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ENVIRONMENTAL CHALLENGES FOR THE MAGNESIUM INDUSTRY

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Abstract

The subject of environmental concerns with magnesium production and magnesium processing first started showing up in technical analysis of problems about the time of Life Cycle Analysis articles. Magnesium is produced and processed in relatively small quantities throughout the world. Annual magnesium production has been around 500-700,000 metric tons per year. This compares to aluminum which is produced in annual amounts up to 35 million metric tons.

There have been some excellent review papers done, but a great amount of the work related to electrolytic magnesium production which was the predominant method of production. That situation has changed totally in the past 10 years and now 85% of the world's magnesium is produced by thermal processes and most of that is in China.

Comparison papers have been written on the environmental impacts of the two main magnesium production processes. As the measurement technology improves and as the total information references are better understood the environmental challenges can be more clearly identified. This paper reviews the situation and suggests some forward looking steps that might need to be taken.

Introduction

Most of the major environmental problem areas can be divided into the electrolytic magnesium and the thermal magnesium production methods. And these areas can again be subdivided into the preparation of the magnesium containing feed materials and the actual processing of this material to produce magnesium metal. All of these areas are impacted by secondary processes which impact the magnesium production such as the production of process power and necessary reduction materials such as 75% ferrosilicon for the Pidgeon thermal reduction process.

The first LCA papers were prompted by the environmental work that was done to get new construction permits for newer electrolytic magnesium plants planned for Canada and Australia in the late 1980's. The work was well done and focused on the GHG (Greenhouse Gas) effect. Some of the work was made part of investigations on the advantage of a lighter weight magnesium car in regard to emissions. For the first time, the advantage of SF_6 as a cover was questioned because of its global warming potential. SF_6 was found to have a global warming potential of 23,900 times that of Carbon Dioxide (CO_2) [1]. This problem was immediately addressed with a partnership between the U.S. Environmental Protection Agency (EPA) and the magnesium community. There were 16 members along with the International Magnesium Association that joined in this work [2]. At that time, the magnesium usage of SF_6 amounted to about 7% of the total world usage. Initially this was estimated to be about 4 kg/metric ton of magnesium product. Later it was found to be closer to 2kg/mt [2].

Electrolytic Magnesium Production

Most electrolytic magnesium production plants have been closed. Some of the original LCA studies were done on the Norsk Hydro plants in Porsgrunn, Norway and Becancour, Québec, Canada [3]. The primary feed for Porsgrunn was sea water and dolomite. Feed for Becancour is magnesite. Total emissions from the two plants were included in the study by Albright and Haagensen. At the time, it was said, "Separate data for emissions from Porsgrunn and Becancour sites during the period 1994 to 1996 were charted. See Table I. For each of the emissions, the 1996 level at Porsgrunn is above the 1995 level at the Becancour plant. This difference arises from the fact that the Becancour plant was constructed with new, improved technology, whereas the older Porsgrunn facility is being continually improved from substantially higher emission levels a decade ago."

Table I. Emissions from Norsk Hydro Production Sites (1995-1996)

	CHC to Water, kg		Dioxins to air, grams		Dioxins to water, grams		SO_2 to air, tons	
Site	1996	1995	1996	1995	1996	1995	1996	1995
Pors-grunn	3.0	3.2	1.3	3.5	2.3	1.6	276	190
Becan-cour	0.4	0.8	0.42	0.51	0.05	0.02	25	3

Albright and Haagensen did not list the production capacities of the plants, although the published estimates for each of these plants were about 40,000 mtpy of capacity [4]. Chlorinated hydrocarbon (CHC) emissions were actually reduced by half at both plants. Dioxins decreased substantially. The authors pointed out, "that in 1997 the permitted values of total dioxin emissions for Porsgrunn are but two grams per year to atmosphere and one gram per year to the water" [5].

Further work on the electrolytic process was discussed in work done by scientists at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia [6]. Unfortunately they used the Australian Magnesium Corporation technology in their calculations. This process was run in a 1500 mtpy pilot operation, but the commercial plant was not constructed. Magnesite was used for the process feed.

The initial calculations were part of a study to assess the environmental impact of a magnesium engine block supply chain. This study also was broadened to include an engine block made from magnesium alloy ingots produced at Becancour and secondary ingots produced in the USA. The study concluded that "the use stage of a passenger car contributes significantly to the total GHG impact of magnesium components over their entire life cycle. A significant reduction in the GHG impact during the use stage, and hence over the entire life cycle, may be achieved from a significant mass reduction of a car by using magnesium components" [7].

A second study was run using a torque converter housing as the automobile part produced [8]. The results were very similar to the engine block study and showed a significant reduction only if there was the substitution of a cover gas which had a lower GWP than SF_6 for the processing. A simple substitution of magnesium without a large reduction in GHG is not competitive environmentally with other metals such as demonstrated in the case of Chinese magnesium.

