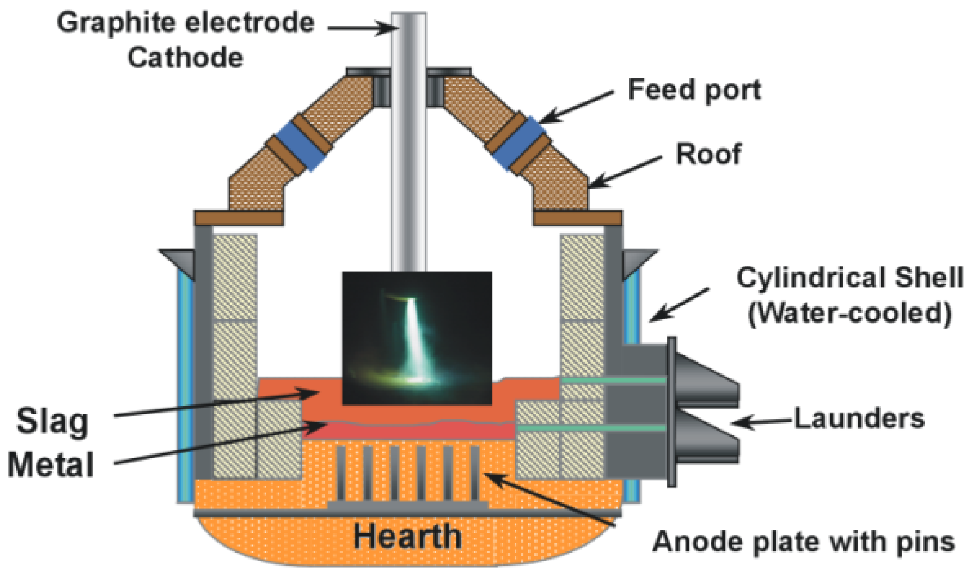

Figure 1: General Testwork DC Arc Furnace Layout

Furnace operation

Operating conditions for each test campaign were designed to evaluate the specific feed material with a view to future commercial applications of the DC-arc ferronickel process.

The following parameters were evaluated to compare the different test results:

- Furnace size (OD) and maximum power (kW)
- SiO_2/MgO ratio of calcined feed material, overall average analyses of test material
- Average slag temperatures as measured with optical pyrometers
- Nickel losses to slag (assuming that dust losses will be recycled to furnace)
- Alloy grade (average alloy grade produced), % nickel in crude ferronickel
- Feedrate, energy requirement, carbon addition, average operating voltage

The flexible operation of a DC-arc furnace (specifically, the lower dependence on electrical properties of the slag, because of open-arc operation, and the ability to run at an optimum slag temperature, due to the open-bath mode of operation) allowed for the successful treatment of ores with varying SiO_2/MgO ratios and nickel and iron content. A frozen lining can be maintained between the molten bath and the refractory lining, in order to assist with vessel integrity. Results of furnace testwork at power levels up to 2MW are presented.

Experimental results

Results for the following testwork campaigns were used. For the larger scale testwork more than one condition of operation was identified as separate test conditions (data samples) in the overall comparison. All feed materials were pre-treated (dehydrated) and the degree of calcination indicated as residual or post-calcination loss on ignition (% LOI).

- Test campaign 1: 1m diameter furnace (total calcine processed = 3.3t)
- Test campaign 2: 2.5m diameter furnace (total calcine processed = 120t)
- Test campaign 3: 2.5m diameter furnace (total calcine processed =183t)

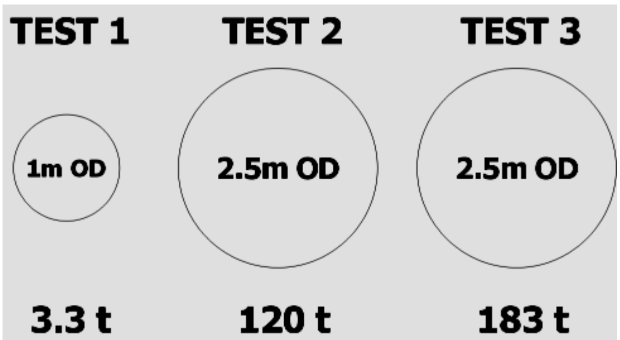

Figure 2: Relative Furnace Dimension and Feed Material Processed in the Tests

Table 1 and Table 2 show the average operating conditions and general feed material properties for the test campaigns.

