TOWARDS COMMERCIALISATION OF MINTEK'S CONROAST PROCESS FOR PLATINUM SMELTING

R.T. Jones

Pyrometallurgy Division, Mintek
200 Malibongwe Drive, Private Bag X3015, Randburg, 2194, South Africa
(E-mail: rtjones@global.co.za)

ABSTRACT

Mintek's ConRoast process for the treatment of nickel sulfide and platinum group metal (PGM) concentrates offers a more environmentally favourable alternative to traditional matte smelting. The process involves the reductive smelting of low-sulfur concentrates (which can be obtained by fluidized-bed roasting), and the collection of precious and base metals in an iron-rich alloy. PGM smelting of difficult-to-treat concentrates can be readily accommodated with extremely high recoveries. A 3 MW DC arc furnace, designed to smelt 2 000 tons per month, has been in operation since October 2008. Plans are currently underway for a larger commercial-scale furnace.

INTRODUCTION

Commercialisation of a new smelting technology or process is not something that happens very often, and, when it happens, it doesn't happen quickly. Typically, it seems to take about fifteen years from the initial work done in a pyrometallurgical research laboratory to reach full industrial implementation.

Mintek's Pyrometallurgy Division has become well known internationally for its work on DC arc furnaces [1]. DC furnaces have been in existence for a very long time, and were used for the bulk melting of metals as early as 1878 (by Sir William Siemens in Europe). However, only in the past few decades have DC arc furnaces been used for smelting processes, where significant chemical reactions are involved. Mintek has been fortunate enough to be involved in the industrial-scale commercialisation of roughly one application of this technology per decade. This started with the smelting of fine chromite ore to produce ferrochromium in the 1980s, and was followed by the smelting of ilmenite to produce titania slag and pig iron in the 1990s. In both of these cases, the process chemistry was well known and the products were familiar (albeit with some minor variations), even though the type of furnace was novel at the time. A further example was the use of a DC arc furnace to recover metals (principally cobalt) from non-ferrous smelting slags [2] early in the 2000s. In this case, a new process was carried out in a 'new' piece of equipment to produce a somewhat unfamiliar intermediate product. This, therefore, required testing and demonstration at quite a large scale. There are currently another two applications of DC arc furnace technology that are poised on the brink of commercialisation – namely the smelting of nickel laterite to produce ferronickel, and the ConRoast process [3] which can be used for both platinum group metal (PGM) and nickel smelting. This paper tells some of the story of the ConRoast process for PGM smelting.

Mintek's ConRoast process was developed to address a number of the shortcomings of the traditional matte smelting process for the production of platinum group metals [4]. It controls sulfur emissions by removing sulfur from concentrates prior to smelting. It easily accommodates high levels of chromite by ensuring that the chromium is dissolved in the slag. The concentrates undergo reduction in the furnace, and the PGMs are collected in an iron-rich alloy that has a similar liquidus ('melting') temperature to that of the slag. Further details of the process have been published elsewhere [3].

CONROAST PROCESS

Mintek has been working since 1994 on the development of an alternative process for base metal and PGM smelting that offers greater flexibility and is more environmentally favourable. The ConRoast process is based on reductive smelting in a DC arc furnace in the effective absence of sulfur, where an iron-based alloy is used to collect the valuable metals. The original impetus for the process was environmental, but, once developed, it became apparent that the process had another significant advantage for the platinum industry in South Africa, as it was not affected at all by the chrome issues that have caused problems for the traditional 'six-in-line' smelters.

The Sulfur Problem

The emission of SO_2 (sulfur dioxide) from furnaces and converters is hard to avoid when using a sulfur-based matte-smelting process. However, the ConRoast process does not rely on the presence of sulfur, as it smelts essentially sulfur-free material in a DC arc furnace and collects the valuable metals in an iron alloy. Sulfur can be removed, prior to smelting, using a fluidized-bed roaster which is a well-enclosed vessel that produces a steady continuous stream of SO_2 that can be used for the production of sulfuric acid (if the concentration and scale warrant this course of action). Compared to the traditional matte-smelting process, emissions of SO_2 can be orders of magnitude lower if the ConRoast process is used. The capital costs of acid production can also be reduced markedly.

