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THE DEVELOPMENT OF THE MULTIPOLAR MAGNESIUM CELL: A CASE HISTORY OF INTERNATIONAL COOPERATION IN A COMPETITIVE WORLD

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Abstract

The author conceived the first multipolar magnesium electrolytic cell in the late 1970s, in order to offset the impact of an 80kA monopolar cell developed in cooperation with Osaka Titanium Company (OTC) being licensed by Alcan to a major competitor of OTC. During the 1980s the commercial value of the multipolar magnesium cell technology was established. The 1990s saw significant further progress by OTC, while attempts by Alcan to commercialize it in magnesium production plants met with technical difficulties and failure, due primarily to the lack of magnesium chloride feed of adequate quality. Now the author plans to commercialize a new multipolar cell design with a target productivity of 8-10 tons/day and a unit power consumption of 8.5-10 KWHR/kg of magnesium.

Introduction

In 2002 Byron Clow, a retired executive vice-president of the International Magnesium Association, reviewed the history of world magnesium production [1]. He listed the electrolytic magnesium plants being closed in the previous ten years due to a twenty-fold increase in production out of China based on the Pidgeon process. Today, only a handful of electrolytic plants are still in operation. While this evidence is compelling, the magnesium industry has seen dramatic swings in production volumes and technologies before, due to the strategic importance of magnesium for military uses and to alternative process challenges. More recently, for the years 2007, 2008 and 2009, the world economic downturn is reflected in primary annual magnesium production worldwide of 792, 722 and 615 kilotons, of which 627, 559 and 470 kilotons originated from China [2].

Bob Brown illustrates the technology issues in a well researched discussion of the techno-economic scenarios [3]. Having introduced Mr. Brown to a ninety-year-old Dr. Lloyd Pidgeon, I still recall how fascinated I was by the quick and passionate responses of the elder scientist to Mr. Brown's questions. Clearly, if you get the magnesium bug at an early stage in your life, it stays with you forever.

As a freshly minted engineer from Italy, in 1957 I was assigned to trouble-shoot technological problems in an under-performing electrolytic magnesium plant at Alcan in Arvida, Quebec, Canada. In less than a year, the 32kA electrolytic cells were performing well and I was asked to estimate how long it would take to fix the chlorinators next door. On my estimate that it would take at least five years, Alcan decided to strike a deal with Dow. Its budding magnesium operation in Arvida was shut down and Alcan became the agent for Dow, selling Dow magnesium all over the world for many years.

Soon afterwards the opportunity arose to continue development activities to improve the Alcan cell design, which as the first diaphragm-less cell was an offspring of the classical I. G. Farben cell, with North American connotations. The activity was carried out *sub-rosa,* without an official budget and without time-sheets. The skunk works consisted of *ad-hoc* meetings at Place Ville Marie with two friends, John Taylor and Meine Vandermeulen, whenever I was in Montreal for other business. We were called the Magnesium Mafia (Tom Anderson was the Godfather, I was the *consigliere* and John and Meine the hit men). As the world was struck by the first oil shock in the seventies, the stage was set for dramatic improvements to occur in cell productivity and energy efficiency. The Alcan multipolar cell was the product of these converging realities and of the cooperation with a Japanese company interested in recovering magnesium and chlorine from the production of titanium sponge by the Kroll process

Enter Osaka Titanium Company

In 1960, eight of the fifty four 32kA Alcan cells from Arvida found a new home in Japan at the Amagasaki plant of the Osaka Titanium Co. (OTC), a young company in the Sumitomo Group. I went to help in the start up of the magnesium plant at the end of 1961 and I experienced firsthand the technical challenges of a plant start-up together with the hospitality and friendship of the Japanese people. Two persons who stood out were Dr. Toshio Noda, a ceramic art collector at heart and the mover and shaker of the Japanese team, and Junkichi Iseki, a young process engineer who was learning the trade and who was to become the Strait of Gibraltar, through which all subsequent technical developments had to pass. These friends and this first plant start-up experience had a lasting effect on the rest of my life.

After two years of monthly reports from Japan and review notes from Canada, the Japanese team was on their own. By the early seventies, they had managed to expand production by increasing the cell amperage to 40kA and by adding a row of new cells supplied by a second rectifier, but housed in the same cellroom. However, power consumption had also increased to 20 KWHR/kg of magnesium and this meant big trouble for the bottom line of OTC when the *oil-shokku* hit Japan.

