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Magnesium Technology

Edited by

John Hryn

Magnesium Technology 2001

Magnesium Technology 2001

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John N. Hryn

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PREFACE

PrefaceMagnesium technology is evolving rapidly to meet market demands for this lightest of structural metals, as the success of last year's inaugural magnesium technology symposium demonstrated. The papers in this volume further document recent advances in magnesium technology. The papers were presented at the Magnesium Technology 2001 Symposium, held at the 2001 TMS Annual Meeting in New Orleans, Louisiana (U.S.A.), February 11 – 15, 2001.

The symposium was divided into seven sessions, to which the seven chapters in this volume correspond:

Magnesium Reduction – Lloyd M. Pidgeon Memorial Session
Refining and Recycling
Casting and Solidification
Alloy Development
Physical Metallurgy
Forming
Corrosion and Future Trends

Of special note was the Lloyd M. Pidgeon Memorial Session on Magnesium Reduction. Dr. Pidgeon was a pioneer in magnesium production technology; his Pidgeon process for producing magnesium metal is still used today, as discussed in a number of papers in the session. The session included a keynote paper describing his career and achievements. His daughter, Ruth Pidgeon Bryson, offers some personal reflections on her father in the Foreword to this volume.

Almost all papers presented here were reviewed for format and technical content. The result, I believe, is a volume of high technical quality. I thank the review committee (composed of the seven session chairs) for their efforts in critically reviewing the papers, and the authors for providing revisions of their papers in time to meet the publication deadline. Thanks also go to the staff at TMS for their efforts to get the volume published prior to the meeting date.

I acknowledge and thank the other members of the organizing committee for their efforts in organizing and promoting this symposium. Joining me on the organizing committee for the Magnesium Technology 2001 Symposium were:

Byron Clow, International Magnesium Association
Gerald Cole, Ford Motor Company
David Creber, Alcan International
Russell Jones, Pacific Northwest National Laboratory
Howard Kaplan, Magcorp
Ramaswami (Neel) Neelameggham, Magcorp
Eric Nyberg, Pacific Northwest National Laboratory
Mihriban Pekguleryuz, Noranda
Nigel Ricketts, CSIRO
Kevin Watson, Noranda

Along with me, these organizers also formed the nucleus of the new Magnesium Committee under the auspices of the Light Metals Division of TMS. The objectives of this committee are to hold an annual symposium on magnesium technology, publish the Magnesium Technology volume, and increase the awareness of magnesium technology worldwide.

Finally, I thank my family, Roberta, Alexander, and David, for being with me in my thoughts wherever I happen to be or whatever I happen to be doing. You make life worth living.

John N. Hryn
Argonne National Laboratory
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Editor's Biography

Dr. John N. Hryn is a metallurgical engineer at Argonne National Laboratory and an active member in TMS. He earned his Ph.D. at the University of Toronto in the field of extractive metallurgy and molten salt electrochemistry. As a post-doc at the Massachusetts Institute of Technology, Dr. Hryn designed and performed cell tests with metal anodes in aluminum electrolysis. In 1993, he joined Argonne to work on molten salt battery applications for electric vehicles, and in 1994, he joined the Process Evaluation Section of Argonne's Energy Systems Division. He has worked on a variety of projects, primarily in light metals technology. Currently, he is the principal investigator on a number of research projects in the light metals area, including recycling aluminum salt cake, reduction of aluminum melt loss, and development of inert anodes for aluminum and magnesium production. Dr. Hryn's research interest is in developing cost-effective and environmentally sound technologies for metals production, processing, and recycling.

FOREWORD

Lloyd Montgomery Pidgeon, 1903-1999

Lloyd Montgomery Pidgeon died at age 96 on December 9, 1999, his long life almost spanning the twentieth century. His career as a scientist and teacher, which is honoured by the Lloyd M. Pidgeon Memorial Session of The Minerals Metals and Materials Society in New Orleans in 2000, had been a distinguished one.

Eldest son of the Reverend Dr. E. Leslie Pidgeon and Edith Gilker Pidgeon of New Richmond, Gaspé, Quebec, Lloyd was raised in a scholarly household which lived in Ontario and the West, as his father's calling took him to various congregations across Canada, ending in Montreal. He distinguished himself at school and in university: B.A., University of Manitoba, 1925; M.Sc. Ph.D., McGill, 1929; B.Sc., Oxford 1931 (as a postdoctoral student). He was gold medallist in chemistry at Manitoba, and Ramsay Memorial Fellow from Canada to Oxford in 1929 (his younger brother was to follow as Rhodes Scholar from McGill to Oxford in 1938). Upon his return to Canada, Lloyd became a researcher in the Chemistry department at the National Research Council of Canada in Ottawa, from 1931 to 1943, and was appointed Professor of Metallurgy and Head, Department of Metallurgy and Materials Science at the University of Toronto from 1943 to his retirement in 1968.