The development of the new electrolytic reduction plant designs, required environmental permitting and such items as chlorine emissions and dioxin generation were addressed in great detail. In the case of the work by Albright and Haagensen a LCI (Life Cycle Inventory) was developed for Norsk Hydro magnesium plants [3]. Clear tables were developed for both pure magnesium production and for magnesium alloy production. See Table II below.

In regard to the emissions and wastes at Norsk Hydro plants, it was reported that "The solid wastes from Hydro's plants consists mostly of inorganic salts and minerals from the raw materials. This waste is disposed of at authorized sites and does not cause any negative environmental impact. The treatment of gas and waste water on site, along with incineration of residues containing chlorinated hydrocarbons, form a portion of the (LCI) analysis as well."

Table II. Life Cycle Inventory for Magnesium Production [3]

	Pure Mg	Mg Alloy AZ91
Total Energy MJ/kg metal	144	151
Global warming effect kg CO_{2eq}/kg	19	19
Acidification kg/kg metal	0.02	0.025
Winter Smog kg/kg metal	0.015	0.017
Solid Waste kg/kg metal	0.5	0.5
Dioxins to air μg/kg metal	0.24	0.21
CHC to air mg/kg metal	13.7	12.4

The subject of chlorinated hydrocarbons, dioxins and chlorine emissions to air is continually addressed in the design and operation of electrolytic magnesium reduction plants [11]. Newer and better scrubbing technology plus process modifications have made great steps in reducing the emissions. Although the construction of electrolytic plants continues to be slow, the research and development of the new equipment and methods should be encouraged on a global basis.

Thermal Reduction Processes

The silicothermic process has been investigated very carefully in several excellent papers [9, 10]. The basis for most of the work is the Pidgeon process as operated in most Chinese plants. Results of these studies indicate that direct comparison with electrolytically produced magnesium shows the GCI (Global Climate Impact) is much greater for the silicothermic process.

The papers qualify their calculations by noting that the Chinese production is continually being upgraded and the effects of these changes have greatly improved the GCI over the past ten years. One inherent advantage of the Chinese casting operations is that they use very small amounts of SF_6 in the ingot casting operations. This has mainly occurred because the majority of the first plants built in China were very rudimentary and used very simple melting and casting operations with sulfur powder directly dusted on the cast ingots to prevent burning during solidification. As the plants increased in size, most of the operations retained the sulfur dusting for convenience and simplicity.

The Chinese magnesium and ferrosilicon operations were impacted by the 2008 Olympic Games that were held in Beijing. A central approach was taken to drastically reduce emissions during this period. Many of the older and smaller Pidgeon process plants with inefficient collection equipment were forced to close to meet the strict guidelines issued. It is predicted that the central approach to control emissions and to encourage greater energy efficiency will continue. This has recently been seen by new rules that have been issued regarding the size and design of magnesium plants that would be given permits [12].

China, in its 12th Five-Year-Plan, is planning to control its annual national output of magnesium, aluminum, copper, nickel, lead, zinc, tin, antimony, titanium and mercury, with total production not exceeding 41 million mt/year until 2015, according to China Nonferrous Metals Industry Association [12].

The government plans to eliminate magnesium smelters with capacities below15,000 mt/year and requires existing plants to have a minimum smelting capacity of 15,000 mt/year, while new entrants must have a minimum capacity of 20,000 mt/year, Ministry of Industry and Information Technology, or MITT, officials said at a magnesium industry conference in Ningxia in October 2010 [12].

In Beijing, a source with China Magnesium Association (CMA) said, "The government's stricter regulations will be good to the domestic magnesium sector as these will help improve industry management, which is in line with the state's macro goal of energy saving and emissions reduction."

According to MITT, the proposed new regulations will require existing smelters to consume a maximum of 5.5-6.0 mt of coal for one ton of magnesium smelting, and for the new smelters, a maximum of 5 mt of coal. Chinese magnesium smelters, over the past few decades, have been consuming as much as 11-18 mt of coal for each ton of magnesium smelting, although some smelters in the last two years were able to cut the usage to around 5-6 mt coal, following the state's advocating a low-carbon economy, according to CMA [12].

The environmental impacts of the products must be compared throughout their entire life-cycle i.e. from "cradle-to-grave", and this is done by Life-cycle Assessment (LCA), also known as Life-cycle Analysis. LCA allows impacts to be assessed throughout all stages of production and use to final disposal.

A newer study has a focus on the global warming impact; a cradle-to-grave life cycle study is conducted using averaged data for magnesium production in China. Calculations show that the cradle-to-grave global warming impact of Chinese magnesium ingots is 42 kg CO_2 eq/kg Mg ingot, within an uncertain range of 37–47 kg CO_2 eq/kg Mg ingot. The value of impact for the magnesium produced in China is ~60% higher than the global warming impact of aluminum, a competing material that is also produced in China in abundance [13].