The feed materials, reductant and calcine, were passed through one or more feed ports in the respective furnace roofs, into the reaction zone. Liquid products, slag and alloy, were tapped intermittently from the furnace, and, in general, nickel extraction from slag exceeded 95%.

Table 1: Test data from Test 1 and Test 2

		TEST 1 Overall	TEST 2 Overall	TEST 2 Period 1	TEST 2 Period 2	TEST 2 Period 3
Furnace OD	m	1 m	2.5 m	2.5 m	2.5 m	2.5 m
Total Calcine Fed	t	3.3 t	120 t	2.2 t	16 t	24 t
Slag tapped	t	2.3 t	100 t	-	-	-
Pre-treatment		Calcined *LOI 2%* 40% -1mm 99% -10mm	Calcined *LOI 8%* 50% -1mm 99% -10mm	Calcined *LOI <0.5%* 50% -1mm 90% -10mm	Calcined *LOI 8%* 50% -1mm 90% -10mm	Calcined *LOI 8%* 50% -1mm 90% -10mm
Nickel oxide ore						
SiO_2/MgO		1.27	1.55	1.55	1.55	1.55
Avg. nickel in feed	%	1.79	2.36	2.36	2.36	2.36
Avg. iron in feed	%	11.3	13.0	13.0	13.0	13.0
Reductant type		*Coal*	*Coal*	*Coal*	*Coal*	*Coal*
Fixed carbon	%	57	57	57	57	57
Volatile	%	26	26	26	26	26
Ash	%	15	15	15	15	15
Moisture	%	2	2	2	2	2
Furnace Operation						
Avg. slag temperature	°C	1700	1680	1680	1660	1660
Avg. nickel grade	%	25	33	32	32	32
Avg. nickel to slag*	%	0.07	0.19	0.09	0.15	0.14
Ni extraction from slag†	%	98	95	97	95	95
Average feedrate‡		120 kg/h	-	1.0 t/h	1.0 t/h	1.0 t/h
Reductant addition§		60 kg/t	50 kg/t	50 kg/t	60 kg/t	54 kg/t
Avg. feed intensity		280 $kg/h.m^2$	340 $kg/h.m^2$	340 $kg/h.m^2$	320 $kg/h.m^2$	320 $kg/h.m^2$
Operating power	kW	175	1000	1000	1300	1300
Average voltage	V	110	300	300	300	300
Specific energy**		795 kWh/t	-	750 kWh/t	970 kWh/t	910 kWh/t

Test 1:
As part of an economic feasibility study, 3.3 metric tons of calcined lateritic ore was fed to a 1m OD DC-arc furnace. A high fraction of the ore body, when treated consisted of a fine, dusty material. The objective of the smelting campaign was to illustrate the ferronickel from laterite process via the DC-arc furnace for the specific ore and achieve an average ferronickel alloy grade of 25% nickel.

The calcined ore was processed in a DC-arc furnace, without operational problems, over a period of 32 hours. The overall nickel recovery to the alloy was 98% and the residual nickel in the slag was less than 0.07 percent by mass.