As a scientist, Lloyd Pidgeon was known for his development, in the late 1930s and early 1940s, of the ferrosilicon process for the production of high purity magnesium from calcined dolomite, which was quickly transferred to industry in Canada and the United States because of the exigencies of the Second World War. As an academic, his achievement was to modernize and expand the Metallurgy department at the University of Toronto, and, with his colleagues and students, to transform it into a graduate school of international stature, which sent many distinguished graduates to the universities and industries of North America and the world. As a teacher and academic supervisor, his commitment to excellence, his intellectual achievements and strong personality served as an inspiration to his students and challenged them to do their best. For his work, he received recognition and many honours, which were always modestly and gratefully received.

Lloyd's students and former colleagues said of him in 1969 that he "was known to all of us for his quick wit, his deep intellect, and for his fairness and strong liberal views." That is a fitting epitaph for the person and scientist whose life and achievements are commemorated by this memorial session.

Ruth Pidgeon Bryson
Kingston, Canada
December 8, 2000

Session One:
Magnesium Reduction - Lloyd M. Pidgeon Memorial Session

Session Chair:
R. Neelameggham, Magnesium Corporation of America

LLOYD M. PIDGEON – MAGNESIUM PIONEER

December 2, 1903 – December 9, 1999

Robert E. Brown

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Abstract

Lloyd Montgomery Pidgeon was an unusual man in an unusual time. His contributions to the development of the magnesium industry have never been appreciated (or even known) by many of today's magnesium followers. Dr. Pidgeon, working with one technical graduate, achieved commercial development of a process to produce magnesium by reducing calcined dolomite with ferrosilicon, i.e. the silicothermic process. He also received patents for electrolytic magnesium processes. He worked with engineers to design and build six magnesium production plants in a very short period of time. The original plant at Haley, Ontario is still operating. Dr. Pidgeon received many technical honors, but was always quick-witted, with a humorous approach to life.

Background

Much of the content of this keynote address is derived from personal interviews with Dr. Pidgeon and from valuable information supplied by Ruth Pidgeon Bryson, his daughter. I personally had a chance to work briefly with Dr. Pidgeon in 1960 when he was retained as a consultant to a new silicothermic magnesium plant in Selma, Alabama. As plant metallurgist, I was part of a team that was struggling to learn how to operate a Pidgeon Process plant.

In 1994, I had the opportunity to personally spend a full day with Dr. Pidgeon and his wife Frankie, who had accompanied him to Selma in 1960. Neil and Ruth Bryson were hosts and guides during this visit which resulted in a biographical sketch printed in Light Metal Age magazine in April 1995.(1) Much of this paper is directly derived from that work.

Biography

Lloyd Montgomery Pidgeon was born in Markham, Ontario in 1903. In discussing his birth, Dr. Pidgeon said he was reminded of the old joke where the Englishman said he was born in Singapore because his parents happened to be there and he wanted to be close to them. Pidgeon's father was a Presbyterian clergyman. Dr. Pidgeon said that he does not remember Markham, but does recall living in St. Thomas, which was located near London, Ontario, on the Michigan Central Railroad. The family moved to Vancouver prior to World War I. His father, Dr. E. L. Pidgeon, was somewhat of a freethinker and was not happy in conservative Vancouver. He moved the family to Winnipeg, Manitoba, where he became a leader in the movement for Protestant church union in Canada. Dr. Lloyd Pidgeon received his B.A. at the University of Manitoba in 1925.

The family moved to Montreal in 1925. Dr. Pidgeon's father moved to a church near the McGill University campus. Lloyd Pidgeon then continued his advanced degree work at McGill University. His doctoral work was on cellulose. He was interested in the paper industry and a Cellulose Institute was planned for McGill. Receiving his Doctorate under the direction of Dr. Otto Maas in 1929, Dr. Pidgeon found that there were very few jobs available.

He sought and won a fellowship grant: The Sir William Ramsay chemical scholarship to Oxford. (Dr. Pidgeon pointed out that Ramsay was the discoverer of the rare gases, helium, xenon, neon, and krypton). At Oxford, Dr. Pidgeon actually worked on and received a B.Sc. Degree under the direction of Sir Alfred Egerton. His work was in the field of anti-knock compounds; investigations were conducted to actually determine just exactly what the "anti

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knock" mechanism did. This was his first exposure to working on high temperature processes. He joked that he only "professed metallurgy" since his Ph.D. was in chemistry. He left Canada in 1929 just as the Great Depression was beginning and returned in 1931.