Meanwhile, I provided technical support to engineering activities and to another magnesium plant start-up in 1967 by Oregon Metallurgical in Albany, Oregon, a new licensee of the Alcan cell. Following that event, physical and mathematical modeling suggested to us that the power consumption could be reduced to 13.5-14.5 KWHR/kg by increasing the amperage to between 80 and 120kA and by tapering the anodes [4]. A new 100kA cell design was prepared for a Greenfield magnesium project under study by Shell/Billington in the Netherlands, based on deep-well brines discovered in Friesland. The Dutch project never materialized, and the new cell design was presented to Norsk Hydro, who intended to revamp their I. G. Farben technology in Posgrun, Norway. A license deal with Norsk Hydro was never sealed.

On a courtesy visit to OTC, I noticed the two 40kA bussbar loops in their expanded cellroom and proposed to OTC to join these loops together in order to provide a site for a scaled-down 80kA tapered-anode pilot cell. This was done successfully and in 1975 the cell produced magnesium, as per design, at less than 14 KWHR/kg [5]. Other improvements, such as the introduction of a heat exchanger, made its operation easier to control [6].

OTC was building a 100kA cellroom when Timet, their main competitor in titanium sponge production, asked Alcan to license the new 80kA cell to upgrade their WWII-era cellroom in Henderson, Nevada, which was still operating with the original 20kA I.G. Farben cells. In January 1976 I took the Timet team through the Amagasaki plant to show them the 80kA pilot cell in operation. They decided that this design was what they wanted but, as expected, OTC was reluctant to cooperate, fearing the loss of their competitive advantage. During a sleepless jet-lagged night at the Royal Osaka Hotel, I drew up the first sketch for a multipolar cell as shown in Figure 1. In a private session with OTC the next morning, I proposed to work together with them on a new cell based on this idea. It is a sign of trust and of courage that Dr. Noda and his team accepted the proposal and released their support to Alcan for licensing the tapered anode cell to Timet.

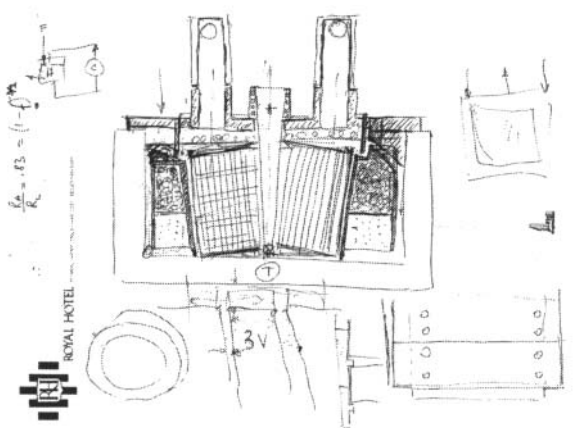

Figure 1. First sketch of a multipolar magnesium cell.

It took until July 1979 to successfully negotiate an agreement on the multipolar cell, but things moved very quickly after the agreement was signed. The events are described in detail elsewhere [7-8]. The design and development activity is documented in several patents [9-13]. The first multipolar cell was started in October 1980 as a retrofitted 40kA cell (AMC1). Twelve other experimental cells at 40kA and one at 100kA were run in 1981 and the 100kA pilot cell was operated while a new magnesium plant rated at 100kA was being built. The new plant adopted the multipolar cell design (AMC3) and started in February-March 1982. The results were a dramatic improvement over the performance obtained with the tapered anode cell, as shown in Table I. In November 1984 the test period was terminated, the objectives of the multipolar cell program having been fully met or surpassed [8].

Table I. Comparative Performance of Magnesium Electrolytic Cells.

Cell type	Power consumption KWHR/kg	Productivity of cell t/day	Campaign Life of cell years
Monopolar			
Alcan 40kA	20	0.4	2
Alcan Tapered	14	0.8-1.1	3
Norsk Hydro	13	4.0	4
MagCorp	12.6	2.8	N/A
UKTMP	13.2	1.8	N/A
Multipolar			
AMC1	16	0.8	N/A
AMC3	10.5	3	N/A
SMC3*	8.5-10	8-10	>5

*Estimated

A joint development program started again in 1989 to develop with OTC a new multipolar cell with removable electrodes [14]. A cell design [15] was finally agreed upon and a full scale pilot test was organized by retrofitting one of the 100kA, AMC3 cells. The first experiment failed because of shorting problems and a second almost had the same fate, as one of the electrode assemblies refused to carry any current. I remember, on the weekend after the start up, going to a Buddhist shrine with Makoto Yamaguchi, a young process engineer in charge of the start up of the second pilot cell, and praying with him for a solution to the mysterious problem (which turned out to be very simple indeed, consisting in raising the electrolyte level to eliminate a freeze-up plug). The new design is still in operation.