The results of other recent studies show that the direct emission of fuel combustion in the process is the major contributor to the pollutants emission of magnesium production. Global warming potential and acidification potential make the main contribution to the accumulative environmental impact. The different fuel use strategies in the practice of magnesium production cause much different impacts on the environmental performance. The accumulative environmental impact of coal burned directly is the highest, and that of producer-gas comes to the next, while that of coke-oven gas is the lowest [13, 14].

Much of the fuel-based pollution will be addressed under the new rules and natural gas is being designed into many of the newer plants where it is available.

Discussion

We know that magnesium is the lightest structural metal and it is basically available in limitless quantities. The earth is literally covered with magnesium as one cubic mile of seawater contains 6,000,000 tons of magnesium and there are 330,000,000 cubic miles of seawater according to The Scientific American. There is magnesium in all of the major salt lakes in the world and it is found in deposits in various forms on all continents.

Unfortunately, it is not easy to recover economically due to some basic quirks of chemistry and the mechanical properties of the final metal produced have some serious limitations. The lightweight that makes magnesium as attractive as a material of construction is also a penalty in the modern method of calculation. Plants are rated in tons per day or tons per year. Extrusion presses are rated by tonnage. Rolling mills are rated by tonnage. Environmental emissions are rated by tonnage. One ton of magnesium is much larger than a ton of lead, hence it takes more material and more processing to produce the end product.

This phenomenon was discussed by Albright and Haagensen [3] where they say, "The energy consumption (at the primary plant site only) to produce magnesium and aluminum has been estimated as 35 and 30 kWh/kg. The comparative number for steel is about 11kWhr/kg. However, when these data are considered on a unit volume basis, which is the common design concern (that is, components must be designed or packaged into a given space or volume), the life cycle advantage of magnesium is more clear. On this basis, the above numbers correspond to 63, 81, and 87 kWh/l for magnesium, aluminum and steel, respectively. For recycled materials, the relative energy used is even more favorable for magnesium; with recycled magnesium energy consumption is only about 1kWh/l."

Cherubini et al. [15] conclude that "World magnesium production contributes to the Global Warming Potential with an emission of about 25.5Mt of CO2 eq. per year. This will be lowered as the substitutions and elimination of SF_6 is taken into account with improved energy efficiency.

China has the higher emissions, but it is important to notice that while it supplies the Magnesium market with about 77% of total production, in terms of emissions it accounts for about 89.7% of the total: Mg industrial production in China is thus more polluting than in other countries, although, by an economic point of view, it is cheaper. This aspect is even more clearly shown by the Acidification Potential (where the contribution of Chinese Mg to the total AP is equal to 93.1%), because of the relatively high sulfur content of the low-grade coal used in China [13].

These concerns are being addressed by several approaches in China and in the many major magnesium production research centers that they have recently established. The newest developments in China indicate that the major environmental challenges are being aggressively addressed by both private and governmental strategies.

The price of magnesium on a world wide basis is still quite high. Most of the small Chinese Pidgeon process plants that used coal for firing and large quantities of hand labor are slowly disappearing. Larger, more efficient plants, with advanced technology for the process and equipment are being built. All areas of the Chinese metals and magnesium community has become very aware of the global climate situation and are working very hard to become cleaner and more energy efficient.

The Chinese are approaching the problem of addressing GWI by improving the production plants and working hard in downstream processing to produce lightweight magnesium products for use in bicycles, motorcycles, cars, trains and airplanes.

The China Magnesium Association (CMA) review of 2009 [16] said, in part: "China's magnesium industry still faces huge challenges of adjusting structure and transforming development mode in 2010. The capability of independent innovation and core competitiveness need to be promoted. It's a brand new topic and task to revive the increasing of magnesium output and improve economic benefits, to expand the domestic demand and guarantee the growth, and to make more breakthroughs in domestic consumption." CMA tried to outline a development layout for China's magnesium industry and bring forward some ideas in the face of weakening global demand for Chinese magnesium.

Developing more new technologies of conserving energy and reducing emissions, developing low-carbon magnesium industry

- Developing and using high-efficient and energy-saving MELZ double-chamber shaft kiln, direct heat-storage U-kiln and annular shaft kiln;
- Developing and using reduction furnace clean production system with vertical retort in which briquette is loading from the top and slag is dripping out of the bottom;
- Developing and using new electric Magnetherm technology;
- Developing electrolytic method of magnesium smelting;
- Recycling the waste heat of magnesium residues;
- Recycling carbon dioxide;
- Exploiting new smelting technologies using olivine, serpentine and brucite.

