CANADA/ALBERTA MINERAL DEVELOPMENT PROGRAM

ECONOMIC DEVELOPMENT SECTION

CANADA/ALBERTA AGREEMENT ON MINERAL DEVELOPMENT

Economic Analysis Study

Economic Analysis of Extracting Calcium Chloride and Magnesium Chloride from Alberta Brines

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ABSTRACT

Both in Canada and the United States the production of calcium chloride and magnesium chloride is characterized by one dominant central producer and a number of smaller satellitic producers. The market for each product is mature and shows no signs of significant growth in the near term. Production capacity of all plants for both products is underutilized because of an oversupply of product in each market. Both the calcium chloride and magnesium chloride industries produce a wide variety of value-added products some of which are market ready and some of which serve as raw materials for further processing in allied industries.

The estimated fixed capital cost, in 1993 dollars, to construct a brine processing plant in Alberta to produce 28,406 tonnes per year of magnesium chloride and 46,480 tonnes per year of calcium chloride is $52.6 million. It is estimated that the average unit cost of production for a combined calcium chloride-magnesium chloride plant would be $299.69 per tonne. This results in an operating loss per tonne for calcium chloride of $65.19 and an operating profit per tonne for magnesium chloride of $112.35. A net annual operating profit of $160,000.00 before tax would be insufficient to retire the fixed capital cost investment of the plant over a 20 year life. This means that the investment in uneconomic.

Upgrading of brine feedstocks must be achieved either by employing solar evaporation or by discovering richer natural brines. Upgrading of brine feedstock through solar evaporation may contribute to the lowering of operating costs per tonne of production. Solar evaporation may also represent a lower initial capital cost alternative to the use of multiple effect evaporators. Additional research is required to evaluate these alternatives.

Through the servicing of local markets, where a product of comparable quality can be offered, a cost advantage may exist based upon lower transportation costs to the consumer. Further reductions in

transportation cost could be achieved through the application of advanced technology to reduce the bulk of the product. On this basis opportunities for market penetration may exist on a regional basis.

Potential secondary economic benefits accruing from the development of the brine processing industry may include the production of magnesium metal from a mothballed magnesium smelter in Aldersyde, Alberta.

INTRODUCTION

This research program was initiated following the establishment of two geoscience programs administered by the Geoscience Technical Committee of the Canada/Alberta Agreement on Mineral Development. These ongoing geoscience programs, each in their first year of research, are entitled;

- "Brine Resources of Alberta" - Geological Survey of Canada
- "Evaluation of the Potential for Recovery of Industrial Minerals from Alberta Brines" - Alberta Geological Survey

These programs are geoscientific in nature and are designed to identify, evaluate and define the known brine resources of Alberta and potential methods of extracting economic industrial minerals from them.

The purpose of this study is to assist the two Geoscience programs by examining the economic and market framework within which Alberta brine production must compete. This examination identifies economic strengths and weaknesses in the proposed development of the industry in Alberta and recommends additional research which is aimed at reducing the overall capital and operating costs of a proposed plant.

This study is economic in nature and takes the form of a literature search which examines the current markets for calcium chloride and magnesium chloride, their respective production methods and identifies major North American producers and their relative impact on the supply of each chemical. Current uses and applications are addressed with a breakdown of their relative importance to the industry. An historical review of the price performance of each chemical when compared to selected economic inflation indicators is presented. An assessment of fixed capital and operating costs is presented. In addition, an indication of the level of profitability is advanced. Areas of sensitivity are identified which impact the profitability of the operation.

Finally, a look into the future examines the direction in which the markets are moving as well as new uses for each product and expected rates of growth in demand for each chemical. From this information an opportunity which exists in Alberta is identified and strategies for the establishment of an economically viable industry are presented.

The fixed-capital-cost, operating cost, and profitability estimates presented in this report are intended for use, only in this study, as "order of magnitude" estimates which have been interpreted and extrapolated from other sources.

OBJECTIVES

The purpose in carrying out this study is to identify economic strengths and weaknesses in extracting calcium chloride and magnesium chloride from Alberta brines. These findings will assist the two geoscience programs involved in brine research, and approved under the Canada/Alberta Mineral Development Agreement, to formulate and implement effective development strategies in Alberta.

The objectives of this study are achieved through the series of steps outlined below.

1. The development of a cost model which identifies the cash flow elements associated with processing Alberta brines.

2. The cost model is used to assess the profitability of extracting calcium chloride and magnesium chloride from Alberta brines.

3. Through the application of sensitivity analysis those cost items which most affect the profitability are identified with respect to their relative impact.

4. Strengths and weaknesses in the proposed processing operation are identified and additional research is recommended to address areas of high cost.

This analysis is developed from the assumption that a proposed processing operation would supply 100 per cent of the projected needs of Alberta for magnesium chloride to supply an idle magnesium smelter and 20 per cent of the Canadian domestic market for calcium chloride.

1.0 INDUSTRY PROFILES

1.1 Market Overviews

1.10 Calcium Chloride

The manufacture of both natural and synthetic calcium chloride in North America is dominated by producers in the United States which is a net exporter of calcium chloride. The leading state in natural calcium chloride production is Michigan followed by California, a distant second. Dow Chemical leads all U.S. producers with an annual production capacity of 635,000 metric tons of 78% flake product. The total U.S. production of both natural and synthetic calcium chloride for 1990 was 626,000 metric tons while the 1990 nameplate capacity for U.S. plants of all types was 1,010,614 metric tons. This yields a capacity utilization rate of 62 per cent for that year.