The Chromium Problem

The traditional matte-smelting process imposes strict limits on the quantity of chromite (prevalent in the UG2 reef) that can be present in the smelter feed. This constraint restricts the recovery of the PGMs in the production of ore concentrates. The ConRoast process eliminates the chromium constraint in smelting and so opens up huge opportunities in the types of materials that can be smelted, and provides an opportunity to significantly enhance the overall process recovery of PGMs (through removing the restrictions in concentrator operations).

The Containment Problem

As the South African platinum producers have moved increasingly to processing ore from the UG2 reef to supplement the previous production from the Merensky reef [4], there have been numerous furnace failures and explosions in the industry. Even though water-cooled copper cooling systems have been introduced in recent years, the highly superheated and corrosive molten matte in traditional smelters is inherently difficult to contain. The ConRoast process is able to use a simple and robust design of furnace, because the melting temperatures of the slag and alloy are close to each other.

HISTORY OF THE PROCESS AND EARLY TESTWORK

As far back as 1994, Mintek was involved in a study that compared a number of pyrometallurgical and hydrometallurgical process routes for the treatment of a nickel-copper-cobalt-PGM concentrate to produce the individual base metals and a PGM-rich residue. During the course of this study, Mintek came up with the concept of a smelting process that involved dead-roasting of concentrate followed by reductive smelting in a DC arc furnace. An economic comparison showed a significant potential advantage resulting from the simplicity and efficiency of this process. Furthermore, it was recognised that legislation on emissions of sulfur and other minor elements will get increasingly tougher over time, and a more environmentally-friendly process is needed for the future.

During 1996 and 1997, initial testwork was carried out on a nickel sulfide concentrate, first with 500 kg of feed material, then with 30 tons. These tests were very successful, and showed high recoveries of the valuable metals. During 1998, a similar 30-ton test was carried out on a PGM ore concentrate (from a blend of Merensky and UG2 ores), involving dead-roasting in a fluidized bed reactor followed by smelting in a DC arc furnace. The resulting alloy was treated hydrometallurgically to remove the iron and to separate the base metals from a PGM-rich residue. Again, the results were highly successful. By 2000, the process had been patented internationally by Mintek. However, the highly conservative PGM industry needed an extended long-term production run to gain sufficient confidence in the process, and this was not easy to achieve because of the very significant cost of roasting sufficient feed material to use for a large-scale demonstration of the smelting process.

Fortunately, a wonderful opportunity came along when a revert tailings material was discovered that was very similar in its characteristics to a dead-roasted concentrate. This material had a low sulfur content, but contained rather high levels of chromite. An initial small-scale smelting test was successfully carried out on this material in 2003. This opened the way for a multi-year demonstration (toll-treatment) smelting campaign at Mintek that began on 1 April 2004, where approximately 37 000 tons of revert tailings was smelted in a 1.5 MW DC arc furnace at a rate of about 1 000 tons per month [5,6]. This convinced the remaining sceptics that the smelting process worked well. However, there were a number of upstream and downstream aspects to the process that still needed to be demonstrated to a similar level to that of the smelting step.

COMMERCIAL PARTNERSHIP WITH ATOMAER / INDEPENDENCE PLATINUM / BRAEMORE RESOURCES

After the completion of laboratory and pilot-scale smelting testwork, Mintek realised that a partner was required in order to provide the considerable funding that was needed for the purpose of taking the concepts of the ConRoast process through further development and demonstration to the point of commercialisation. Numerous presentations were given to all of the established South African PGM producers, as well as to the many emerging PGM miners that were coming onto the scene during a period of great change in the South African mining industry.