Expanding magnesium application and boosting domestic consumption, trying to build innovative strategic alliances

- Chery, partnered with North University of China and Shanxi Yinguang Huasheng Magnesium Co. Ltd, built a magnesium innovative strategic alliance in the aim of promoting magnesium alloy wheels' application on automobiles;
- CHANA Automobile built an innovative strategic alliance cooperated with Chongqing Boao Mg-Al Manufacturing Co. Ltd. And Chongqing University in the aim of promoting magnesium alloy's mass application on automobiles;
- Promoting magnesium alloy's application on trains.

China will continue industrial restructuring for the purpose of optimizing magnesium industry and upgrading competitiveness.

Targets will be to achieve low carbon economy, symbolized with low energy consumption, low pollution and low emission, they are now orienting and guiding the business of industrial restructuring. China efforts should be stepped up to adjust the structure of product, industry and industrial distribution in terms of the Planning for Adjusting and Reviving of the Non-ferrous Industry.

- ✧ Main smelters are gradually congregated in resource- and energy-intensive areas while processing companies are located in consumer-intensive areas;
- ✧ More products of high-quality, high value-added, high technology content and high competitiveness are manufactured;
- ✧ The development mode of energy-saving, low emission, clean, safe and recycling is widely adopted.

Boosting China magnesium's quality and profitability by transforming development mode

- ✧ To set up magnesium industry model bases and strength their guide role by enhancing their ability of independent innovation, extending and maturing industry chain as well as expanding industrial scale;
- ✧ To eliminate the under-developed capacity through competition. It is urgent requirement of transforming development mode and enhancing economic growth quality and profitability. It's also requirement of dealing effectively with financial crisis. Similarly, it is requirement of promoting energy-saving & emission-reducing and tackling global climate changes.

The Chinese review concluded by saying "In the era following the financial crisis of 2008, we believe that the global magnesium industry will have a bright and promising future only if international coordination and cooperation are being increased, only if the idea of win-win is being truly carried out, only if common challenges are being tackled jointly. "

The US Government is also moving more into taking control of the emissions of several areas including magnesium. The reporting of greenhouse gas emissions by major sources of these pollutants is gaining momentum [17].

The U.S. Environmental Protection Agency (EPA) is finalizing requirements under its national mandatory greenhouse gas (GHG) reporting program for underground coal mines, industrial wastewater treatment systems, industrial waste landfills and magnesium production facilities. The data from these sectors will provide a better understanding of GHG emissions and will help EPA and businesses develop effective policies and programs to reduce them.

It is encouraging that the total Global Warming Potential of the magnesium operations is being addressed. It has been reported that carmakers in the EU are cutting their fleets' carbon dioxide emissions faster than expected and will reach the European Union targets ahead of time [18].

Europe has instituted the REACH program which is also covering magnesium. The program is named for the description of Registration, Evaluation, Authorization and restriction of Chemicals. A group of companies with similar interests and handling the same class of materials can form a consortium. This has been done by many of the companies directly importing, using, or producing magnesium metal in Europe. A Substance Information Exchange Forum (SIEF) has been established as a joint registration forum.

Over three months have passed since the first survey carried out by Magnesium REACH Consortium (MAREC) for its members' registration intention. The questionnaire covers the check of substance sameness, indication of envisaged registration deadline, registration intention, nomination of Lead Registrant (LR) and SIEF Formation Facilitator (SFF) and so on. Magnesium Elektron UK won the LR nomination, replacing previous ECKA Granulate Essen GmbH.

Magnesium (EC No.231-104-6) SIEF is a large SIEF with up to 2,441 members. However, it is unexpected that so far only 152 companies have given feedbacks. Furthermore, the number of SIEF members has sharply decreased to 104 now, which greatly increases individual costs. For this reason, MAREC has planned to launch another survey, which is the final survey for registration intentions of SIEF members [19].

In the meantime, it is reported that the use of SF_6 gas has been eliminated in magnesium processing in Europe [20].

Conclusions

Magnesium as an industry has recognized the major problems with its position in Global Warming Potential. Many various companies, researchers, universities have responded rapidly and effectively to identify and address the problems. The largest problem areas have all had actions taken to quantify and address the problems.

China is the world leader in magnesium production and is making great efforts to mobilize an effective force to improve their environment. New magnesium production methods are being investigated and tested for favourable impact on the GWP. They have also started a REACH program and are cooperating with several European groups to get help in establishing their program. Magnesium was not specifically mentioned.

Europe continues to serve as a leader in its aggressive approach to overall analysis and addressing of the problems, including the use of Life Cycle Analysis (LCA) on the newer car designs.

The US EPA actively and positively stepped into the SF_6 cover gas problem as have several producers of more environmentally friendly materials. The Australian research community is also working on cover gas development.

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