In Canada, in 1990, the nameplate capacity of all calcium chloride plants was 584,000 metric tons with total production in that year of 295,300 metric tons. This yields a capacity utilization rate of 51 per cent. In 1990, Canada imported 21,700 metric tons of calcium chloride, mainly from the U.S., while at the same time exporting 109,700 metric tons, all of it to the U.S. Canadian exports of calcium chloride to the U.S. increased rapidly in 1987 with the closure of the Allied Chemical production facility in Syracuse, New York.

Canadian production of calcium chloride is dominated by General Chemical Canada Ltd. (formerly Allied Chemical Canada) from its 400,000 metric ton per year facility in Amherstburg, Ontario.

1.1 Magnesium Chloride

"Seawater, brines and bitterns represent vast sources of magnesium and magnesium compounds. In the United States more than 60% of the magnesium compounds produced annually is recovered from seawater and brines, and 80% of the magnesium metal production capacity uses seawater as a raw material".(1)

Magnesium chloride is produced by industry as an intermediate step in the production of magnesium metal and magnesium compounds. Therefore, its rate of production depends heavily on the prevailing market conditions for finished magnesium products. Two forms of magnesium chloride are produced - hydrous and anhydrous. Both forms can be used as a feedstock for electrolytic recovery of magnesium metal, or in the production of synthetic magnesia and other magnesium compounds.

"Japan and the United States account for 59% of the world's magnesium compounds production capacity from seawater or brines".(2) U.S. primary magnesium producers operated at about 73% of their rated capacity in 1991, and total production dropped by about 6% from 1990.(3)

Because magnesium metal is light and imparts strength to materials it is used alone and as an alloy of aluminum. Its higher cost is compensated for by its strength and lower density in applications where these are important factors.

1.2 PRODUCTION METHODS

1.21 Brine Extraction

In Michigan, Dow Chemical extracts natural brines from the Sylvania and Filer formations of Lower Devonian age. Wells are drilled into the sandstone formations on 1.2 mile centres such that injection wells are alternated with production wells. The sandstone has an average porosity of approximately 10% and a permeability of approximately 500 millidarcies. Pumps placed downhole lift the brine to the surface.(4)

Plants utilizing these brines operate either on a bromine or a magnesium ion basis. The waste brine, still containing calcium chloride, is reinjected into the formation to maintain pressure at the producing wells.(5)

Calcium chloride is produced by two methods. Natural calcium chloride is extracted from natural brines while synthetic calcium chloride is produced by reacting hydrochloric acid with limestone. U.S. production of natural calcium chloride from brine wells in Michigan represents 63% of production capacity. Approximately 28% is produced synthetically with a small amount of natural production from dry lakebed brines in California.

1.22 Chemical Production

The General Chemical Canada facility in Amherstburg, Ontario produces calcium chloride as a byproduct of its sodium carbonate unit which uses distiller waste liquor as a feedstock.

Potash Corporation of Saskatchewan is seeking an interested party to produce calcium chloride from brines that seep into the mine workings. A subsurface brine resource has been identified by drilling and is known to contain 28% calcium chloride.

Electrolytic recovery of magnesium requires a magnesium chloride feedstock that normally is prepared from seawater or brines. Two types of magnesium chloride can be made - hydrous and anhydrous. In the preparation of hydrous magnesium chloride, used by Dow Chemical Co., "magnesium hydroxide is produced by precipitation of the magnesium ions by the use of a base such as calcium hydroxide, $Ca(OH)_2$ or sodium hydroxide, NaOH. The $Ca(OH)_2$ is obtained either from high calcium limestone or dolomitic limestone. The limestone is calcined in a rotary kiln to produce lime. The lime is reacted with water (which may be the water in brine) to give $Ca(OH)_2$ which reacts with the Mg ions in the brine to give $Mg(OH)_2$. One-half of the $Mg(OH)_2$ comes from the lime when dolomitic limestone is used. The slurry of $Mg(OH)_2$ in $CaCl_2$ brine is thickened in settling tanks, filtered and the $CaCl_2$ is washed out of the cake with water".(6) Adding hydrochloric acid to the magnesium hydroxide produces a neutralized magnesium chloride solution. This solution is dehydrated until it contains about 25% water and then is fed directly to electrolytic cells.

"Magnesium Corp. of America (MagCorp) and Norsk Hydro A/S of Norway use an anhydrous magnesium chloride feed for their electrolytic cells. MagCorp uses solar evaporation initially to concentrate magnesium chloride brines from the Great Salt Lake. After adding calcium chloride to precipitate sulphate impurities and removing boron by solvent extraction, the brine is concentrated further and dehydrated in a spray dryer. The resulting powder is purified, concentrated, prilled and dehydrated to produce anhydrous magnesium chloride. Norsk Hydro starts with concentrated magnesium chloride brine which is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride".(7)

"Magnesium International Corp. developed a one-step process for producing anhydrous magnesium chloride that was demonstrated at Magnesium Co. of Canada Ltd.'s (MagCan) new plant at Aldersyde, Alberta that opened in 1990 and closed in 1991. Reacting magnesite ($MgCO_3$) with chlorine gas in the presence of carbon monoxide in a packed-bed reactor at 900°C produces magnesium chloride and carbon dioxide. Liquid magnesium chloride collects at the bottom of the reactor and is tapped periodically for transfer to electrolytic cells".(8)