Dr. Pidgeon was married to Frances Rundle in Winnipeg in 1928. The Rundle family was one of the pioneer settlers of Winnipeg and Western Canada. The couple lived together for 66 years. (Mrs. Pidgeon passed away in Dec 1994). After completing his studies at Oxford, Dr. Pidgeon returned to Canada and got a job with the National Research Council. His work was centered around experimentation with carbon black and on the utilization of Canadian natural gas (then becoming available in Alberta) to make carbon black for the reinforcement of rubber.

General A.G.L. McNaughton, an ex-military man was the head of the NRC. As war in Europe seemed near, the General felt that magnesium would be needed. He ordered the head of the chemistry department to put someone on magnesium research. Dr. Pidgeon was handed the undefined assignment.

Dr. Pidgeon began to work on the chlorination of brucite and subsequent electrolysis. He went on, "We had an associate committee on metallic magnesium which was set up with representatives from the Research Council, namely me, and a couple of fellows from the Mines Branch (normally responsible for metals) and a couple from the Armed Forces."

Based on literature research, two basic processes were chosen: the electrolysis of a fused salt and a distillation process that depended on the relative volatility of magnesium. Pidgeon advertised for a high-temperature electrochemist and hired Norman Phillips who immediately started to work on the electrolysis process based on the chlorination of brucite.

Dr. Pidgeon is given full credit in the published literature and technical reference books for developing and commercializing the magnesium production process that used silicon (in the form of ferrosilicon) to reduce calcined dolomite. [Note: Pidgeon reiterated over the years that he did not invent the process or put his name on it. Someone else did that.] It sounds very simple today in the brief encyclopedic descriptions. However, picturing an organic chemist with one assistant struggling with the total literature picture of magnesium production in 1938 is mind boggling. General McNaughton finally said that they were to develop a magnesium process that was energy efficient and would have to use readily available, native Canadian materials. The work with electrolysis was dropped and work was concentrated on the thermal reduction process.

The literature contained some references and patents of the work that was being done in Germany on thermal reduction. However, the process would depend on the ability to produce magnesium vapors and condense them. They would have to be produced by the high temperature reduction of MgO by a suitable reducing agent and the condensation of the evolved magnesium vapor into a dense, solid form.

Only two practical reducing agents were considered: carbon (Hansgirg Process) and silicon. Carbon, by far the cheapest, was ruled out because of its volatile oxide (carbon monoxide). Silicon was readily available as ferrosilicon. The reaction of ferrosilicon and calcined dolomite will produce magnesium vapor, the pressure of which will depend on the temperature of the system. The published vapor pressure over the charge was reported by Doerner of the U.S. Bureau of Mines to be 1.5 to 2.0 mm at 1100°C. This made it unlikely that there could ever be a commercial process developed in a temperature range that would permit alloy steel materials to be used for construction.

At this point, Dr. Pidgeon of the National Research Council in Canada and Glenn Bagley of Union Carbide in the U.S. conducted experiments which were designed to verify the vapor pressure of magnesium over the dolomite charge at 1100°C. They worked separately and independently with no knowledge of the other's existence. They both came up with the determination that the pressure over the charge was actually more in the order of 30 mm. This would make it possible to design steel reactors to produce magnesium. Pidgeon went with the horizontal tubular retort and Bagley went with very large vertical retorts (2).

Laboratory experimentation was conducted on a simple retort process by the NRC. Experiments concluded that it was possible to use silicon to reduce calcined dolomite and produce commercial magnesium at temperatures where an alloyed steel retort would have a reasonable life. After the pilot plant was built with 2-4" retorts, the first indications that alkali metals could become a problem were seen. These metals, mainly sodium and potassium, would not condense easily and would sometimes run out of the retorts. Special design modifications had to be made as the process developed to handle the sodium and potassium contents.

One of the big secrets of the Pidgeon Process success was the fact that the process was designed to be operated continuously at the reduction temperature. This prevented the large grain growth in the retorts that was so evident in the other processes such as the Bagley process that involved heating and cooling. Dr. Pidgeon also proved that it was also true that the condensing had to be done at a high temperature to get good crystalline deposits with no powder.

At this point, because the NRC did not go beyond the laboratory experimental stage, outside help was sought to continue process development. Two Canadian gold miners, Walter Segsworth (Mich. Tech '06) and Robert Jowsey, were looking for ways to help the Canadian war effort. They searched for a suitable source of dolomite and eventually found a very pure deposit in the Ottawa valley near Haley, Ontario. The promoters also included Thayer Lindsley (Falconbridge Nickel). They built a 5,000-tpy silicothermic plant at Haley, Ontario, adjacent to a very pure dolomite deposit. The company was called Dominion Magnesium and continues to operate today as Timminco. Dr. Pidgeon was appointed to be Director of Research at Dominion Magnesium in 1941.

