Magnesium - Raw Materials, Metal Extraction and Economics - Global Picture

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ABSTRACT: Magnesium raw materials are available worldwide. In the free market, the prevailing price of primary magnesium metal determines which combinations of raw material/extraction method are economically viable. Over the last 20 years, China's exports benefited from favourable currency exchange rates and positive relations with the USA and European countries. Lax environmental regulations, in conjunction with low labour costs, availability of inexpensive energy and a favourable tax regime resulted in China's domination of the magnesium market. The Pidgeon process (dolomite - main ore, ferrosilicon - reducing agent and coal - energy source) is the main production method in China. It involves lower capital costs but it is less environment-friendly relative to the electrolytic processes favoured in the west. As the magnesium production costs in China are rising and environmental restrictions are being enforced the potential of development of magnesium resources outside of China, especially in North America is increasing.

KEYWORDS: magnesium metal, resources, extraction methods, economics

1 RAW MATERIALS

Magnesium (Mg) is a widely distributed element in nature. There are over 80 minerals that have more than 20% Mg within their crystal structure. However, only magnesite, dolomite, brucite, bishovite, carnallite and olivine (Figure 1) have been used or are considered as raw materials for Mg metal production along with brines, bitterns, fly ash, and serpentine -rich ultramafic rocks (including asbestos tailings). Magnesite and brucite are also commonly used in the production of caustic, dead-burned, and fused magnesia. Although huntite and hydromagnesite have high Mg content, their greatest potential currently appears in flame-retardant applications (Simandl *et al.* 2001). Dolomite [$CaMg(CO_3)_2$] and magnesite [$Mg(CO_3)$] are the most commonly used Mg metal ores. Dolomite is a widespread carbonate, available on every continent and is the main Mg ore used in China. Magnesite has higher Mg content than dolomite (Figure 1); however, large mag

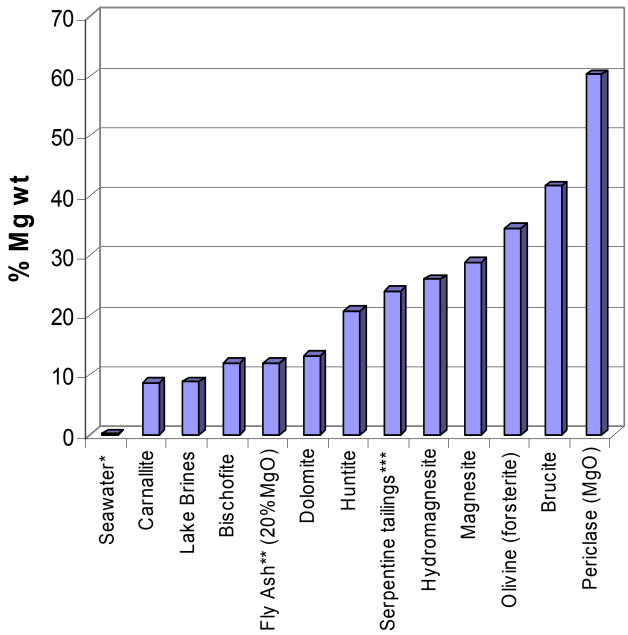

Figure 1. Grade of raw materials in Mg production (*average, **Hazlewood Project, Australia, ***Magnola Project, Canada).

nesite deposits are geographically restricted. World magnesite resources are estimated at over 12 billion tonnes with the majority located in China, Russia, North Korea, Australia, Slovakia, Brazil, Turkey, India and Canada. Over 90% of magnesite resources are sedimentary-hosted, either sparry type (also called Mount Brussilof type) as defined in Simandl and Hancock (1998) or Kunvarrara type as defined in Simandl and Schultes (2005). The balance of the resource (<10%) occurs as veins (Paradis & Simandl 1996) or talc-magnesite bodies within ultramafic-rocks (Simandl & Ogden 1999). Magnesite production is estimated at 19 million tonnes per year and over 85% of it is the sparry variety (Wilson & Ebner 2006). The production of Mg metal from magnesium silicates is technically feasible as demonstrated by the Magnola plant, which operated from 2002 to 2003. However, associated production costs are too high in relation to current Mg-metal prices. Brucite has a higher Mg content than the above listed minerals with the exception of periclase. Unfortunately, large-tonnage, high-grade brucite deposits are uncommon (Simandl *et al.* 2006). Periclase is unstable in nature and it retrogrades into brucite.

2 EXTRACTION PROCESSESS

Known Mg extraction methods belong to either *thermal reduction* or *electrolytic* categories (Table 1). Thermal reduction methods (silicothermic, aluminothermic and carbothermic) operate at high temperatures. The Silicothermic process relies on the use of ferrosilicon to reduce magnesium oxide to a molten slag at temperatures between 1200ºC-1600ºC. A reduced gas pressure above the slag produces magnesium vapour. This vapour is condensed at a location removed from the main furnace or in the low temperature zone of the converter. The crowns of condensed magnesium are then re-melted, refined and casted. The Pidgeon, Magnetherm and Bolzano processes were all successfully used in the past (Aghion & Golub 2006). The Pidgeon process is the simplest, oldest, least energy efficient, and most labour intensive production process. However, it requires the lowest capital investment (Table 1). This process is widely used in China, which dominates world magnesium production and effectively controls the price of magnesium metal. Not surprisingly, the environmental impact of Chinese Mg-metal production on global warming is substantial (Ramakrihnan & Koltun 2004). The main advantage of the thermal reduction methods is that, under the right conditions, high purity metal (99.95% Mg) is produced. Dolomite and to a lesser extend magnesite, are the key ore minerals in the production of Mg metal by thermal reduction methods (Table 1).