"The early processing technology developed in 1914 in Michigan used three vacuum evaporators to extract various brine components. Bromine was extracted first by carefully controlling the electric current in an electrolytic cell. The bromine was blown out the brine with air and reacted to form various compounds such as potassium bromide. The debrominated brine was then processed through a steam heated vacuum evaporator. This process precipitated sodium chloride which was used to produce chlorine, hydrogen, and sodium hydroxide. The remaining brine was then sent to a second evaporator where magnesium chloride was precipitated out. A reaction with slaked lime produced magnesium hydroxide which was reacted with sulphuric acid to produce magnesium sulphate (epsom salts). Magnesium chloride was converted to magnesium oxychloride for use as a "synthetic stone" flooring and a hardener for stucco. Some magnesium chloride was fed into an electrolytic cell to produce magnesium metal. The brine from the second evaporator went to a third evaporator, which produced precipitated hydrates of calcium chloride and a 38% calcium chloride product and also to precipitate hydrates of calcium chloride".(9)

1.23 Dow Process

"Today, the process has been expanded and improved to extract, in sequence, iodine, bromine, magnesium chloride and calcium chloride. Calcium chloride is obtained as a byproduct in the ammonia-soda (Solvay) process, and as a joint product from natural salt brines. The method of production is essentially the same in each process after the natural brines have been purified; that is the calcium chloride-containing liquors are concentrated and crystallized". (10)

Natural brines contain a mixture of calcium and magnesium chlorides, usually in a ratio of 1 part magnesium chloride to 3 to 6 parts calcium chloride (see Table below). For example, a typical analysis showing the principal constituents of a Michigan brine in the two producing formations is as follows:

Table 1

Composition of producing Michigan brines

	Sylvania Fm.	Filer Fm.
NaCl %	5	2
$CaCl_2$ %	19	17
$MgCl_2$ %	3.6	10
Br %	0.26	0.25
I ppm	30	nil

Source: J. Pavlick, SME Preprint 84-385, 1984

The following is a comparison of the chemical composition of a number of the world's brines;

Table 2

Chemistry of World Brines

Sample type	Chemical constituents (mg/l)								
	Na	Ca	Mg	Cl	Br	I	SO_4	HCO_3	TDSolids
Sea water	10,760	413	1,294	19,353	67	0.06	2,712	142	35,000
Great Salt Lake	91,000	<200	12,400	166,000	-	-	23,400	-	298,500
Dead Sea	34,940	15,800	41,960	208,020	5,920	-	540	240	315,040
Michigan Dow Chemical	22,500	74,800	9,960	208,000	2,910	40	40	-	331,000
General Chemical Drumheller	36,700	15,717	1,564	92,224	na	na	63	462	150,731
Ward Chem. Calling Lk.	14,396	124,656	13,888	283,234	na	na	na	34	436,208
Tiger Calcium Mitsue	39,745	122,217*	na	277,438	na	na	0	61	439,461

* = Ca+Mg na = not analyzed - = nil TDSolids = Total dissolved solids

Sources: Research Council of Alberta Economic Geology Report No. 1, Energy Resources Conservation Board files

"The Michigan brine is generally treated to recover the bromine and sodium chloride. The brine that results from this treatment is rich in calcium and magnesium chlorides (approximately a 3:1 ratio) and may be concentrated and crystallized to yield a calcium chloride-magnesium chloride mixture. This product is suitable for some uses such as dust control. However, the presence of magnesium chloride tends to lower the melting point of the mixture, making it difficult to obtain a solid product. Magnesium chloride is also undesirable because it is so corrosive, however, corrosion inhibitors are now admixed with the product to reduce undesired effects".(11)

"The magnesium chloride is removed from natural brine by treating the liquor with calcium oxide (lime), which converts the chloride into the hydroxide. The magnesium hydroxide precipitates and is removed by settling and decantation, or by use of countercurrent thickeners of the Dorr type. The process may be varied by removing the bulk of the magnesium chloride by fractional crystallization. The brine, containing a 1:3 weight ratio of magnesium and calcium chloride, is concentrated in evaporators to form the double salt, tachydrite. This salt ($2MgCl_2 \cdot CaCl_2 \cdot 12H_2O$) has a magnesium chloride/calcium chloride ratio of 2:1. The precipitation of the salt depletes the magnesium chloride content of the solution, until the equilibrium ratio of 1:10 (magnesium chloride/calcium chloride) is reached. The depleted mother liquor may be treated with lime (as previously) to remove the last traces of magnesium chloride".(12)

"Distiller waste liquor from the Solvay (ammonia-soda) process is practically free of magnesium chloride and requires no subsequent purification. The clear solution contains calcium chloride, sodium chloride, and a small amount of dissolved calcium sulphate".(13)

"Natural brines, after purification, or the ammonia-soda waste liquors as they come from the plant, are charged into triple-effect evaporators and concentrated. Both these raw materials contain sodium chloride, which is very slightly soluble in concentrated solutions of calcium chloride. Most of the salt, together with a small amount of calcium sulphate (Solvay liquors), crystallizes out in the first effect. After settling, the salt is discharged into centrifuges, washed, and packaged. The evaporation is continued until the specific gravity of the liquor in the last effect reaches 1.41. Practically all the sodium chloride has crystallized at this point and can be settled out. The clarified liquor is decanted from the evaporator and pumped into a single-effect finishing pan or cast-iron pot, where it is concentrated further (until a solids content of about 75% is reached). The molten mass is discharged into steel drums, where it solidifies on cooling. The product is known as 75% calcium chloride and corresponds to the formula $CaCl_2 \cdot 2H_2O$. Alternatively, the molten material may be run over a flaker, yielding 75% calcium chloride flakes".(14)

"Anhydrous calcium chloride may be prepared by heating the 75% calcium chloride in a reverberatory furnace or rotary calciner. Some of the salt is decomposed, giving calcium oxide and hydrogen chloride. The evolution of the gas yields a porous mass of fused calcium chloride, which assays about 95%. The cooled anhydrous material is crushed, screened, and classified before packaging".(15)

"Calcium chloride solutions, used as cooling brines and antifreeze solutions, are withdrawn at various steps in the evaporation (concentration) process, depending on the specific gravity desired".(16)

1.2.4 Solar Evaporation

Natural solar evaporation of seawater is used by Solarchem Resources (Cargill) of San Francisco, California to produce hydrous magnesium chloride for road dust control. Some of this product was utilised by Magnesium Company of Canada Ltd. as feedstock for its magnesium smelter during the period of its operation.