Major C.J.P. Ball, the British magnesium pioneer said, "This successful translation of the Pidgeon Process from pilot plant to commercial production in such a relatively short period of time was a remarkable achievement, of great value to Canada and the USA, where five similar plants were built."(3)

During this time, Dr. Pidgeon was immersed in the rapid development of magnesium that was taking place throughout North America. He was contacted by many industrialists, including Henry Kaiser, for advice and consulting for silicothermic magnesium plant design. He worked with a large engineering firm, Singmaster and Breyer, to design and construct several of the plants built by the US Defense Plant Corporation. One of these plants was located at Luckey, Ohio and was run by National Lead. This plant was the most efficient of all the Pidgeon Process plants. (The plant manager was Edward Rowley, later Chairman of NL Industries and a leading proponent of the Great Salt Lake Magnesium project. The Luckey plant engineer was Robert Couch, later President of Amax Specialty Metals, who purchased the GSL Magnesium plant from NL Industries.}

Dr. Pidgeon was appointed Professor and head of the Department of Metallurgical Engineering at the University of Toronto in 1943. He was very successful in building a strong graduate school in Metallurgy and his department was one of the best in Canada. Many of his graduate students went on to leading positions in industry and academia. His appreciation of the physics of metals led to the growth of physical metallurgy. The department also expanded to include Material Science in 1965. He retired and was made Professor Emeritus in 1969.

Dr. Pidgeon was awarded major honors including the MBE (Member of the British Empire, awarded by King George VI), Officer of the Order of Canada, INCO Medal for contributions to Extractive Metallurgy, The Monel Medal of Columbia University for distinguished achievements in Mineral Technology, the Alcan Medal for contribution to the field of Metallurgy, the Falconbridge Innovation Award (with Timminco Metals).

He also received honors from many of the major metals organizations including The International Magnesium Association, The Canadian Institute of Mining and Metallurgy, The American Institute of Mining and Metallurgical Engineers. He is listed in Who's Who in Science, Who's Who in Canadian Science, Canadian Men of Science, and several other publications.

Silicothermic Production

The total amount of magnesium produced by the Pidgeon (horizontal retort) Process from the first plant at Haley, Ontario, Canada, through to about 1980 was an estimated 600,000 long tons of magnesium (4). This does not count production from the Italian process, the Brazilian process, the Magnetherm process, nor the Bagley vertical retorts in Spokane. These are technically silicothermic processes, but they use other furnace arrangements.

It appears from the production numbers available, that China has equaled this total magnesium production by the Pidgeon Process. Expansion in the number and capacity of the Pidgeon process plants in China is continuing.

Acknowledgments

The author is deeply indebted to Light Metal Age magazine for permission to use much of this material which was printed there first. Deepest thanks to Neil and Ruth Bryson for their warm hospitality and help in developing the original profile of Dr. Pidgeon. Special thanks to Ruth for her co-authorship of the original biographical sketch of Dr. Pidgeon. (1)

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1. R.E. Brown and Ruth Bryson, "Magnesium Industry Legend", Light Metal Age, Volume 53, No.3 & 4, April 1995, pp. 44-45

2. L.M. Pidgeon and W.A. Alexander, "Thermal Production of Magnesium", Transactions of AIMME, Volume 159, 1944 pp. 315-352

3. C. J.P. Ball, "The History of Magnesium", Presidential Address to British Institute of Metals, 1956

4. Klagsbrunn, H.A., "Wartime Aluminum and Magnesium Production", Industrial and Engineering Chemistry, Vol. 37, No. 7, July 1945

Addendum

List of Canadian Patents by Dr. L.M. Pidgeon

1.	463416	Production of Calcium
2.	424665	Magnesium Producing Apparatus
3.	424664	Volatilizable Metal Recovery Apparatus
4.	424663	Volatilizable Metal Recovery Apparatus
5.	424662	Magnesium Producing Apparatus
6.	420245	Magnesium Production Apparatus
7.	420244	Magnesium Producing Apparatus
8.	420243	Magnesium Producing Apparatus
9.	420242	Ductile Magnesium Production
10.	420421	Volatilizable Metal Recovery Apparatus
11.	420240	Thermal Magnesium Production
12.	420239	Thermal Magnesium Production
13.	415765	Magnesium Producing Apparatus
14.	415764	Volatilizable Metal Recovering Apparatus
15.	412169	Anhydrous Magnesium Chloride
16.	361606	Aromatic Liquid and Carbon Black Production

Author Note

Dr. Pidgeon also has many U.S. Patents that followed the same line as the Canadian patents.

