Technological breakthrough of the Mintek thermal magnesium process

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Journal Paper

Synopsis

The Mintek Thermal Magnesium Process (MTMP) was successfully demonstrated in November 2004. The pilot plant was operated continuously for 8 days, during which about 30 tons of magnesium producing recipe was smelted in a DC (direct-current) arc furnace at a feed rate of 525 kg/h. The furnace was operated at power levels of 700 to 850 kW, resulting in slag tapping temperatures of 1600 to 1700°C. Magnesium extraction averaged 77 per cent and was as high as 85 per cent during good extraction periods.

The furnace generated 70 to 85 kg/h magnesium vapour that was delivered to the condenser where the temperature was controlled at 680 to 720°C. The novel condenser captured the magnesium in a liquid state, which was tapped periodically as required. In total, 15 magnesium-tapping operations were carried out, proving that online magnesium tapping can be consistently performed without any major difficulty. About 3500 kg of crude magnesium was produced with a quality that was similar to, if not better than, that of the Magnetherm's crude metal. The condensation efficiency averaged 85 per cent, and peaked at 87 per cent, which exceeded the target of 80 per cent set for the pilot scale.

A brief magnesium market study was also carried out. Magnesium demand is expected to keep on growing by 6 to 8 per cent over the next 10 years and could reach 2 million tons by the year 2020. The growth will be mainly in the die-casting sector for light-weight automotive applications. China is likely to remain the dominant supplier of primary magnesium but competitively priced non-Chinese magnesium producers will be needed to sustain the anticipated growth of 6 to 8 per cent over the next 10 years.

In addition, a prefeasibility study was undertaken for a commercial plant. The study confirmed the relatively low capital costs of the MTMP process, as well as the competitiveness of the operating costs, as compared to the industrial electrolytic process.

Introduction

Two basic processes for magnesium production are currently employed: fused-salt electrolysis of magnesium chloride, and thermal reduction of magnesium oxide. Presently, the dominant technology is the 'Pidgeon' process[1], used by the Chinese magnesium producers. It is a thermal reduction method carried out under vacuum in coal-fired retorts, and is based on the reaction of calcined dolomite with ferrosilicon. The Pidgeon process was invented and developed in Canada in the 1940s. It is a labour-intensive batch process. The production capacity per retort is only 50 kg magnesium per day at a cycle time of roughly 10 hours.

In the 1960s, a semi-continuous, scaled-up Pidgeon process was developed in France by Pechiney[2,3]. The process is known as the Magnetherm process and is based on AC submerged-electrode smelting of calcined dolomite in the presence of ferrosilicon and aluminium. The process is carried out under a vacuum of 0.05 to 0.10 atm. The production capacity per reactor is 20 ton magnesium per day, the cycle time is about 12 hours, and the condenser efficiency is 85 to 90 per cent. Every 12 hours the vacuum has to be broken, in order to periodically remove the slag from the furnace, and to replace the full condenser with an empty one.

The Mintek Thermal Magnesium Process (MTMP)[4–10] is a further advancement of the Magnetherm process, allowing continuous operation of magnesium production. In the Mintek process a DC open-arc furnace is used and the reaction is carried out at atmospheric pressure instead of the vacuum operations of the Pidgeon and Magnetherm processes. The furnace operating temperature is 1700°C to 1750°C. The magnesium vapour that is generated in the furnace is condensed in a separate condenser vessel. The Mintek process is also based on the reduction of magnesium oxide in calcined dolomite, using ferrosilicon as the reducing agent, in conjunction with aluminium if market conditions are favourable. The production capacity is about 100 ton magnesium per day for a 35 MW furnace.

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* *Mintek.*

During the year 2000, a 100 kg/h magnesium MTMP pilot plant was designed and built. The pilot plant includes a 1.5 MW DC open-arc furnace and a novel condenser to allow continuous, or semi-continuous, magnesium production. The pilot plant was commissioned in 2001 and during the period 2001–2004, ten magnesium-smelting campaigns were carried out on the pilot plant.

This paper gives the main operational data and metallurgical results achieved on the Mintek pilot plant. A brief magnesium market study is also included. In addition, a preliminary techno-economic assessment of the MTMP process is presented and the results are compared with the techno-economic data of an electrolytic magnesium process.