The South African Mineral and Petroleum Resources Development Act (MPRDA) came into effect on 1 May 2004. Prior to the implementation of this legislation, the majority of mineral rights (which include mining and prospecting rights) in South Africa were privately held. The MPRDA introduced a fundamental change that brought South Africa more in line with the practice of many mining countries elsewhere where mineral rights are owned and regulated by the state. Mining companies were required to apply to convert their 'old-order' mining licences and prospecting permits into 'new-order' mining and prospecting rights within a period of five years. When considering the granting of the new rights, the government would take into account a number of factors, including the requirement that at least 26 per cent of the equity of mining companies must be owned by historically disadvantaged South Africans (HDSAs) within ten years. Mining companies were also no longer permitted to hoard vast tracts of unused mining land. This opened up many opportunities for emerging PGM miners to establish their own mines and concentrators. However, because of the expense of building smelters and refineries, the concentrate would typically still need to be treated by the well-established PGM producers.

An Australian technology development company, Atomaer, recognised the potential of the ConRoast technology, and entered into an agreement with Mintek to fund a three-year (US $15 million) development and demonstration programme in exchange for a ten-year period of exclusive use of the ConRoast process. This agreement was signed on 30 May 2006, with a commencement date of 1 October 2006. The intention was to promote the development and mining of platinum projects for emerging PGM miners in South Africa by providing them access to the ConRoast facility and technology. A black-empowered smelter / refiner would be established to treat materials from the new independent PGM mines and concentrators. The corporate vehicle for doing this was known as Independence Platinum [7].

Braemore Resources plc (about 40% owned by Atomaer) acquired Independence Platinum on 20 December 2006, and this entity was renamed Braemore Platinum Smelters. Braemore Resources was initially listed (on 10 March 2005) on the Alternative Investment Market (AIM) of the London Stock Exchange, and was subsequently listed on the JSE on 16 July 2008. Braemore plans to work with various emerging platinum mining companies through technical co-operation, strategic alliances, joint ventures, off-take-, toll-refining-, and marketing agreements.

Clearly, one of the challenges of obtaining off-take agreements is that a mining company will only be willing to commit to providing concentrate to a smelter that is already operating, and a new smelter can only get funds to operate if it can show that it has signed off-take agreements. The way around this impasse was to use the Mintek demonstration furnace to start processing various feed materials on a small commercial scale. While operating the existing plant at Mintek, Braemore has plans to establish larger capacity smelting plants in the Bushveld Complex.

CONROAST TESTWORK FOR BRAEMORE PLATINUM SMELTERS

A wide range of metallurgical testwork has been carried out during the past two years.

Small-scale roasting and smelting tests on a range of PGM concentrates have been completed at Mintek. Pilot-plant roasting testwork has been carried out successfully by Technip [8] in the USA, and by Outotec [9] in Germany, in order to demonstrate the viability of the roasting process and to obtain sufficient engineering data for the design and costing of the full-scale equipment. The scale of operation considered for the fluidized bed roaster design was for a plant capable of processing at least 360 000 tons per annum of PGM-containing sulfide concentrates (potentially a mix of UG2 and Platreef concentrates). It was necessary to operate the roasting process at around 1000°C. The roasting testwork clearly demonstrated that it is possible to decrease the total sulphur content of a PGM ore concentrate from about 7% to as low as 0.3% in the cyclone product, with 0.4% as a weighted average of the cyclone and bag-house products.

The demonstration roasting of 300 tons of PGM-bearing flotation concentrate (containing about 7% sulfur) in Germiston, South Africa has also been completed, in preparation for further smelting testwork using this material.

The ConRoast process produces an iron-rich alloy. After tapping the alloy from the furnace, it needs to be produced in a physical form that is conducive to further processing. Water atomisation or granulation of the molten alloy can be used for this purpose. Granulation is currently routinely carried out on the alloy produced from the Mintek smelter. However, water atomisation can be used as an effective intermediate step between the production of a molten alloy from a smelting furnace and a leaching operation. This is especially appropriate for alloys that are not readily crushable. Very fine particles can be produced by the impingement of high-pressure water jets on a molten alloy stream. The use of very fine material as a feedstock for the leaching process allows for considerable savings in residence time, reactor volume, and lower power consumption for stirring. Testwork was carried out at Atomising Systems Ltd [10] in the UK that successfully demonstrated the production of fine powders, as small as 20 microns, that are very suitable for further hydrometallurgical processing. The relationship between the pressure of the water jets and the size of the resulting particles is such that the mean particle size can be halved by doubling the water pressure (over the range of conditions of interest).