Method	**Electrolysis**	**Thermal Reduction**
Raw Materials	magnesite, dolomite, bischofite, carnallite, serpentine, olivine, sea water, brines	dolomite, magnesite
Energy type	hydro-electric, gas, oil	coal, gas
Energy requirements (MWh / tonnes of Mg)	18-28	45-80
Process	continuous	batch
Capital investment (US $/tonne of Mg capacity)	10 000-18 000	≤ 2000
Manpower requirements	X	5X

Table 1. Comparison of Mg metal production methods.

Plants using Mg electrowinning methods are less labour and energy-intensive than thermal reduction processes, but they require higher capital investments (Table 1). There is a large number of technically proven, electrolysis-based processes; however, commercial magnesium electrolysis is conducted most commonly in a chloride melt of mixed alkali metals at temperatures below 700°C (Duhaime, Mercille & Pineau 2002). The feed to the electrolysis process is either anhydrous magnesium chloride, $KMgCl_3$ produced from the dehydration of carnallite or partially dehydrated magnesium chloride. The later feed can be derived from a variety of raw materials including dolomite, magnesite, bishofite, serpentine group minerals, sea water or brines (Figure 1). Although pure anhydrous magnesium chloride is probably the preferred feed material, the production of magnesium chloride with low levels of magnesium oxide is difficult due to its hygroscopic nature. Plants based on the electrolytic approach have difficulty achieving metal purity over 99.8%;

although they benefit from continuous operation (Table 1). Considerable research is underway to optimize established and newly proposed methods (Schounkens *et al*. 2006; Brooks *et al*. 2006) and a single technological breakthrough may completely alter the current situation. Recent research suggests that the carbothermic route of Mg metal production may have the potential to become the most cost effective production method (CSIRO 2006a, b).

3 ECONOMIC AND ENVIRONMENTAL CONSTRAINTS

In theory, considering all the key parameters such as energy efficiency, labour requirements, environmental impacts and economy of scale, electrolysis should be preferred over the high temperature processes (Table 1) when targeted production exceeds 10,000 tonnes per year. In practice, this is not the case as labour costs, access to inexpensive Mg raw materials and abundant, low-cost energy are controlled in part by geography and political factors. Furthermore, environmental standards vary between countries, and the costs required to adhere to strict western standards are high. It is difficult for a western Mg-producer to successfully compete with the current low cost Mg exports from China and to provide an acceptable return on investment for its shareholders. However, this may change in the foreseeable future. Several small Mg-producing plants in China recently closed because they were unable to satisfy minimum environmental requirements when enforced by the government. This trend may continue if environmental restrictions similar to those in North America and Europe become the norm in China. Many countries maintain antidumping duties on Chinese Mg imports. Furthermore, the production of Mg is extremely energy-intensive. As China's economy progresses at a rapid pace, the country is becoming susceptible to the same energy limitations as most developed countries and the availability of inexpensive energy resources that could be allocated to the industry is shrinking. Chinese export taxes may reflect this. In September 2006, China cancelled the export tax rebate on unwrought Mg, Mg alloys, granules and scrap. In November 2006, China introduced a 10% tax on selected silicon metal products. At the time of writing, there were several indications suggesting that China may start to implement a new export tax (5 and 15%) on magnesium in early 2007. The apparent objective of this new tax is to reduce internal industrial energy requirements and to moderate exports of energy-intensive products.

4 INTERPRETATION

China is the world's largest Mg producer. Its dominance could be affected by changes in trade relations, currency exchange rates, internal environmental standards and increases in energy and labour costs. Under such circumstances, western secondary Mg industry, automakers and the aeronautic industry will be adversely affected by high Mg prices. However, Mg resources outside of China may become amenable to development. British Columbia, in particular, has exceptional potential in terms of sparry magnesite deposits (Simandl & Schultes 2005; Simandl 2002) and good exploration potential for the discovery of brucite deposits (Simandl *et al*. 2006). It has serpentine tailings from the closed Cassiar mine operation (Voormeij & Simandl 2005) which are chemically similar to those used by Noranda's Magnola project. It is also home to several Mg-olivine/serpentine deposits. Leader Mining International Inc. is considering developing one of these olivine deposits through its wholly owned subsidiary, North Pacific Alloys Limited. Magnesite deposits outside of China, located near existing infrastructure, in geographic areas with inexpensive energy, may become key sources of raw materials for Mg production.

ACKNOWLEDGEMENTS

Laura Simandl from St. Margarets School in Victoria, BC, Canada provided invaluable assistance in the field during the study of Australian magnesite deposits. Brian Grant, David Lefebure and Melanie Irvine of the British Columbia Ministry of Energy and Mines helped to improve early versions of this manuscript. Melanie Irvine also drafted the figures used in this document.

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