Pilot plant description

A schematic diagram of the 100 kg/h magnesium pilot plant is shown in Figure 1. The equipment consists of a 1.5 MW (10 kA) power supply, a DC (direct-current) arc furnace, a raw material feed system, a magnesium condenser, a combustion chamber, a gas-cleaning system, and ancillary equipment.

The Mintek Thermal Magnesium Process (MTMP) is based on the silico-thermic (and alumino-thermic) reduction of magnesium oxide in calcined dolomite, and is carried out in a DC open-arc electric furnace, at atmospheric pressure and at a temperature of about 1700°C. The magnesium vapour that is generated in the furnace is captured in a condenser as liquid magnesium. The condenser is connected behind the furnace, and magnesium is periodically tapped from the condenser. The airtight furnace has an internal diameter of 1.2 m and a shell diameter of 1.9 m. The feed system is capable of supplying 250 to 500 kg/h dolime (calcined dolomite), 40 to 80 kg/h ferrosilicon, and 15 to 60 kg/h aluminium to produce 50 to 100 kg/h magnesium vapour.

Operation of the pilot plant and main results

Since early 2001, 10 test campaigns, or runs, were carried out on the Mintek pilot plant. In the first 9 campaigns (Runs 1 to 9), about 40 tons of magnesium-producing feed materials were processed. The new magnesium process was demonstrated at a relatively large scale of 50 to 75 kg/h magnesium vapour-generation and condensation. The furnace was operated at power levels of 600 to 800 kW, with feed rates of raw materials of 400 to 525 kg per hour. Magnesium extraction in the furnace reached 85 per cent, and the condensation efficiency was between 70 and 75 per cent. However, during Runs 1 to 8 continuous operation was not sustained for 20 hours, or more, as targeted. The runs were terminated prematurely due to blockages in the ducts of the pilot plant equipment. In the best of these 8 runs, 5 tons of magnesium-producing materials were fed over periods of about 10 hours.

Before Run 9, two mechanical cleaning-devices (plungers) were installed in critical places as a means of dealing with blockages. This was considered to be necessary in order to achieve at least 20 hours of 'feed-on' time, and so to obtain more accurate condensation-efficiency data.