In 1995, the Alcan Multipolar Magnesium Cell was awarded the International Magnesium Association Award for Process Excellence, an honor that Mr. Iseki and I accepted in Berlin, Germany, on behalf of our companies.

There is life after retirement

In 1995, at the time of my retirement from Alcan, MagCorp (now US Magnesium LLC) started a revamp project [16]. This revamp was certainly successful and is one of the reasons why US Magnesium LLC is the sole survivor in North America of the onslaught by the silico-thermic magnesium production from China. Nevertheless, it is obvious from the reasons mentioned in [16] that the step from the I.G. Farben technology to the Alcan Multipolar Cell was too risky for MagCorp to take at that time.

My main preoccupation during retirement has been for the Magnola project. After supervising the design of the "slice" for the Valleyfield pilot plant, my offers of advice (centered on the need to develop a probe to monitor on-stream the quality of the

enriched electrolyte in its return path to the cell and being at the intersection between the Alcan and the Noranda technologies) found no takers.

My recommendation to Noranda to continue the operation of the Valleyfield pilot plant while the Danville, Quebec, facility was being built fell on deaf ears. Alcan was mindful that a failure of the Alcan Multipolar Cell in their backyard would be embarrassing, and could compromise any future licensing activity. As the events unfolded, the operation of the plant in Danville proved to be unsatisfactory. Based on information published by Noranda [17], the performance of the Magnola electrolysis cells can be summarized as follows.

As of Q3-2002, some 27 months after equipment commissioning was scheduled to be completed, the plant was producing at a rate of 28,000 tons/yr, against a rated capacity of 63,000 tons/yr, with 20-22 of 24 cells in operation at 65-70% of nominal current. Over the extended start-up period, progress was slowed by numerous problems involving the electrolysis cells, including a fire, electrolyte leakages, premature cell failures and damaged electrodes. A news release has also reported issues with the production of chlorinated hydro-carbons (CHCs) in excess of the levels expected, a telltale sign that the quality of the feed supplied to the cells was below the required standard.

Elsewhere, the operation of a full scale Alcan Multipolar Cell in the pilot plant of the Australian Magnesium Project was reportedly successful. Unfortunately, this project ran into financial difficulties while in the construction phase of the production plant and was suspended. I had the opportunity to meet the team at the Queensland Metals Corp. (Ian Howard-Smith, Ray Koenig) and at the CSIRO (Dr. Malcolm Frost and Bill Kreuse): great engineers and scientists, full of life, talent and vision.

Calendar time is a precious resource to mature one's thoughts and to revisit one's past experiences. Time and again, partially fulfilled objectives can be reviewed and the reasons for some limited successes can be examined. If one keeps the focus on first principles and on the vision of a logical outcome, it is very rewarding to try and solve problems without constraints of project deadlines. This challenge has kept me amused over the last fifteen years, whenever I was thinking magnesium.

The first problem I tackled was to make the electrode assemblies truly removable and replaceable, without emptying the cell. To do that, the curtain wall became a hood attached to a removable cover [18]. Cell campaign life was to be significantly extended by this method. The second challenge was to deal with the issue of ingress of ambient air via the porous graphite anodes. The proposed solution was to insert triangular anodes through the back of the cell, below the electrolyte level [19]. It is well-known that oxidation of the hygroscopic electrolyte leads to poor metal coalescence. The recent paper by Dr. Boyd Davis's team [20] and the video of their lab experiments clearly show the cathodes affected by poor metal coalescence. The trouble is that the solution of the problem proposed in [19] rendered the first objective utterly impossible to achieve.

After several tentative designs, the two conflicting objectives have been finally met in a satisfactory manner. Mathematical modeling has guided the evolution of the cell geometry from the one described in reference [14] to a new cell design, the SMC3, whose estimated performance is reported in the last row of Table I.

A new patent application covering the novel features of this cell design has just been filed as a measure of protection in support of commercialization activities now underway in collaboration with engineering and technology sale partners.