The alloy product from the DC arc furnace requires iron removal. The two principal options that have been explored are to do this either pyrometallurgically (by converting) or hydrometallurgically (by leaching).

Small-scale converting tests of the PGM alloy have been conducted at Mintek [11]. Significant iron removal has been demonstrated in a liquid-state oxygen converting process at laboratory scale, where it was possible to change the distribution of sulfur between the alloy, slag, and gas phases by changing the CaO content of the slag. Some preliminary pilot-scale converting work has also been done at Mintek. A few conceptual designs of various converting options have been prepared. Plant-scale trials have been successfully conducted where alloy was co-converted with conventional matte.

A comprehensive leaching test programme has been undertaken, and a conceptual design has been prepared for a hydrometallurgical pilot plant. (The hydrometallurgical work is not included in the scope of this paper.)

A definitive feasibility study for a 10 MW furnace in the Rustenburg area was completed by TWP Consulting in July 2008. This 10 MW furnace was designed to smelt 80 kt/a of concentrate, with an alloy end-product. A number of variations (including different capacities) were then investigated around this base case. The intention is to start up the first fully commercial furnace around the end of 2010.

OPERATION OF 1.5 MW FURNACE AT MINTEK

Mintek operated a 3.0 m (1.5 MW) furnace from 1 April 2004 to 8 August 2008. During that period, over 37 000 tons of PGM-containing feed material was dried and smelted [6]. (Of that amount, 9 500 tons of feed material was smelted for Braemore.) Braemore signed a five-year toll-treatment agreement with Mintek in September 2007. The first alloy for Braemore Platinum Smelters was tapped on 2 October 2007. In a period of just over ten months, more than 9 500 tons of PGM-containing feed was smelted, resulting in the production of 840 tons of alloy, containing over 16 000 ounces of PGMs on a 4e (Pt+Pd+Rh+Au) basis.

FURNACE UPGRADE FROM 1.5 MW to 3 MW

In order to demonstrate (and benefit from) the economy of scale that results from greater throughput, the smelter was upgraded during August and September 2008 to a 4.25 m (nominally 3 MW) furnace that was designed to have a capacity that was double that of the previous furnace (i.e. 2 000 tons per month instead of 1 000 tons per month).

In the first six months of commissioning, ramp-up, and operation, the new furnace smelted over 6 000 tons of PGM-containing feed material, and produced almost 15 000 ounces of PGMs in alloy form. Table 1 shows that, after the initial start-up period, there were four months of operation where the PGM recovery was in excess of 99.5%.

Table 1 – Mintek's 3 MW furnace production summary for first six months (Oct 2008 – Mar 2009)

	Oct 2008	**Nov 2008**	**Dec 2008**	**Jan 2009**	**Feb 2009**	**Mar 2009**	**Total**
Tons smelted, t	304	814	1 266	1 229	1 349	1 196	6 158
PGM oz (4e) in alloy	622	1 327	3 972	3 400	2 392	3 208	14 920
PGM (4e) in slag, g/t	2.59	0.71	0.33	0.31	0.34	0.28	-
Built-up Recovery*	96.8%	98.9%	99.7%	99.7%	99.5%	99.7%	-

* Built-up recovery = Mass of PGM (4E) in alloy / (Mass of PGM in alloy + Mass of PGM in slag)

During the upgrade, an industry-standard flash drier and pneumatic feed system was also added to the plant. When the new plant is run at full capacity, together with an expected increase in feed grade, Braemore expects the increased capacity to result in an annual production of about 60 000 oz of PGMs.

Figure 1 – First slag tap from Mintek's 3 MW furnace, 4 October 2008

OPERATIONAL CHALLENGES

The initial commissioning and ramp-up of production of the upgraded smelter went reasonably well, especially given that a number of completely new units (flash drying plant, pneumatic conveying system, feed storage silo, new feed system, and gas scrubber) were brought on-stream more or less simultaneously. A number of challenges were experienced with regard to the nature of the feed materials that needed to be dried and smelted. Tramp materials caused some blockages and damage to the flash drying unit, and very large lumps of feed occasionally proved difficult to handle in the drying plant. An excessively high moisture content in the feed resulted in decreased capacity of the drying plant from time to time.