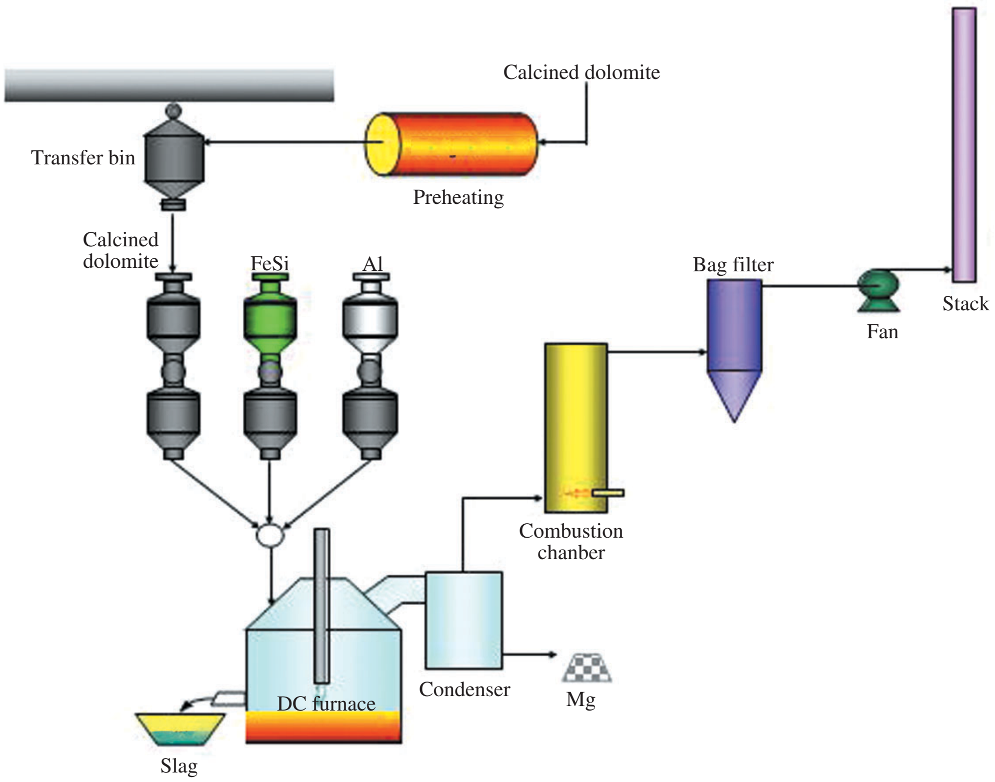

Figure 1—Schematic diagram of the MTMP pilot plant

A step-change in operability was achieved in that, during Run 9, the MTMP process was operated continuously for about 20 hours. Roughly 10 tons of raw materials were processed at a feed-rate of 520 kg/h. During this Run 9, three magnesium taps, totalling 290 kg crude magnesium, were carried out. Further reheating of the condenser crucible and co-melting of salt flux (NaCl and KCl) resulted in the recovery of an additional 615 kg of crude magnesium. Data analysis revealed that the condensation efficiency was about 75 per cent for the entire duration of Run 9, and that the magnesium was of a similar quality, and in most cases of better quality, than that produced in conventional thermal magnesium processes. After magnesium Run 9, it was concluded that another, more drastic step-change was needed, this time involving the condenser design, to achieve continuous operation for longer periods of time.

The last magnesium smelting campaign (Run 10) was carried out in November 2004. This campaign was conducted with a new condenser, designed to prevent the build-up of dross that limited previous runs to about 20 hours of continuous operation. The modified condenser performed quite well, achieving continuous production with a condenser efficiency of 85 per cent. During the eight-day run, about 30 tons of feed materials were smelted in the DC furnace, which was operated at power levels up to 850 kW, and the magnesium was extracted as vapour for delivery to the condenser. Fifteen taps of liquid magnesium, totalling 3500 kg of magnesium metal, were carried out from the condenser during online operation. The crude magnesium was again of a similar quality to that produced by conventional thermal processes.

Chemical analyses of the crude magnesium produced during Runs 1 to 10 are shown in Table I, together with the standard specifications of a typical ASTM grade (ASTM designation B92, grade 9980A, 99.8 % Mg). In general, the crude magnesium conforms to the chemical requirements of ASTM magnesium ingot, or is close to the specifications. Consequently, less salt flux than used in the conventional thermal processes might be required for the refining of the MTMP magnesium.

The calcium content of the crude magnesium was relatively low (see Table I) as compared to 0.85 per cent reported for crude magnesium produced by the Magnetherm process[11].

Table I

Analyses of Mintek crude magnesium and standard specification (ASTM) of magnesium ingots, mass %

	Si max	Mn max	Al max	Fe max	Ca max	Ni max
ASTM* B-92	0.05	0.10	0.05	0.05	0.05	0.001
Mintek Crude+	0.02 0.20	0.02 0.03	0.01 0.10	0.01 0.05	0.10 0.20	0.001 0.010

* Other impurities each max 0.05%
+ Mintek crude magnesium, Runs 1-10, range of analyses

The Run 10 campaign demonstrated, for the first time, the feasibility of a continuous atmospheric process for thermal magnesium production. The robustness of the MTMP process was shown by the ability of the condenser to withstand a furnace shutdown—for example to clear a blocked feed port or to add an electrode section—and immediately restart production and tapping of magnesium. It was demonstrated that the magnesium pilot plant could be maintained online for several days, without dismantling and cleaning of the condenser components, as practised in industry. Technically, the MTMP process is now ready for scaling up to a demonstration- and further to an industrial-size operation.

Magnesium market and price

The magnesium market has undergone major changes over the last ten years. World primary magnesium production rose by an average of 7 per cent per year, and die-cast automotive components are replacing aluminium alloying additions as the major magnesium application[12,13]. Magnesium demand is expected to continue increasing by 6 to 8 per cent over the next 10 to 15 years, and the magnesium could become a two million ton per year industry by the year 2020.