Seawater is drawn into Cargill's 16,188 hectare pond system that surrounds the San Francisco bay. After five years, the wind and sun have evaporated enough water for sodium chloride to crystallize out. The remaining liquid is placed into another series of ponds, or crystallizer beds, and allowed to concentrate for an additional four years. At this point a highly concentrated form of liquid magnesium chloride is derived. More than a million short tons of salts are harvested from September through December before winter rains threaten the new crop.

North American Producers

1.25 Calcium Chloride

"In 1990, Michigan was the leading state in natural calcium chloride production with California well behind in second place. The Dow Chemical Co. and Wilkinson Chemical Corp. recovered calcium chloride from brines in Mason and Lapeer Counties, Michigan. Dow's Ludington plant produced calcium chloride pellets, flake and liquid; Wilkinson marketed calcium chloride solutions only. In addition, Martin Marietta Magnesia Specialties marketed some byproduct calcium chloride from its brine operations in Michigan. National Chloride Co. of America, Cargill's Leslie Salt Co. (now Solarchem Resources), and Hill Brothers Chemical Co. produced calcium chloride from dry-lake brine wells in San Bernadino County, California. Hill Brothers Chemical also produced from a second operation near Cadiz Lake, California. Magnesium Corp. of America marketed some byproduct calcium chloride from its magnesium production operations in Rowley, Utah".(17)

"Allied-Signal Inc., recovered synthetic calcium chloride as a byproduct at its Baton Rouge, Louisiana plant using hydrochloric acid and limestone. Tetra Chemicals produced calcium chloride from a plant near Lake Charles, Louisiana and from its liquids plant at Norco, Louisiana. Occidental Chemical Corp. manufactured calcium chloride at Tacoma, Washington using limestone and hydrochloric acid. Additional synthetic calcium chloride production came from Stanford Chlorine at Delaware City, Delaware".(18)

"In Canada, the major producer of calcium chloride is General Chemical Canada Ltd. (formerly Allied Chemical Canada) in Amherstburg, Ontario. Using the Solvay process calcium chloride is produced as a byproduct of its sodium carbonate process. The calcium chloride facility was expanded in the mid-1980's to respond to the closure of the Syracuse plant".(19) The Amherstburg plant is said to be an outdated facility with some significant pollution problems. General Chemical also makes small quantities of 25 per cent calcium chloride solution at its Drumheller and Brooks, Alberta brine well facilities. Other Alberta producers are Ward Chemical at Villeneuve and Fort Saskatchewan and Tiger Calcium at Smith. Production capacity of the Tiger Calcium plant is 50,000 tonnes per year consisting principally of 30 to 42 per cent calcium chloride solution. Ward Chemical operates two plants, one at Fort Saskatchewan which is rated at 50,000 tonnes per year, and one at Villeneuve which is rated at 75,000 tonnes per year. Jointly these two plants produce 100,000 tonnes of calcium chloride product which is sold principally as 32 to 40 per cent solution.

Table 3

Calcium Chloride Producers

Producer	Capacity tonnes per year
Dow Chemical, Ludington, MI	635,000
Magnesium Corp. of America, Salt Lk. City, UT	31,751
Wilkinson Chemical, Mayville, MI	24,000
Allied-Signal, Baton Rouge, LA	172,400
Lee Chemical, Cadiz Lake, CA	13,608
Leslie Salt (Cargill), Amboy, CA	16,329
National Chloride, Amboy, CA	9,980
Occidental, Tacoma, WA	7,258
Standard Chlorine, Delaware City, DEL	6,350
Tetra Technologies, Lake Charles, LA	22,680
Tetra Technologies, Norco, LA	73,483
	=========
Total nameplate capacity	1,010,614
General Chemical, Amherstburg, ONT	400,000
General Chemical, Brooks, AB	4,500
General Chemical, Drumheller, AB	4,500
Ward Chemical, Fort Saskatchewan, AB	50,000
Ward Chemical, Villeneuve, AB	75,000
Tiger Calcium, Smith, AB	50,000
	=======
Total nameplate capacity	584,000

Sources: Chemical Marketing Reporter, Camford Information Services

1.26 Magnesium Chloride

Anhydrous magnesium chloride feedstock is required in the production of magnesium metal by electrolytic recovery. Three U.S. producers prepare anhydrous magnesium chloride from well brines and lake brines. In Michigan, The Dow Chemical Co., Martin Marietta Chemicals and Morton Chemical Co. manufacture magnesium chloride from well brines. In Utah, Great Salt Lake Minerals & Chemicals Corp., Magnesium Corp. of America and Reilly Industries Inc. manufacture magnesium chloride from the lake brines of Great Salt Lake.
In Canada, Norsk Hydro manufactures magnesium chloride for its electrolytic plant at Bécancour, Quebec.