THE PIDGEON PROCESS IN CHINA AND ITS FUTURE

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Abstract

Magnesium production in China has been growing steadily over the past 10 years. Most of the metal has been produced by the Pidgeon process. This process uses horizontal steel tubes called retorts, in furnaces and under vacuum. In the retorts mixtures of finely ground calcined dolomite and ferrosilicon formed into briquettes react to form magnesium vapors which are condensed and later remelted into ingots. The Pidgeon process was long thought to be uneconomic and obsolete. The Chinese have used the advantages of excellent raw material, location, large skilled labor supply, and low capital costs to produce magnesium by this process. The Chinese magnesium is being sold at the lowest prices in the world and lower than aluminum on a pound for pound basis.

Introduction

The first magnesium meal was produced by Fushun Aluminium Plant by the electrolytic process in 1958. The first metal produced by the Pidgeon process was in Nanjing in 1978, but the costs of production were much higher than the electrolytic process. In 1988, Shenyang Al and Mg Engineering & Research Institute completed the design and installation of the first Magnesium plant using the Pidgeon Process. It was located in Tongshan, Hubei Province with a design capacity of 500 metric tons per year.

After this plant was started, two Pidgeon plants were set up in Ningxia with a total capacity of 2000 metric tons per year. Additional Pidgeon plants were built in Shanxi and Henan provinces. The number of magnesium production plants using the Pidgeon Process was over 200 by 1997. The plant sizes varied from 100 metric tons per year to 3000 metric tons per year. The total Chinese capacity was more than 200,000 metric tons per year in 1999, while the actual production reached 160,000 metric tons. There were 3 special features that assisted in the development of the magnesium industry,: 1) Good raw material and large labor supply (no high technology, small investment); 2) Private and family businesses (not the normal state-owned plant); 3) World market oriented.

Magnesium produced in China has had a big impact on the world market. It is available in large quantities for an extremely low price compared with other magnesium. The quantity and price of Chinese magnesium has helped to increase the interest of many industries, particularly automotive. Rapid reduction in selling prices also caused many of the smaller Chinese magnesium plants to close. These closures were also due to the anti-dumping duties and the decrease in the prices in Europe and North America.

Chinese producers are consolidating their process knowledge and working with research and engineering institutions to further improve the process, improve productivity and quality with better service, to reduce costs, and to increase the production capacity.

The development of the Chinese magnesium industry has changed the structure of world supply and demand, facilitated and encouraged the technical development and new applications in many new fabrication and industry areas.

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Present Situation

The Pidgeon Process is used in China to produce over 95% of all primary magnesium. About 40% of the world production is by the Pidgeon Process. Other countries that use the Pidgeon process are Canada, India, and North Korea. Today, there are about 130 plants running with Pidgeon process in China. Average capacity is over 1000 metric tons per year. There are 10 plants with over 4000 metric tons per year capacity and four plants with a capacity of over 10,000 metric tons per year. In the past several years, many of the small magnesium producers have merged together to become larger enterprises.

There are about 10 joint ventures for producing magnesium. The largest foreign investment in these ventures is from Japan and then North America. Participation from Europe has been small. Norsk Hydro is talking about alloy production in Xi'an, Ningxia with a capacity of 5000 mt per year.

In 2000, owing to the weak magnesium market price in the world and new anti-dumping charges in Europe, many small magnesium production in China are expected to close. However, Ningxia Huayuan Magnesium Group plans to increase its magnesium output capacity by 12,000 mt in 2001. Wenxi Yinguang will also add 10,000 mt within 2001, Taiyuan Tongxiang Magnesium will add 7,000 mt at end of 2000. The total magnesium production capacity is expected to be about 260,000 mt in 2001 and 300,000 mt in 2002, including alloys, anodes and powder/granules.

The Pidgeon Process has developed rapidly in China for several reasons:

1. There is a rapidly increasing demand for magnesium on the world market
2. There are convenient circumstances in China, flexible structure, global oriented production and marketing.
3. Excellent raw material. For example, Ningxia has 5 to 100 million tons of dolomite resources; 200,000 tons of locally produced ferrosilicon; 30 to 200 billion tons of high quality Anthracite coal; 2.2 million KW at US$0.03/Kwh; suitable dry climate, annual precipitation of 200-700 mm.
4. Qualified and experienced operating workers; reasonable labor costs; more mechanical/automatic equipment.
5. Plants require small initial investment and have a very short payback period.

Process Improvement History

In the past ten years of operating the Pidgeon process in China, the theory remains the same. However, some technical advantages have developed that have improved quality and reduced the cost of operation.