Test 2:
The testwork was completed over a period of 7 days. Approximately 120 metric tons of calcine (rotary kiln product and dust) was processed together with 5.7 tons of South African bituminous coal. The

* Residual nickel in discard slag, nickel losses
† Recovery of Ni or extraction from slag [mass of Ni in feed –mass of Ni in slag]/[mass of Ni in feed]
‡ Target calcine feedrate to furnace
§ kg reductant per ton calcine, reductant addition to furnace
** Specific energy requirement for smelting, kWh per ton calcine

testwork was conducted to demonstrate operational stability for the specific feed material and extract scale-up parameters required for commercial applications. The overall average residual nickel in slag and average nickel recovery for the test campaign was 0.19 percent nickel and 93.4%, respectively. Pre-treatment included calcining the ore off-site in a rotary kiln. The material was not completely calcined; approximately 8% residual water (based on Loss on Ignition values or LOI=8%) remained. A batch of the same feed material, approximately 2.5 metric tons, was re-calcined to LOI values of less than 0.5% and processed during the testwork in a separate condition (Table 1, Test 2, Period 1). The data collected for this period is given as a separate condition within the overall testwork. Nickel recovery for the period was 97%, compared to the overall recovery of 95%. The residual nickel in slag was less than 0.09 percent nickel, compared to the overall average of 0.19 percent nickel.

The three conditions during the test campaign are presented as separate periods of operation. The results are presented in Table 1 together with the overall results for the testwork. Operation and feed material conditions shape the operation of the furnace. Stable operation of the furnace and effective control of variables, model theoretical projections well.

Processing of the highly calcined feed (LOI of less than 0.5 percent) improved the stability of operation and recoveries significantly. During this period, the specific energy requirement for smelting was 750kWh/t calcine, which agreed well with predicted theoretical energy requirement.

Table 2: Test data from Test 3

		TEST 3 Overall	**TEST 3** Period 1	**TEST 3** Period 2	**TEST 3** Period 3
Furnace OD	M	2.5 m	2.5 m	2.5 m	2.5 m
Total calcine fed	T	182 t	12 t	49 t	18 t
S1ag tapped	T	149 t	9 t	41 t	16 t
Pre-treatment		Calcined LOI 1.6% 53%- 2mm 99%-10mm	Calcined LOI 1.6% 53%- 2mm 99%-10mm	Calcined LOI 1.6% 53%- 2mm 99%-10mm	Calcined LOI 1.6% 53%- 2mm 99%-10mm
Feed Materials					
SiO_2/MgO		1.28	1.28	1.30	1.25
Avg. nickel in feed	%	2.22	2.15	2.25	2.18
Avg. iron in feed	%	14.9	15.5	13.4	16.0
Reductant type		*Coal*	*Coal*	*Coal*	*Coal*
Fixed carbon	%	59	59	59	59
Volatile	%	24	24	24	24
Ash	%	14	14	14	14
Moisture	%	3	3	3	3
Furnace Operation					
Avg. slag temperature	°C	1690	1710	1690	1710
Avg. alloy grade	%	24	20	25	20
Avg. nickel to slag	%	0.13	0.09	0.12	0.11
Ni extraction from slag	%	95	97	96	96
Avg. feedrate		-	1.0 t/h	1.5 t/h	1.75 t/h
Reductant addition		67 kg/t	71 kg/t	67 kg/t	65 kg/t
Feedrate intensity		-	350 $kg/h.m^2$	530 $kg/h.m^2$	610 $kg/h.m^2$
Operating power	kW	-	1200	1500	1800
Average voltage	V	-	350	350	350
Specific energy		795 kWh/t	815 kWh/t	795 kWh/t	810 kWh/t

Test 3:
A 10-day demonstration-scale DC-arc furnace campaign was conducted to demonstrate production of a 25% ferronickel grade at smelting rates of 350kg/h.m^2 to 610kg /h.m^2 while achieving consistent recoveries of nickel. During the test campaign, a total of 183 metric tons of pre-treated calcine was fed to the furnace.

The average nickel content of the feed material was 2.2 % by mass. The feed material was calcined in a rotary kiln prior to the test campaign to achieve average LOI values of 1.6%. The overall nickel recovery was more than 95% with periods during the campaign as high as 97%. The average residual nickel in the slag was 0.13 percent nickel with values below 0.10 achieved for significant periods during operation. The average alloy grade produced during the campaign was 24% nickel and 75% iron, approximately 14 tons of metal was tapped. The average reductant addition, as coal, was 67 kg per ton calcine (as carbon: 39.5 kg per ton calcine).