China has become the dominant magnesium producer over the last ten years. Its magnesium production has increased rapidly from only 5 000 tons in 1990 to 400 000 tons in 2004. In the 1990s a large number of relatively small Pidgeon plants were built in China[14,15], reaching a total annual output of 200 000 ton by the year 2000. In 2004, the world production of primary magnesium was around 570 000 ton, and China accounted for 400 000 ton, or 70 per cent of the total 2004 production.

The magnesium price has been steadily declining from about 140 c/lb (US cents/pound) in the mid 1990s to 85 c/lb in June 2005. The above are European free market prices obtained from *Metal Bulletin*. The ratio of the price of magnesium to that of aluminium is critical for the replacement of aluminium by magnesium in structural and especially motor vehicle applications. It is generally accepted that at a Mg/Al price ratio of 1.5 or less, magnesium could replace aluminium in motor vehicles to a significant extent. Since 2000 the price ratio has been consistently below 1.5, and since the beginning of 2005 the ratio has been close to unity.

Table II

Costs summary

Element	US$ / lb Mg		
	Electrolytic Canada	MTMP Canada	MTMP S. Africa
Capital	0.52	0.32	0.25
Variable costs	0.73	0.59	0.62
Fixed costs	0.37	0.30	0.14
TOTAL	1.62	1.21	1.01

A great potential exists for increased usage of magnesium in motor cars. Magnesium in automobiles is the fastest growing sector in terms of magnesium demand in the form of die-cast motor components[12]. In 2004 the magnesium content in motor vehicles was about 3 kg per vehicle, on average. At a world production of motor vehicles of roughly 50 million units per year, this translates into a consumption of 150 000 tons magnesium for the manufacture of motor components in 2004. Magnesium usage in motor vehicles could grow to 20 kg per vehicle, or to a one million ton yearly demand for magnesium.

Economics of the MTMP

A comparison between an electrolytic plant and an MTMP facility, both located in Canada and rated at 40 000 ton/year magnesium, is presented in Table II, in terms of capital and operating costs estimates. The major assumption made was that the capital costs for the two plants are US$ 8000[12] and US$ 5000/annual ton magnesium, and is depreciated over a 7-year period.

The capital and operating cost estimates for an MTMP plant located in South Africa are also included in Table II. Here, the capital costs amount to just over US$ 3800/annual ton of refined metal, and reflects the importance of site selection on the overall economics of the plant.

Despite the absence of aluminium in the feed mix, the sole reductant, i.e. ferrosilicon (FeSi), constitutes over 50 per cent of the total variable costs, with calcined dolomite and electricity being the next highest. Crucial to the study is the assumption that FeSi is priced at US$ 0.45/lb of contained Si. The question is whether the recent high prices were aberrations or whether the alloy has moved from the previous level of 35 cents to 45 cents as a long-term price. Sensitivity analysis suggests that the internal rate of return (IRR) is greatly affected by the cost of FeSi, as well as by the selling price of magnesium ingots. The economic analysis is based on a selling price of US$ 1.0/lb of refined metal. Capacity and capital costs appear to affect the IRR to a lesser extent (Figure 2). Of the total cash costs, the fixed component contributes less than 20 per cent, the four major items being labour, maintenance, insurance and overheads.

Conclusions

➤ *Piloting of the Mintek Thermal Magnesium Process* (MTMP)—Ten magnesium-smelting campaigns were carried out at the Mintek pilot plant during 2001 to 2004. The last campaign, carried out in November 2004, was extremely successful. Over an 8-day period, about 30 tons of feed materials were smelted in the DC furnace, which was operated at power levels up to 850 kW, and the magnesium was extracted as vapour for delivery to the condenser. Fifteen taps of liquid magnesium, totalling 3500 kg of magnesium metal, were carried out at the condenser during online operation.