Table 4

Magnesium Metal and Magnesium Compound Producers

Company	Location	Raw Material	Annual Capacity tonnes
Dow Chemical	Freeport, TX	Seawater	109,000
Magnesium Corp.	Rowley, UT	Lake Brines	35,000
Dow Chemical	Ludington, MI	Well brines	200,000
Martin Marietta	Manistee, MI	Well brines	275,000
Morton Chemical	Manistee, MI	Well brines	10,000
Norsk Hydro	Bécancour, PQ	Magnesite	60,000

Source: Magnesium and Magnesium Compounds, Annual Report, 1991
U. S. Bureau of Mines

1.3 Uses and Applications:

1.30 Calcium Chloride

Calcium is the fifth most abundant element in the earth's crust and is chemically very active in combining with numerous other elements.

"The American Society for Testing Materials (ASTM) issues a standard specification for calcium chloride designated D 98. It covers technical-grade calcium chloride to be used for road conditioning purposes, ice removal, concrete curing acceleration of the set of concrete, and as a desiccant. D 98 covers two types of calcium chloride, solid (Type S) and liquid (Type L). Solid occurs in flake, pellet, granular, and powder form in concentrations of 77%, 90%, and 94% minimum. Liquid occurs as water solutions of calcium chloride in concentrations varying from 30% to 45%. Calcium chloride is divided into three grades: Grade 1 - 77% minimum, Grade 2 - 90% minimum, and Grade 3 - 94% minimum. Within each grade there are seive-size requirements for flake, pellet, granular, and powder forms".(20)

"In the United States the relative volume usage of calcium chloride in descending order is; pavement deicing, dust control, stabilizing of road bases, as a freeze-proofing agent for coal and other bulk materials, in oil and gas well drilling, as an accelerant admixture in concrete to hasten hardening, and other miscellaneous applications which include food grade applications. The greatest use of calcium chloride is as a deicing agent on road surfaces. Because of its much higher cost but greater efficiency at lower temperatures when compared to rock salt, a mixture of the two is commonly used mainly in the Northern and Eastern states".(21)

"In Canada, in 1990, the usage pattern is distributed as follows; dust control 50.5%, potash mining 4.4%, road deicing 4.1%, waste newsprint deinking 2.4%, sodium chlorate production 1.6%, oilwell cementing 1.4%, tire ballasting 1.1%, and export sales 34.5%. The total consumption of calcium chloride in Canada in 1990 was 317,000 tonnes. Canada is a net exporter of calcium chloride".(22)

Calcium chloride is used as a dust abatement agent because of its beneficial properties of hygroscopicity and deliquescence. Its hygroscopic nature allows it to absorb moisture from the atmosphere and its deliquescence enables it to become liquid in the process of absorbing moisture. Where marginal gravels which are contaminated with clay and silt are used in road construction the annual application, in spring, of 1.6 to 2 pounds per square yard serves as a dust palliative and aids in compacting the surface of the roadway. Amounts ranging from 6 to 10 pounds per ton of granular calcium chloride in solid or solution form are utilized in the development of new roadbases to assist in compaction and to reduce the need for blading.

In oilwell cementing calcium chloride is used because of its accelerating properties and freezing point depression capability. Its high specific gravity (circa 1.41) aids in displacing drilling mud to fill the space between the well bore and the casing thereby restricting fluid movement between formations and bonding tightly to the casing pipe.

"A relatively new application for calcium chloride was introduced by International Chemicals in 1987, when the company started experimenting with chemical grouting to control water inflow at its potash mine at Esterhazy, Saskatchewan. However, this application appears to work only at that location because of its particular [soil chemistry]".(23) A calcium chloride solution was used to control the invasion of formation waters containing high levels of sodium. By saturating a solution with calcium chloride and pumping it into the formation from which the brine was flowing, sodium chloride was precipitated thereby sealing off the mine workings by plugging up the porous layers through which the brine had invaded. It is not likely that other mines will utilize this method of water control.

"Calcium chloride is used in deinking plants as an agent in the preparation of water to allow the deinking chemicals to work efficiently".(24)

Producers of crystal sodium chlorate use calcium chloride in the purification process to precipitate calcium sulphate from sodium sulphate.

Other markets for calcium chloride include feed additives, tire ballasting, freezeproofing of ores, in refrigeration brines, as a desiccating agent, as a sequestrant in foods, as a firming agent in tomato canning, and in pharmaceuticals and electrolytic cells.

1.31 Magnesium Chloride

Magnesium is the eighth most abundant element and constitutes about 2% of the earth's crust. It is the third most plentiful element dissolved in seawater, with a concentration averaging 0.13%.

The principal application of magnesium chloride is in the production of anhydrous magnesium chloride as a feedstock in the production of magnesium metal. Secondary uses include; chemical processing and oxychloride cements. Magnesium chloride brines are used for road dust control and chemical processing. The use of magnesium chloride in dust control is being actively marketed by Solarchem Resources following the development of admixed corrosion inhibitors which eliminate the highly corrosive effects of this product.

In Canada there is no domestic production of magnesium chloride except for captive use in the production of magnesium metal by Norsk Hydro.

1.4 Price History

In the period 1977 to 1992 the year-end selling prices for calcium chloride and magnesium chloride are plotted on Figure 2 with reference to both the Consumer Price Index (CPI) for that period and the Raw Materials Price Index (RMPI) for the period 1987 to 1992.

1.40 Calcium Chloride

Calcium chloride price increases in the period 1977 to 1979 are slightly lower than the corresponding increases in the CPI. From 1980 to 1982 some dramatic price increases in excess of the CPI values are recorded. These price increases occurred during a time when the CPI showed a greater rate of increase when compared to the previous three years. Between 1983 and 1989 the calcium chloride rate of price increase is slightly greater than the CPI, but in 1989 is slightly lower. The 1990 increase is slightly greater than the CPI increase followed by two years in which the price increase is less than the CPI. On a cumulative basis over the 15 year period the total calcium chloride price increase amounts to 130 per cent whereas the CPI increases are approximately 101 per cent.