The demonstration-campaign processed the feed materials at high smelting intensities whilst also achieving the required recovery of nickel to alloy. Graphite electrode consumption, energy flux and electrical properties of the slag were investigated for scale-up purposes.

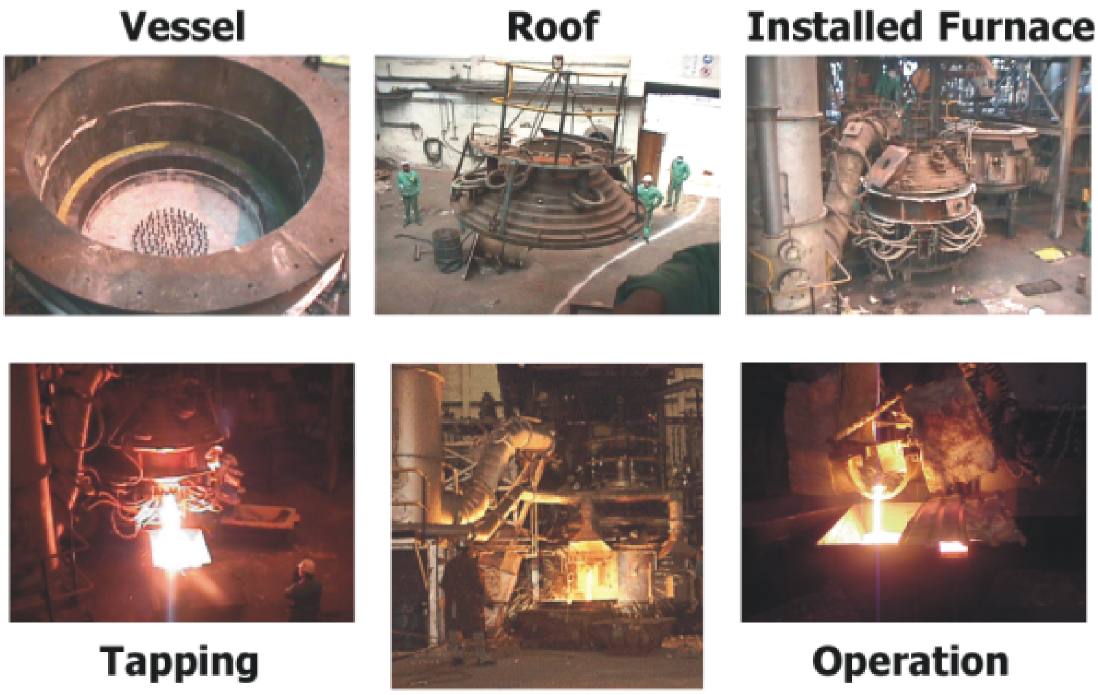

Figure 3: Photographs of Installation and Operation of Test Furnaces at Mintek's Pilot Plant

Conclusions

Mintek has been working on the production of unrefined ferronickel from nickel-containing laterite in DC-arc furnaces since 1993. In this process, lateritic material is fed, together with a carbonaceous reducing agent, to the central region of the molten bath of a cylindrical DC-arc furnace. During the late nineties larger scale tests were conducted and as during previous testwork the DC-arc furnace technology was successfully applied to the production of ferronickel from laterite ores and dusts. With the additional tests, primarily on larger scale DC furnaces the next generation of results confirmed all the previous results and highlighted previous claims of high levels of recovery, flexibility and intensity achievable in the DC furnace.

The latest pilot plant testwork at Mintek demonstrated that lateritic feed of a wide compositional range can be smelted effectively to produce a wide range of ferronickel grades while still achieving excellent extraction of nickel from slag (i.e. residual nickel in consistently less than 0.2%). Large-scale confirmed results from previous small scale testwork, and showed that feeding material at high intensities has no adverse effect on operational stability.

DC-arc furnace technology provides an alternative process option with considerable flexibility and advantages in the treatment of nickel oxide ores, without the limitations usually associated with conventional electric-furnace smelting.

Acknowledgments

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