The novel condenser performed quite well, achieving continuous production with a condenser efficiency of 85 per cent. This magnesium smelting/condensing campaign demonstrated, for the first time, the feasibility of a continuous atmospheric process for

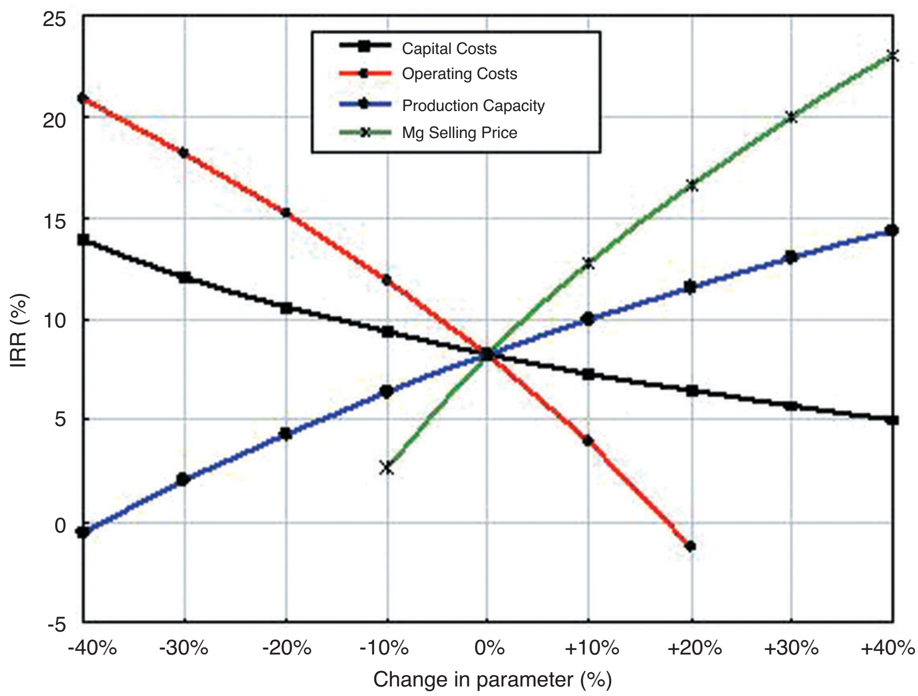

Figure 2—Sensitivity of IRR to changes in capital costs, production capacity, operating costs, and magnesium selling price

thermal magnesium production. It was demonstrated that the magnesium pilot plant could be maintained online, without dismantling and cleaning of the condenser components, as practised in industry. The crude magnesium was of a similar quality to that produced by conventional thermal processes. The calcium content of the crude magnesium was relatively low, and consequently less salt flux than used in the conventional processes, might be required for the refining of the MTMP magnesium. R&D work at the Mintek pilot plant scale has been completed successfully. Mintek and its partners are evaluating the commercial possibilities of implementing the new technology. It is anticipated that magnesium production could start at a rate of 15 000 ton per year, in a single MTMP furnace. Magnesium production by the MTMP could be further raised to a 70 000 ton per annum in a plant comprising two 35 MW furnaces.

➤ *Magnesium market*—In 2004, the primary production of magnesium was 570 000 tons. Demand is expected to grow by 6 to 8 per over the next 10 to 15 years. Primary magnesium production is expected to become a 2 million ton/year industry by the year 2020. The growth will be driven by the automobile sector where the growth was around 12 per cent over the last 10 years. This end-user sector is expected to expand from 180 000 ton/year in 2004, to one million tons by the year 2020, i.e. half of the primary magnesium production. China is likely to remain the dominant supplier of primary magnesium but competitively priced non-Chinese magnesium producers will be needed to sustain the anticipated growth of 6 to 8 per cent over the next 10 years.

➤ *Economics of the Mintek Thermal Magnesium Process* (MTMP)—The economics of an MTMP plant were compared with those of a fused-salt electrolysis plant for the production of magnesium, both plants being located in Canada. The cash operating costs (variable + fixed costs) of an MTMP and an electrolytic plant, are US$ 0.89/lb magnesium and US$ 1.10/lb magnesium respectively. The overall costs, including capital costs (i.e. cash operating costs + capital costs), are US$ 1.21/lb magnesium and US$ 1.62/lb magnesium, respectively. It appears that the overall costs of an MTMP magnesium plant are 75 per cent of those of an electrolytic plant for magnesium. For an MTMP plant located in South Africa, the operating costs are US$ 0.76/lb magnesium, which is substantially lower than the corresponding costs (US$ 0.89/lb magnesium) for a plant in Canada.