Technical Improvements in Pidgeon Process

A summary of the improvements that have been made and are being made include the following:

1. Heating of reduction furnace is improved with anthracite or coal powder instead of coal gas. Cost reduction of more than 10 million RMB (about $1.2 million) for one plant with capacity of about 6000 mt per year. It means that the cost of one metric ton of pure Mg metal shall be lowered by $450.
2. Vacuum for the process to be supplied by steam jet ejectors instead of mechanical pumps. The new process is more effective and faster (30 min instead of 2 hours to lower pressure to 10 Pa or under). It requires lower maintenance and no vacuum oil. Steam comes from surplus energy of reduction furnaces in a waste heat recovery boiler. More than US$150,000 shall be reduced in the installation of a 6,000 mtpy plant and 932 KW of electric capacity eliminated. The production costs per ton of pure magnesium shall be reduced by US$80 (for electricity and vacuum oil).
3. Coating the surface of the reduction tubes with special paint would extend the lifetime of the tube from 4 months to 8 months. That will cut costs by US$85-150 per ton of pure magnesium.
4. Weighing and making up the charges will be computer rather than manual, which will increase precision and uniformity of the charges, ending waste, especially of FeSi.
5. Casting ingots in a continuous conveyor by pumping reduces oxidation and burning loss, improved internal cleanliness and surface appearance.
6. Double quality inspections: Chemical and Spectrometer, raw materials & semi / end products.

Prospect of Pidgeon Process In China

Overview

As can be seen from the prior discussions, the development of the Chinese magnesium industry is very young. The production of magnesium metal by the Pidgeon Process is expected to have some impact on the world market.

The total Chinese magnesium production capacity will increase to 300,000 metric tons per year in the next 2-3 years. China's magnesium producers need to improve quality control and service. They need to work to eliminate any anti-dumping charges from other countries, and to help develop the domestic automobile market. Also, if the demand for magnesium in the European and North American markets increases, it will provide a bright opportunity for the Chinese magnesium sector.

Investors from Western Europe, North America, Japan and Taiwan are welcome to work together to develop the Mg sector using the Pidgeon process. The development would be under the fair participation and technology exchange. With the abundance of raw materials in China, the foundation for the magnesium industry is very solid.

Summary

In the last part of 2000, the magnesium price for Chinese magnesium dropped to US$1400 / mt, FOB Chinese port, because of the weakness of the Euro and purchasing panic on the announcement of increased anti-dumping duties in EC. Because there are a large number of small Chinese magnesium producers, independent and speculative traders, a defense against the challenger is very difficult. It can be seen that Chinese magnesium is too dependent on the international free market.

Fig. 1 List of Pidgeon Process Plants with Capacities of over 3000 metric tons per year.

Province (Total plants)	Plant	Capacity (metric tons/year)	Expansion projects for 2000-2001
Henan (45 plants)	Huaqi Mg Plant	8,000	2,000 mt
	Hebi Longxiang Mg Plnt	3,000	Alloy production
	Henan Wuhua Mg Co	3,000	No
	Fuda Mg Plant	3,000	No
	Yufeng Mg Plant	3,000	No
Shanxi (72 plants)	Taiyuan Tongxiang Mg	12,000	7,000 mt
	Wenxi Yinguang Mg	11,000	5,000 mt/2000 5,000 mt/2001
	Taiyuan Tongxiang Mg	15,000	No
	Guangling Jinghua Mg	8,000	No
	Tongbao	6,000	2,000 mt/ 2000
	Wenxi Hongfu Mg	3,000	2,000 mt/ 2001
	Pingding Maikelin Mg	3,500	No
	Taiyuan Longhe Mg	3,000	No
Ningxia (13 plants)	Gold River Mg Plant	9,000	12,000 mt/2001
	Huayuan Zhongwei Changle Mg	3,000	3,000 mt/ 2000
	Huinong Mg Plant	4,500	No
	Huayuan Shizuizhan Mg	8,000	No

Fig. 2 Technical and Economic Comparison between Chinese and Japanese Pidgeon Process.

Item	Unit	Chinese Process	Chinese Process	Japanese Process	Japanese Process
		1995	2000	Koga	Ube
Dolomite	Mt per Mt of Mg	14.0	11.0	12.56	11.52
Ferrosilicon (75)	Mt per Mt of Mg	1.35	1.10	1.20	1.16
Electricity	Kwh/ Mt of Mg	2000	888	1440	2560
Coal	Mt		10.5		
Heavy Oil	Mt				4.31
Coal Gas	Cu M/Mt of Mg	60,000			
Gas	Cu M/Mt of Mg			5090	
Burden/Mg ratio		7-8	6.20	6.25	6.30
Crown Recovery	Per Cent	75	85.5	81.3	83.5
Refinery Recov.	Per Cent	93	96	94.5	93

Table 1. Magnesium Process Comparisons
World Electrolytic vs. Pidgeon Process in Ningxia