The main claim of the patent application reads: Claim 1. A process for the production of molten magnesium metal by electrolysis in a cell with an electrolysis chamber and a metal collection chamber, said process comprising electrolyzing in said electrolysis chamber an electrolyte containing a fused salt of said metal to produce said metal, said electrolyte having a greater density than said metal, and at least one electrode assembly that comprises a cathode defining within it a cavity, an anode disposed within the cavity and at least one intermediate bipolar electrode disposed between the anode and the cathode within said cavity, said electrolytic cell being characterized by a primary barrier wall that can be separately removed and replaced while the cell is in full operation, as it is for other modular and durable components, such as the cover of the metal collecting chamber and the equipment assembled to it, while the cover of the electrolysis chamber and the electrode assemblies are replaceable by shutting down the cell operation, but without the need to empty the cell, so that the campaign life of the cell and of each consumable component inside it can be extended to their individual useful limit.

Another claim reads: Claim 8. An electrolytic process as claimed in claim 1, characterized by means to increase cell productivity and power efficiency by improvements in metal coalescence obtained by sealing said cell to prevent any ingress of ambient air during normal cell operation into the chlorine room and into the front compartment.

Critical details on how the new cell is going to be built are being designed and tested experimentally to prove their operating reliability in the field.

What will happen next?

Magnesium chloride sources are practically inexhaustible from natural brines and bitterns from solar evaporation of sea water in natural basins or man-made ponds. Oxidic ores are natural products of the reaction of chlorides with CO_2 in the atmosphere and they can be easily converted back to artificial brines. The electrolysis of molecules into simpler constituents has been a foundation for two centuries of industrial inorganic chemistry. The main obstacle to electrolytic magnesium is the hygroscopic nature of the magnesium chloride cell feed. This is where the breakthrough will occur, once we focus on this long-term grand challenge. Unfortunately, in many ways we still require "at least five years to fix the chlorinators next door".

The Chinese are keenly interested in reaching the one-million-ton-a-year production target but the Pidgeon process route will become more and more a handicap for them as their labor rates normalize.

So, the door is open for those who are ready to come through. Young technologists, for example Dr. Boyd Davis of Kingston Process Metallurgy and others with new ideas and who are not

afraid to invest their time and attention on developing the missing link, and engineers with competence in light metals technology will find support either from established industrial enterprises or from entrepreneurs and venture capitalists who can see the long-term potential and the opportunity that lays ahead. Chances are good for the future millionth ton of magnesium to be produced electrolytically.

In what direction is the technology wind blowing? The Kroll process will see the magnesium/chlorine recovery circuit integrated with the titanium reduction step. The production of electrolytic magnesium for sale will see the last step of the feed preparation process done just-in-time, to recover surplus heat from the cell and to avoid any moisture pick up by the feed while in storage. But the two processes will have to sing along carrying the same tune, as, if the quality of the feed is inadequate, the cell will be unforgiving. And, as they say, at the end of the day the process will tell.

Conclusions

Luke 13.12-30 describes how difficult it is to enter the Kingdom of God and how those left out will be weeping and gnashing their teeth. An old magnesium process engineer, after listening to the sermon, approached the preacher saying: "Preacher, but I have no teeth left." To which the preacher replied: "Don't worry; teeth will be provided." For some people, the electrolytic magnesium technology has lost its teeth in the struggle mounted from China by the Pidgeon process. My hope is that they will re-examine their lack of faith or teeth, and find their way to Damascus.

Superficially, my effort may be interpreted as a personal odyssey, but I have attempted to shine some light on the tall people I have met in my journey, who were instrumental in the achievement of the technological progress made over the many years, and to summon the help of some new talent to bring out the full potential of the electrolytic route to produce magnesium.

The human content of a development effort is rarely appreciated by the decision makers, who are more interested in the financial outcome of a project and fail to recognize that the two are intimately linked. Any financially successful project starts with trust and courage and evolves with the tenacity, patience and perseverance of a few individuals who can see the light at the end of the tunnel and are not afraid to be run over by an incoming train. Experience has shown, however, that even if one is on the right track, he may be run over if he does not keep his ear to the ground (see the Magnola project).

Cooperation and competition are the Yin Yang of all business ventures, and the magnesium business has seen both in various times and places, as pointed out in this paper.

Acknowledgments

The history of the multipolar magnesium cell reported here could never have been realized without the efforts of many individuals who soldiered over the years to make things happen. I was fortunate to have met them in the trenches when the technology battles were fought. To them, too numerous to mention, and to those I mentioned and to those who shared data with me in their private communications for this paper goes my deep appreciation.

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