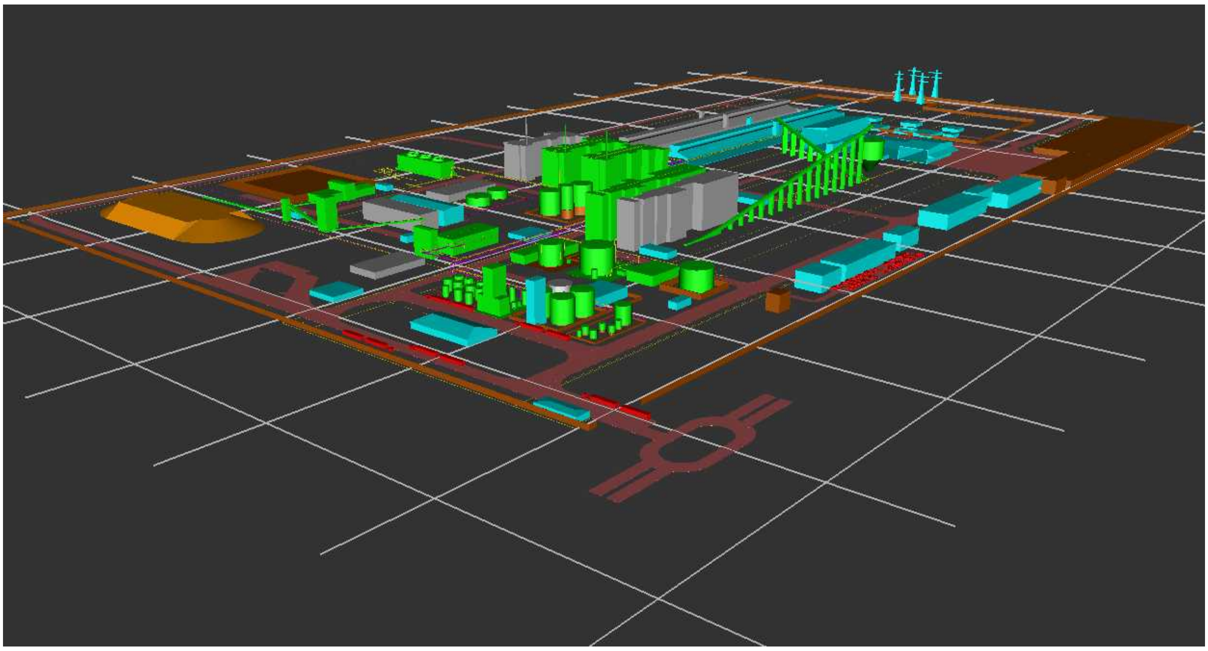
MIL Magnesium Smelter Technology

Information for Sub-licensees

1. Introduction



Revision	Date	Prepared	Approved
3	17 December 2007	P Cameron	P Baily

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1. Introduction to MIL Magnesium Smelter Technology

Executive Summary

Magnesium, a light metal with high strength, finds applications in the aircraft, automobile and steel-making industries. Global consumption of 500,000 tpy has been increasing at 6% per year for the last decade with the market dominated by Chinese suppliers using the thermal Pidgeon Process in small plants with high operating costs.

Market growth and the pursuit by consumers to find an alternative supplier with low operating costs provide a business opportunity for a project utilising the proven Dow electrolysis process.

Production of magnesium in the lowest quartile of the operating cost curve requires:

- Robust electrolysis technology with a proven track record: *Dow produced 3.5 million tons of magnesium*
- Low cost electric power
- Close proximity to the source of magnesium ions (magnesite or sea water and dolomite)
- Low cost skilled labour

Dow Chemical Company developed an electrolysis process for the production of magnesium in 1916 and produced over 3.5 million tonnes of pure magnesium metal and alloys until 1998.

In 1999 Magnesium International Limited (MIL) obtained the license to the Dow Process Knowledge for the production of magnesium metal by electrolysis and the manufacture of magnesium alloys. The original intent was to produce magnesium in South Australia from magnesite sourced from MIL's Mt Hutton deposit.

MIL developed Magnesium Smelter Technology from the Dow Process Knowledge which incorporated process improvements recommended by Dow and accommodated magnesite as the feedstock. The MIL technology was encapsulated in the "Principal's Project Requirements" as the basis for engineering design and construction. However, power and labour costs in Australia were too high to provide an acceptable return on the investment.