Items	Electrolytic	Pidgeon in Ningxia
Investment per Metric Ton of Installed Capacity US$/Mt	Dead Sea Magnesium $15,300/mt	Huayuan Shizuishan $3,370/mt
	Noranda Magnesium $ 8,200/mt	Gold River Mag $1.020/mt
	Australian Average $ 6,100/mt	
Production Costs US$/metric ton	Australian Mag Corp $2,070 /mt	Huayuan Shizuishan $1,446/mt
	Dead Sea Magnesium $1,784	Gold River Mag $1,265/mt
	Norsk Hydro Norway $1,872/mt	
	Norsk Hydro Canada $1,630/mt	
	Russia $1,388/mt	
	Australian Average $1,344/mt	
Quality	CHN GB II-III Mg 99.8-99.90%	CHN GB I-II Mg 99.90-99.95%
Environmental Protection	Chlorine, closed workshop	Clean production, few dust and SO_2

Comments and Opinions

1. The capacity of Chinese magnesium industry shall be increased to meet the world demand. The price will be going down further to where the supply and demand of domestic supply shall be changed slightly. Under this assumption , the Mg supply and demand gap will be widened in the world market in 2000-2001. However, after this period, the outlet for this demand will increase.

2. The low price and large capacity will make it difficult for new projects already running or just being planned. But it will encourage new applications in different areas. If China can enter the WTO smoothly in 2001, we believe that western enterprises will participate in the magnesium industry in China.

3. Because of unreasonable anti-dumping duties, the export of Chinese magnesium shall be prevented from reaching many markets.

4. Use of magnesium in the domestic market by automotive, electronic, and metallurgical industries is an important factor. But it is presently a secondary role as they need qualified manpower, machinery , money and markets.

5. The price of alloys is directly affected by the price of pure magnesium. The price will continue to stay low for the next few months. Further effort to improve the quality and service is needed. Aluminum and magnesium prices are related. Magnesium is used in many aluminum alloys. A magnesium price of US$1,900 to 2,100/mt would be very good both for the users and the producers.

CHINESE ADAPTATION OF THE PIDGEON PROCESS

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Abstract

The author recently participated in the first Chinese Magnesium conference in Beijing and visited 5 plants, 4 of which were primary producers and 1 which was only a recycler. He will discuss the Chinese method for producing ultra low-cost Mg and will examine the potential impact of this low cost metal on the West. He will support his observations through video analysis of the modified Chinese Pidgeon process.

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VERTICAL LARGER-DIAMETER VACUUM RETORT MAGNESIUM REDUCTION FURNACE

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Abstract

A new magnesium reduction technique has been developed to improve the Pidgeon reduction process. A demo-plant of 1000t magnesium per year succeeds in applying this new technique. Firstly, a new furnace is developed and a larger-diameter vertical settled vacuum retort is used instead of traditional horizontal retort. So the furnace can be designed with more compact structure to raise the magnesium output per furnace volume. Secondly, calcined dolomites and ferrosilicon is compressed into given unitary shape for enhancing heat and mass transfer during the reduction and shorten remarkably the reduction time. The shape is designed with reference to the numerical simulation result. Demo operation shows that, with application of the technology, significantly production capacity increases in the same furnace, reduction period decreases (only two thirds of the traditional reduction period), energy consumption decreases too, retort's life extends, operation becomes easy and the total production cost reduces.

Introduction

Among the techniques of magnesium production, Pidgeon reduction process is one of those that have been widely applied. The advantage of Pidgeon process is that it produces high purity magnesium that especially meets the requirement of automotive industry. Its shortage is that in the commonly used horizontal reduction furnace (Figure 1), heat and mass transfer conditions in the retort is very poor, so that its energy consumption is high, productivity is low, operating condition is intensive, unit investment is high, facility needs more area and it is not suited for large scale production and management.

Based on the situation of China resources, Pidgeon process will still be the main technique for producing magnesium in future. This paper will introduce a Vertical Larger-diameter Vacuum Retort Magnesium Reduction Furnace and its demo-plant of 1000t that has overcome the shortage of horizontal magnesium reduction furnace, and that will make larger-scale production by using Pidgeon process possible.

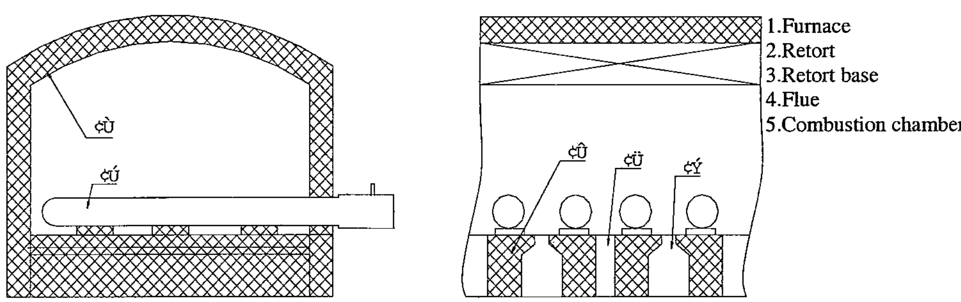

Figure 1: Typical horizontal retort reduction furnace

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Enhancing Reduction Process

Horizontal retort

In the horizontal reduction furnace, calcined dolomite and ferrosilicon (>75%Si) are finely ground, mixed, and compressed into briquettes, then packed in paper bags and thrown into the retort. At a temperature of 1150℃~1200℃ and 5-20 Pa vacuum, after 12-14 hrs chemical reaction, magnesium is reduced. Figure 2 shows a section draft of a typical horizontal retort.