Acknowledgements

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Australia to head global minerals research programme*

Australia will head a global research programme to find radical new ways of extracting minerals from the earth, the Australian Research Council (ARC) announced in November 2005.

In one of the biggest developments in the mining and minerals industry since Australia discovered the flotation process more than 100 years ago, the programme will explore highly experimental new science to develop more efficient and low-impact ways of mining minerals such as zinc, copper, coal, platinum and titanium.

'This research is vital to safeguarding the future viability of Australia's $75-billion-a-year minerals export industry,' Chief executive officer of the ARC Professor Peter Høj said. 'It could revolutionize the global mining industry and have major applications in the massive food and pharmaceuticals industries.'The head of the research programme, Professor John Ralston, from the University of South Australia, said: 'It's time for a new way. Growing pressure for much greater efficiencies and much less impact on the environment mean radical and novel new methods must be found.'

The research programme, believed to be the biggest of its kind in the world, involves: industry giants BHP Billiton, Rio Tinto, Anglo Platinum, Phelps Dodge, Orica Mining and Xstrata Technology, the universities of South Australia, Queensland, Newcastle and Melbourne, a global network of 24 collaborating organizations, and a team of top Australian and international scientists in physics, chemistry, engineering, bioscience and earth sciences, including the winner of this year's Prime Minister's Science Award, Professor David Boger from the University of Melbourne.

The Australian Government will provide $8.6 million to the $22.6 million research programme. The minerals companies are contributing $7.5 million (brokered by AMIRA International), the universities of South Australia, Newcastle, Melbourne and Queensland are contributing $4 million and the South Australian Government is contributing $2.5 million.

One of the new approaches to be examined is '*in situ* extraction', flowing special fluids through natural cracks in rocks to collect the minerals underground and bring them to the surface. Another method to be explored is 'dry processing', separating particles by changing the charge of their surface, requiring no water.

'It's unthinkable for BHP Billiton to achieve its growth plans without a strong involvement in fundamental science," Vice President of Technology Dr Megan Clark said.

'To do something new, to create significant economic value, needs scientific discovery and breakthrough. 'This project brings together the two things needed to make the breakthroughs; basic scientific research and cross-disciplinary teams.'

The project was one of 1 214 new research projects announced by the Minister for Education, Science and Training, Dr Brendan Nelson. The new projects start in 2006. The Australian Government will provide $370 million for the projects over the next five years. The projects are awarded on the advice of the Australian Research Council.

'The minerals research programme typifies the importance of ARC-funded research to Australia's future,' Professor Høj said.

Details of the AMIRA research programme and the full list of ARC grant recipients can be found at: http://www.arc.gov.au ◆

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Miners prepare for silicosis battle—Winners receive awards*

Silicosis is a disabling, non-curable disease produced by breathing in, the commonly found but dangerous dust (crystalline silica) in mines. Silicosis, is faced by our gold and coalmine workers every time they venture underground.

In 1930, the World Health Organization committed itself to eliminating the disease by 2030. Now, with 25 years to go until that deadline, much has to be done in South Africa to achieve that goal.

The South African government, through the Department of Minerals and Energy and the Mine Health and Safety Council, embarked on one of the biggest silicosis control programmes in the world. This comprises dust measurement and reporting, environmental engineering and dust control.

About R25m will be invested in the programme over 5 years.

The National Institute for Occupational Health was awarded the contract to raise awareness on this programme, through communications, interaction, competitions and training. To this end, a competition was initiated among worker representatives to come up with ideas to promote the programme and to raise awareness. The winners were awarded their prizes at an awards ceremony held at the Mines Health and Safety Council offices in Braamfontein on 22 November 2005.

Dr Audrey Banyini who heads up the programme at the Mine Health and Safety Council commented, 'This programme is the first of its kind in South Africa and involves health and safety representatives from different mines to assist in promoting and raising awareness'.

The first prize for the best idea to capture the essence of branding this huge programme was awarded to Masia Kaibe of Harmony number 2 gold mine in Orkney. Second prize went to Myoliswa Magqabaza of Evander gold mine and the third prize was claimed by Agostinho Sumbane of Cooke 1 gold mine in Randfontein. ◆

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