Subsequently, MIL re-located the project to Egypt where power and labour costs were relatively low. Studies for a 100,000 tpy magnesium smelter indicated a favourable return on investment could be realised:

- Capital cost estimate was in the order of USD 550 million
- Operating costs of 60 US cents per pound of magnesium alloy were in the lowest quartile for the magnesium industry
- Internal Rate of Return on investment was >25% at a price of USD 1.45 per pound Magnesium alloy; current price (May 2007) is >USD 1.60 per pound
- Environmental Impact Assessment for the smelter was approved

- The smelter would have 540 employees and consume:
  - 220 MW of electric power
  - 400,000 tpy of magnesite
- Construction quantities for the smelter were estimated at:
  - Concrete: 80,000 cubic metres
  - Structural Steel: 10,000 tonnes
- An Independent Technical Engineer reported project risks were low, the capital estimate was to the ±25% accuracy claimed and the implementation plan was appropriate for the project
- A metal sale agreement was in place with Thyssen Krupp Metallurgie for export of product to the automotive industry in Europe and USA but lapsed due to project delays, however MIL believes it can be re-activated if required by an incoming party

Due to MIL's inability to attract financing when the spot price for magnesium alloy was around USD 1.10 per pound, the project in Egypt was placed on a maintenance basis in March 2007.

MIL is seeking to Joint Venture or License the Magnesium Smelter Technology which consists of:

- Dow Process Knowledge: technical reports, operating data and drawings
- Principal's Project Requirements (PPR) developed by MIL
- Engineering carried out by MIL
- Feasibility studies carried out by MIL
- Data and reports on magnesite resources carried out by MIL
- Test-work reports on Mt Hutton and Sul Hamed magnesite carried out by MIL
- Marketing studies by Clarke and Marron commissioned by MIL

The MIL Magnesium Smelter Technology provides a low risk package ready to complete the engineering and construct a sustainable long-term business.

MIL Magnesium Smelter Technology Package

The Magnesium Smelter Technology is presented as a series of papers on relevant topics.

References to supporting documents are available in an electronic "data room" for review by potential sub-licensees. The technology package consists of:

1. Introduction

2. Dow Magnesium Process Knowledge

- Dow Magnesium Process
- Magnesium Document Agreements
- Dow Magnesium Documents
- Ex-Dow Engineers

3. MIL Magnesium Smelter Technology

- Principal's Project Requirements
- Nameplate capacity
- Basic Engineering
- Conceptual Capital Cost Estimate
- Owner's Capital Cost Estimate
- Operating Cost Estimate
- Financial Model
- Feasibility Studies

4. Independent Technical Engineer Review

5. Source of Magnesium Ions

- Occurrences of Magnesite
- Guidelines for Magnesite Quality
- Other Options for Source of Magnesium Ions

6. Selection of Smelter Location

7. Environmental Impact Assessment

8. Marketing

- Clark and Marron projections for supply, demand and price
- Metal sale agreement

9. Risk Assessment

10. Way Forward

- Reactivation plan

Process Description

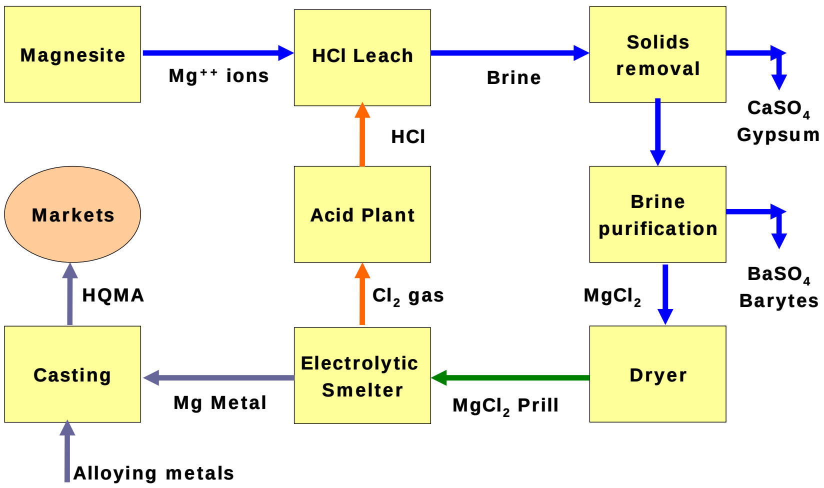
The proven "Dow" process for magnesium smelting was developed in 1916. Dow built seven plants with the last two operating in Texas, USA until 1998.