In the period 1987 to 1992 the percentage change in the RMPI is generally negative showing a decrease of approximately 10 per cent over the period. An exception to this is a 10 per cent increase in 1988. Calcium chloride price increases have, therefore, outperformed the overall increases in raw materials prices.

1.41 Magnesium Chloride

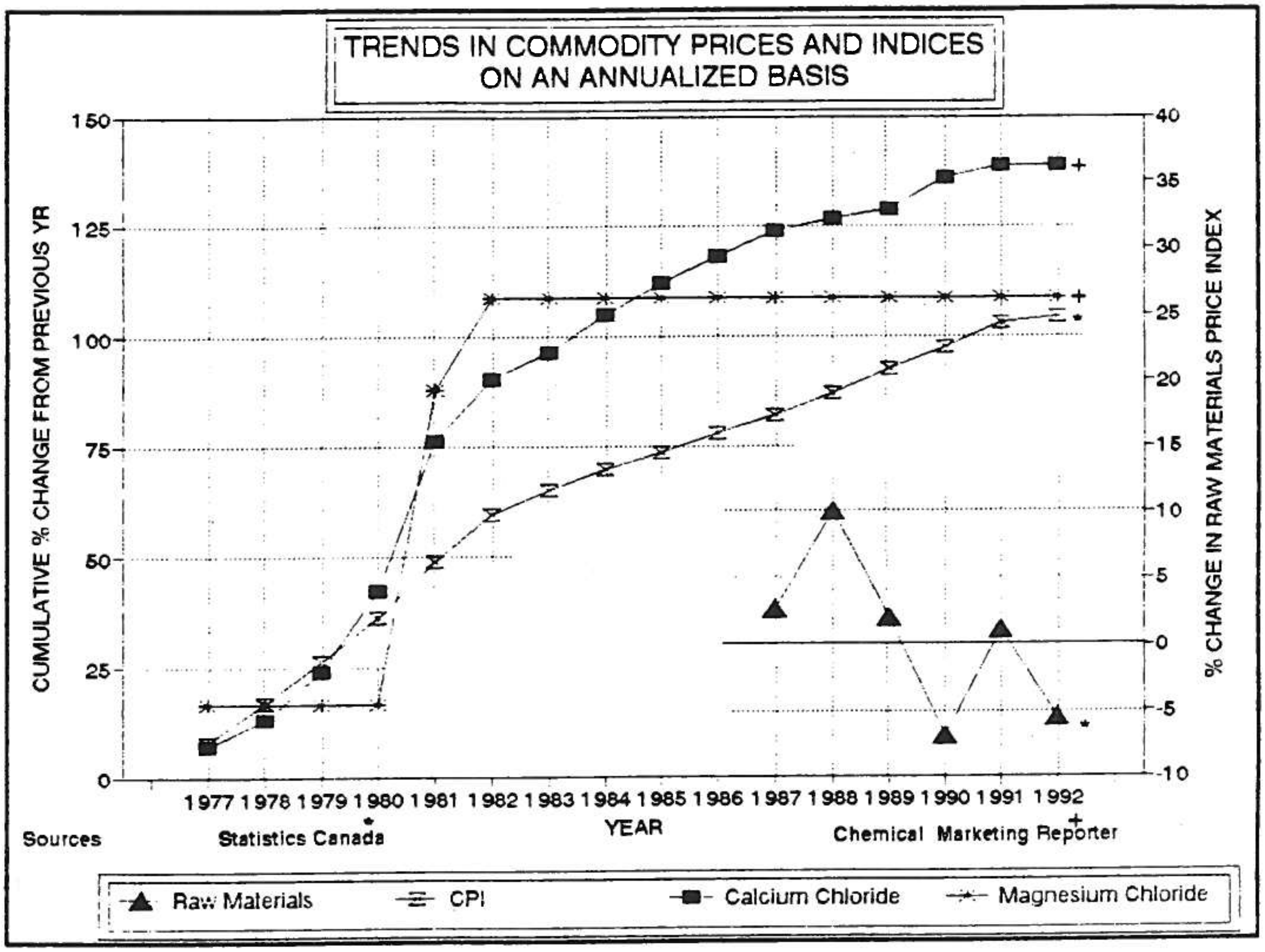
Magnesium chloride prices thoughout the period 1977 to 1992 were flat except for the significant price increases in 1981 and 1982. In these two years price increases of 71.4 per cent (1981) and 20.8 per cent (1982) were recorded. The corresponding CPI increases were 12.4 per cent (1981) and 10.9 per cent (1982). For the remainder of the time span in which magnesium chloride prices are reported there were no other price increases.

For the period 1987 to 1992 the RMPI is decreasing, except for 1988, whereas the magnesium chloride price remains flat without increases. Other than possible erosion of profit margins caused by inflation, the magnesium chloride price increases outpaced the general chemical industry.