A variety of feed materials have been treated, with a wide variation in composition. The furnace was remarkably tolerant of most variations. There were some feed materials with a very low iron content, and, when these were smelted, it was necessary to ensure that they were blended with other materials with a higher iron content. The process is based on the collection of the valuable metals in an iron alloy, so there obviously has to be sufficient iron present to do this. One good solution is to use a PGM-containing iron source, such as converter slag, as a part of the feed to the furnace.

However, the most serious challenge occurred as a result of feed materials arriving with too high a sulfur content. This resulted in the formation of an alloy with a much lower liquidus temperature than the process is designed to accommodate. The superheated alloy then caused rapid wear of the side-wall refractories, resulting in a leak adjacent to the alloy tap-hole on 27 March 2009. The escaping stream of superheated molten alloy cut through one of the cooling circuits, resulting in a series of metal-water explosions just outside the furnace. This incident was well managed and there were no injuries or burns, but it did cause a three-week shutdown of the furnace while repairs were carried out. The incident highlighted the benefits of operating in a low-sulfur alloy-smelting mode, as about four and a half years of previous incident-free operation were starkly contrasted with a mere six months of operation in high-sulfur mode. This clearly pointed out the limitations of high-sulfur feed materials, and the necessity for a full implementation of the process including the roasting step. It had been expedient to simply smelt the feed materials directly without first installing a roaster, and this worked quite satisfactorily as long as the sulfur content of the feed was low.

The availability of sufficient feedstock of suitable feed materials was also sometimes problematic, especially during times where mine production was curtailed and existing smelters had a high demand.

CURRENT ECONOMIC ENVIRONMENT

Edwin Land (the inventor of the Polaroid camera) once said, "My personal philosophy is not to undertake a project unless it is manifestly important and nearly impossible". This approach to project selection seems to accord well with the current set of challenges facing the PGM industry in general, and smaller companies in particular. The world economic crisis that came to the fore in 2008 has curtailed a number of otherwise promising mining projects because of the low availability of credit, the significant decline in the platinum price, and the strengthening rand (for an industry that incurs its costs in rands, but earns its revenues in dollars). If companies can survive the 'interesting times' in which we are living, they will be well poised for significant growth when the economy improves in the years ahead.

CONCLUSIONS

Metallurgical testwork for the demonstration of the full ConRoast process has proceeded successfully. Work done to date has included fluidized bed roasting, water atomisation of alloys, converting for iron removal, and a comprehensive programme of hydrometallurgical testwork.

Braemore Platinum will be proceeding with the implementation of plans for the development and commissioning of independent smelting and base metals refining facilities in South Africa. This will be done in a staged approach, commencing with demonstration smelting on a commercial scale at Mintek, which is already underway.

Braemore has become a new PGM producer, having smelted 16 600 tons of PGM-containing feed materials from the beginning of October 2007 to the end of May 2009 at Mintek, thereby producing more than 32 000 ounces of PGMs (4E: Pt, Pd, Rh, Au) in granulated alloy form. This operation allowed Braemore to start generating a cash flow at an early stage of the project. Sales contracts for future delivery of smelted PGM alloy have been entered into with a number of refiners and PGM producers. During this period of operation, the sulfur dioxide (SO_2) emissions from the smelter were negligible, with the off-gas from the stack averaging around two parts per million (ppm).

The Mintek furnace has been upgraded from 1.5 MW to 3 MW, thereby doubling its capacity to allow it to smelt 2 000 tons per month.

ACKNOWLEDGEMENTS

This paper is published by permission of Mintek and Braemore Resources. The commercialisation of a new process involves the work of many people, too numerous to list individually. The assistance of many colleagues at Mintek and Braemore Resources and their contributions are gratefully acknowledged.