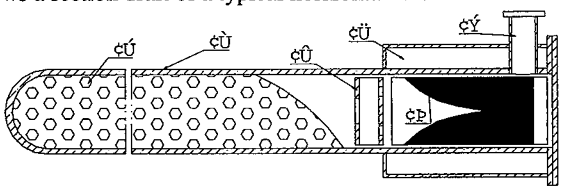


Figure 2: Typical horizontal retort

1—Retort, 2—briquettes, 3—Baffle, 4-- Cooling jacket,
5-- Vaccum pipe, 6-- Crystal magnesium

In the process, due to its structure, heat can only transfer in one direction, meanwhile the heat conductivity of retort contents is very low, so it warms up very slowly, thus cause the long reduction time cycle and vast energy consumption. Since the retort diameter is short, the material loading is little, so the productivity is not high.

Vertical retort

To overcome the shortages of horizontal magnesium reduction furnace, and make large-scale production by using Pidgeon process possible, heat and mass transfer of material in the retort must be enhanced. In view of the shortages of horizontal retort, vertical retort is introduced to shorten reduction time, reduce energy consumption and increase loading of unit retort through enhancing reaction process.

1—Retort,
2—Circularity Reduction stuff
3—Suspender & heat reflector

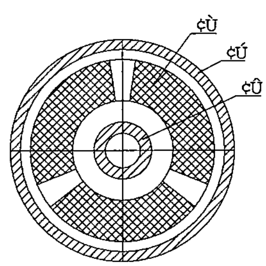
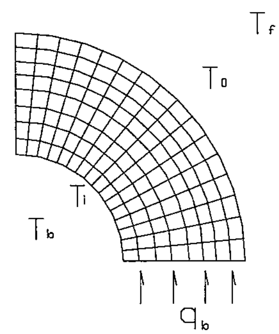


Figure 3: Section draft of vertical retort

It is shown in Figure 3 that calcined dolomite and ferrosilicon are mixed, crushed and compressed into circularity with slots. All circular stuff are overlapped on a suspender, and then put into furnace by using a lift. Due to slots in the circular stuff, the retort can heat the metal suspender through radiation quickly, and make the suspender become another heat source, thus change the heat transfer from one way to two directions, heat transfer in the stuff is thus enhanced. Meanwhile, slots in the stuff, spaces between suspender, stuff and retort also improve the mass transfer condition. So the stuff can be heated up quickly, and the reaction speed is faster.

Numerical optimization

A numerical model of heat and mass transfer in the vertical retort was set up. Figure 4 shows the two-dimensional model structure. There is radiation heat exchange between retort and stuff outer surface, between retort and suspender, between suspender and stuff inner surface, and between retort, suspender and slot sections. In the stuff, there is conduction heat transfer from surface to center, and also convection heat transfer and mass transfer while magnesium is reduced and magnesium vapor moves out. The model is to optimize the process, the dimensions of retort and circular stuff, and reaction cycle. Calculation was validated by experimental and operation data.



T_f—Retort temperature
T_o—Stuff outer temperature
T_i—Stuff inner temperature
T_b—Suspender temperature
Q_b—Heat flux

Figure 4: Model structure

Example of calculation results

Under the conditions of same/different thickness, loading and retort temperature, reaction processes of circular stuff with and without slots were all simulated. Table 1 is one of the results.

Table Ⅰ Comparison for different shapes with same loading

	Horizontal retort	Vertical retort	
		Without slots	With slots
Retort dimension (mm)	D300x2700	D300x1800	D300x1800
Circularity thickness (mm)	/	60	60
Stuff Loaded (kg)	150	150	150
Reaction time (hrs)	12	12	7
Stuff magnesium ratio	7：1	6：1	5.5：1

Vertical Retort Reduction Furnace

Based on the above analysis and study, a new reduction furnace was designed. The retort is set vertically in the new furnace, instead of horizontally, thus the structure of the furnace is entirely different from the old one. Figure 3 is a section draft of the new vertical retort reduction furnace. It is composed of retort (vertical), furnace and combustion chamber. It can burn gas, diesel, heavy oil or coal. Reduction stuff is first pressed into pellets, and then compressed into circularity with slots as shown in figure 2. Stuff is set on the suspender and then put into furnace for reduction. In designing the new furnace, numerical optimization was used for