Table 5

Raw Data, Figure 2, Trends in Commodity Prices and Indices on an Annualized Basis

Year	CPI annual movement	RMPI % change from year previous	$CaCl_2$ high $CDN per tonne	$CaCl_2$ low $CDN per tonne	$MgCl_2$ $CDN per tonne
1976	7.5		$88.00	$82.50	$170.50
1977	8.0		94.60	88.00	198.91
1978	9.0		99.00	94.60	198.91
1979	9.1		116.00	99.00	198.91
1980	10.2		137.75	116.00	198.91
1981	12.4		185.00	155.75	340.99
1982	10.9		203.00	185.00	412.04
1983	5.7		208.00	203.00	412.04
1984	4.4		239.00	208.00	412.04
1985	3.9		239.00	239.00	412.04
1986	4.2	2.5	268.00	239.00	412.04
1987	4.4	10.0	268.00	268.00	412.04
1988	4.0	2.4	276.00	276.00	412.04
1989	5.0	-7.5	287.00	276.00	412.04
1990	4.8	1.0	316.42	287.00	412.04
1991	5.6	-5.5	319.68		412.04
1992	1.5	-1.0	319.68		412.04
Sources:	Statistics Canada	Statistics Canada	Chemical Marketing Reporter and Camford Information Services		


TRENDS IN COMMODITY PRICES AND INDICES
ON AN ANNUALIZED BASIS
CUMULATIVE % CHANGE FROM PREVIOUS YR
% CHANGE IN RAW MATERIALS PRICE INDEX
150
125
100
75
50
25
0
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5
0
-5
-10
1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992
YEAR
Sources
Statistics Canada *
Chemical Marketing Reporter +
Raw Materials
CPI
Calcium Chloride
Magnesium Chloride

Figure 1

2.0 ECONOMIC ANALYSIS

2.1 Introduction

The capital cost and operating cost estimates developed in this study are derived from cost factors gleaned from many sources both public and confidential. Where appropriate, cost factors have been interpreted and extrapolated to provide order of magnitude estimates of costs as they relate to this study.

The results of this economic analysis provide an 'order of magnitude' assessment of the related costs, cash flow and profitability of such a proposed brine processing operation in Alberta. This operation would utilize subsurface formation brines as feedstock and modern processing technology based, in part, on the Dow Chemical process.(see Figure 1)

The framework upon which this economic study is based is focussed on potential demand for both calcium chloride and magnesium chloride in Alberta and its trading area. The potential demand for these products is based on two factors; that the proposed plant is constructed with sufficient capacity to meet the production volumes necessary to supply 20 per cent of the identified Canadian market for calcium chloride; and, that the plant capacity is also sufficient to meet 100 per cent of the feedstock volume requirements for magnesium chloride of a mothballed 10,000 tonne per year magnesium smelter at Aldersyde, Alberta.

A brine feedstock, utilized by Ward Chemical in the Calling Lake field, was selected from among those wells in Alberta identified as being utilized solely for brine feedstock purposes. The calcium and magnesium values as recorded for the Ward Chemical brine are among the highest of those known to occur, to date, in Lower Devonian age carbonate rocks of the Elk Point Subgroup of Alberta.