REFERENCES

1. R.T. Jones, N.A. Barcza, and T.R. Curr, "Plasma developments in Africa", Second International Plasma Symposium: World progress in plasma applications", Organized by the EPRI (Electric Power Research Institute) CMP (Center for Materials Production), Palo Alto, California, 9-11 February 1993.
http://www.mintek.co.za/Pyromet/Files/PlasmaDev.pdf

2. R.T. Jones, G.M. Denton, Q.G. Reynolds, J.A.L. Parker, and G.J.J. van Tonder, "Recovery of cobalt from slag in a DC arc furnace at Chambishi, Zambia", SAIMM Journal, Vol.102, No.1, January/February 2002, pp.5–9.
http://www.mintek.co.za/Pyromet/Files/Chambishi.pdf

3. R.T. Jones, "ConRoast: DC arc smelting of dead-roasted sulphide concentrates", Third International Sulfide Smelting Symposium (Sulfide Smelting '02), R.L. Stephens and H.Y. Sohn (Eds.), TMS (The Minerals, Metals, & Materials Society), Seattle, Washington, USA, 17–21 February 2002, TMS Annual Meeting, pp.435–456.
http://www.mintek.co.za/Pyromet/Files/ConRoast.pdf

4. R.T. Jones, "An overview of Southern African PGM Smelting", Nickel and Cobalt 2005: Challenges in Extraction and Production, 44th Annual Conference of Metallurgists, Calgary, Alberta, Canada, 21–24 August 2005, pp.147–178.
http://www.mintek.co.za/Pyromet/Files/2005JonesPGMsmelting.pdf

5. R.T. Jones and I.J. Kotzé, "DC arc smelting of difficult PGM-containing feed materials", International Platinum Conference 'Platinum Adding Value', The South African Institute of Mining and Metallurgy, Sun City, 3–7 October 2004, pp.33–36.
http://www.mintek.co.za/Pyromet/Files/2004JonesConSmelt.pdf

6. I.J. Geldenhuys and R.T. Jones, "Four years of DC arc smelting of PGM-containing oxide feed materials at Mintek", Nickel and Cobalt 2009: Advances in the Processing of Nickel,

Cobalt and PGMs using Pyrometallurgical Techniques, 48th Annual Conference of Metallurgists, Sudbury, Ontario, Canada, 23–26 August 2009. http://www.mintek.co.za/Pyromet/Files/2009Geldenhuys.pdf

7. R.E. Phillips, R.T. Jones, and P. Chennells, "Commercialization of the ConRoast process", Third International Platinum Conference 'Platinum in Transformation', The Southern African Institute of Mining and Metallurgy, 2008, pp.141-147. http://www.mintek.co.za/Pyromet/Files/2008Phillips.pdf

8. E. Eccleston and J. White, "Development of roasting parameters for the ConRoast process with low-sulfur feedstock", Third International Platinum Conference, Platinum in Transformation, The Southern African Institute of Mining and Metallurgy, Sun City, 5-9 October 2008, pp.149-154. http://www.mintek.co.za/Pyromet/Files/2008Eccleston.pdf

9. J. Hammerschmidt, "The roasting of PGM-ore concentrates in a circulating fluidized bed", Third International Platinum Conference, Platinum in Transformation, The Southern African Institute of Mining and Metallurgy, Sun City, 5-9 October 2008, pp.161-167. http://www.mintek.co.za/Pyromet/Files/2008Hammerschmidt.pdf

10. J.J. Dunkley, D. Norval, R.T. Jones, and P. Chennells, "Water atomisation of PGM-containing intermediate alloys", Third International Platinum Conference, Platinum in Transformation, The Southern African Institute of Mining and Metallurgy, Sun City, 5-9 October 2008, pp.155-159. http://www.mintek.co.za/Pyromet/Files/2008Dunkley.pdf

11. S.D. McCullough, I.J. Geldenhuys, and R.T. Jones, "Pyrometallurgical iron removal from PGM-containing alloys", Third International Platinum Conference, Platinum in Transformation, The Southern African Institute of Mining and Metallurgy, Sun City, 5-9 October 2008, pp.169-176. http://www.mintek.co.za/Pyromet/Files/2008McCullough1.pdf