The Dow process is energy efficient, robust, tolerant of impurities and cost effective. With 50 years of continuous improvement, Dow engineers improved efficiency and productivity by a factor of four. Further improvements can be achieved

The MIL magnesium smelter consists of four main process areas:

1. *Hydrometallurgical plant:*
   - MIL designed the wet plant to leach magnesite ore in hydrochloric acid to form magnesium chloride brine which is purified and dried. Dow previously assessed this process and concluded that it would be economically and technically viable. Norsk Hydro at Becancour use magnesite ore as a feedstock to their plant.
   - Dow used sea water and dolomite to form magnesium hydroxide which was neutralised with hydrochloric acid to form magnesium chloride. The chemistry of this process is similar to the MIL process which uses magnesite ore as a feedstock.
2. *Electrolytic smelter:* Pure $MgCl_2$ solids are fed to a salt bath at 700^0C in the electrolysis cells where it is transformed by an electric current to magnesium metal and chlorine gas. This is the heart of the Dow process and is simple, robust and efficient compared to other magnesium electrolysis processes. This process area is similar to aluminium smelters.
3. *Acid plant:* Chlorine gas from the electrolysis cells is transformed into hydrochloric acid and recycled to the leach. Although similar to other hydrochloric acid plants, the Dow acid plant is specifically designed to accept the off gases of the Dow magnesium electrolysis process.
4. *Casting:* Magnesium metal is alloyed with aluminium and other metals to produce High Quality Magnesium Alloys (HQMA) for the automotive and other industries. This is the same as other magnesium casting operations.

MIL Magnesium Smelter



1. Hydrometallurgical Plant

Magnesite is leached with hydrochloric acid and the $MgCl_2$ brine is purified for feed to the electrolysis process.

This plant consists primarily of tanks and pumps, a thickener, filter, ion exchange and dryer with associated materials handling equipment and intermediate storage facilities. The unit operations are common to the mining and chemical industries. Appropriate materials of construction are used throughout for maintainability; sophisticated materials are not required.

Leach

Magnesite is leached in hot hydrochloric acid to form magnesium chloride brine. Calcium carbonate and other metal ions in the ore also dissolve.

$$MgCO_3 + 2\,HCl \rightarrow MgCl_2 + H_2O + CO_2$$

Carbon dioxide may be sold as a by-product.

The leach step is the only non-Dow step in the process. However, this step was evaluated by Dow and considered to be a viable and cost effective alternative to sea water. Former Dow engineers were involved with MIL in developing this step.

Brine Pre-Treatment

Sulfuric acid precipitates the calcium as gypsum:

$$CaCl_2 + H_2SO_4 \rightarrow CaSO_4 \text{ (gypsum)} + 2HCl$$

Magnesium hypochlorite, $Mg(OCl)_2$, oxidises the leach liquor and MgO neutralises the leach liquor to convert metal impurities in the brine to insoluble solids.

Solids (Gypsum) Removal

Liquid solids separation is by thickening and filtration and solids will be transported to the residue disposal area or sold as by-products.

Purification

Purification, by precipitation and ion exchange, produces high purity magnesium brine to maximise electrolysis efficiency and produce a high purity product. Barium chloride removes magnesium sulfates and precipitates barytes ($BaSO_4$) which will be filtered and co-disposed with the leach residue or sold as a by-product.

$$MgSO_4 + BaCl_2 \rightarrow MgCl_2 + BaSO_4$$

Drying

The purified magnesium chloride solution will be evaporated in a Dow-designed fluid bed dryer to produce solid crystals. Evaporated water is condensed and recycled.

2. *Electrolysis*

Dow designed electrolysis cells filled with molten salts operating at 700^{O}C produce pure magnesium metal:

$$MgCl_2 \rightarrow Mg + Cl_2$$

One cell house (200m x 24m x 21m high) containing 72 cells will be installed for each smelter module. 80 kg per hour (650 tonnes per year) of magnesium metal will be produced per cell.

3. Acid Plant

The acid plant extracts off gases from the cell house which contain chlorine and hydrogen chloride. Chlorine is converted to hydrogen chloride in a gas fired furnace at 1,100^{O}C. Hydrogen chloride gas is absorbed into water to produce hydrochloric acid which is re-cycled to the leach.

4. Casting and Alloying

Pure magnesium metal produced in the cells is alloyed and cast into ingots for sale. The primary alloying elements are aluminium and zinc.

Casting lines produce 8 kg or 12 kg ingots which will be automatically weighed, stacked into bundles, shrink-wrapped and packed into containers.

Engineering Development

MIL carried out engineering to transfer the Dow Process Knowledge to permit the design, construction and successful commissioning of a magnesium smelter.

The technology developed was encapsulated in the Principal's Project Requirements (PPR) which contains for each process area:

- Specifications outlining process description, operational details, instrumentation and process control functions
- Design Criteria
- Equipment List
- Process Flow Diagrams
- Material Flow Diagrams including notes on materials of construction
- Piping and Instrumentation Diagrams
- Equipment design drawings and fabrication specifications

The PPR was used to develop basic engineering and conceptual capital estimates (±25%) for project locations in Australia and Egypt.

Conclusion

MIL Magnesium Smelter Technology is sufficiently advanced to provide a low risk, commercially ready package to complete the engineering and develop it into a profitable long-term venture.

Smelter capacity can be optimised to suit requirements relating to the location.