When comparing the brine feedstock used by Ward Chemical to the

FLOW CHART OF MIDLAND BRINE CHEMICALS

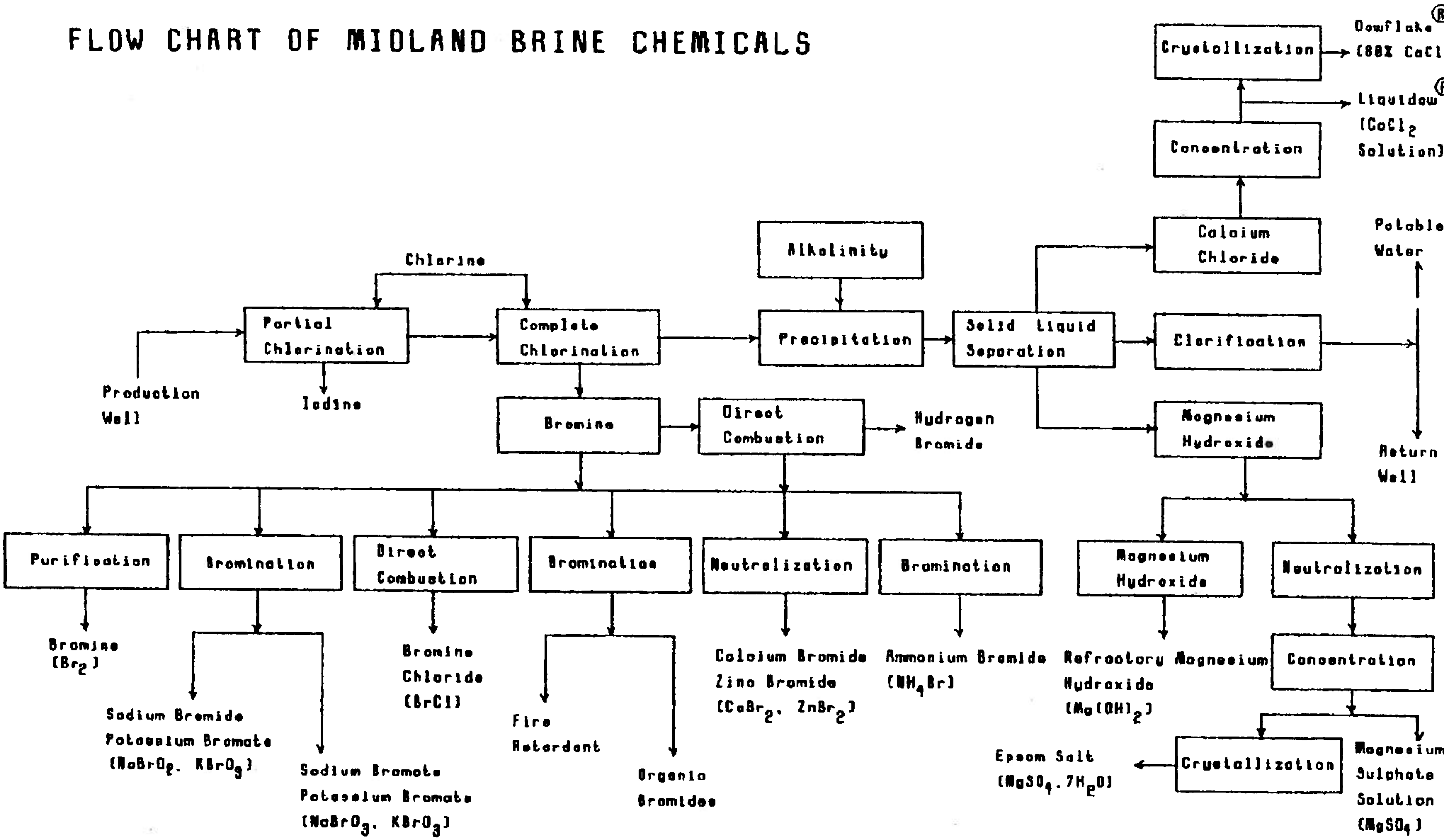

Figure 2 . Example of an integrated brine chemicals facility using brine from the Sylvania formation

feedstocks used by General Chemical and Tiger Calcium, the Ward Chemical brine, because of its higher calcium and magnesium values (see Table 3) is assumed to be a richer feedstock than either of the other brines. For this reason it is assumed it will yield more product per litre of processed brine and, therefore, prove to be more economic.

2.2 Cost Model

It is assumed that the brine processing plant will operate 350 days per year, three shifts a day, with an annual capacity to process 2.65 million tonnes or 2.03 billion litres of formation brine. Such a plant would operate at 100 per cent of capacity. Total annual production would amount to 28,406 tonnes of magnesium chloride and 46,480 tonnes of calcium chloride. These figures represent, in turn, 100 per cent of the potential demand in Alberta for magnesium chloride and 20 per cent of the known demand in Canada for calcium chloride.

No allowance has been made for royalty payments, income tax or property taxes, nor payments to an arm's length supplier to secure brine feedstock. The feedstock brine is assumed to contain neither deleterious hydrocarbons nor other contaminants that would present technological problems for the proposed operation. The proposed plant flowsheet follows the Midland brine processing flow chart of Dow Chemical. (see Fig.1)

The capital cost of the proposed plant is derived through the use of the capital ratio method of Lynn and Howland (25) wherein the capital ratio (CR) cost for the development of a green-field site is defined as the ratio of the fixed capital investment (C_{FC}) to the annual sales revenue (A_S), as follows;

$$CR = C_{FC} \div A_S$$

A typical cost ratio for chemical plants is 2.02.(26) Where annual sales revenue (A_S) can be determined, the value of 2.02 is substituted for the capital ratio (CR) and the equation is solved for the remaining unknown, fixed-capital investment (C_{FC}).

2.3 Capital Cost Estimate

The following factors are considered when developing the fixed capital investment for a proposed plant:

All dollar amounts are quoted in Canadian currency

Brine salinity: Ca 125,000 mg/l, Mg 14,000 mg/l
Annual production: 46,480 tonnes/year $CaCl_2$,
28,406 tonnes/year $MgCl_2$
Annual plant capacity: 2.03 billion litres brine feedstock
No. of triple-effect evaporators: 5 connected in series
Capital cost per unit for evaporators: $2.06 million
Selling price: $CaCl_2$, conc., reg. grade, 77 - 80%, flake, bulk, carload, F.O.B. works, $234.50 per tonne
$MgCl_2$, hydrous, 99%, flake, bags, carload, FOB works, $412.04 per tonne (Chemical Marketing Reporter)
Annual revenue: $CaCl_2$ $10,899,560.00
$MgCl_2$ $11,703,988.00
Total annual sales (A_S): $22,603,548.00
Capital cost ratio (CR), chemical plants: 2.02
Canadian construction cost factor: 1.15 times U.S. cost

$$CR = C_{FC} \div A_S$$
$$\therefore C_{FC} = A_S \times C_R$$
$$= \$22.6 \text{ million} \times 2.02$$
$$= \$45.7 \text{ million}$$

Applying the Canadian construction factor to this amount yields:

Fixed capital cost = $52.6 million

2.4 Operating Cost Estimate

The following estimate of operating cost is derived from confidential data and relates to a two-product brine processing operation to which triple-effect evaporators have been added.

Annual processing capacity: 2.03 billion litres brine
Operating days per year: 350
Cost of steam generation: $9.03 per 1000 pounds
Fuel cost: $7.74 per 1000 pounds steam
Electricity cost: $0.077 per Kwh
No. of triple-effect evaporators: 5 connected in series
Annual operating cost per evaporator: $2.06 million (27)
Annual operating cost for plant incl. evaporators: $22.4 million
No. of employees: 38 shift workers, 3 administrative workers

Estimated plant operating costs include the following costs; raw materials, utilities, direct labour of 41 person-years, plant maintenance, payroll overhead, and operating supplies. Payroll overhead includes vacation, sick leave, social security and fringe benefits. Indirect costs include; accounting, plant safety, control laboratories, plant administration, marketing and company overhead. Research and overall company administration costs outside the plant are not included. Fixed costs include taxes (excluding income tax), insurance, and straight-line, 20 year depreciation.

2.5 Profitability

Operating cost per tonne of product: $299.69
Operating profit per tonne $MgCl_2$: $112.35
Operating loss per tonne $CaCl_2$: ($65.19)
Net annual operating profit: $160,000 before tax

This net annual operating profit, before tax, is not sufficient to amortize the fixed capital costs of the plant over a 20 year period.

The investment, therefore, is uneconomic and not without a considerable element of risk. The profitability is estimated on a before-tax basis because of the uncertainty of the tax treatment of such an operation by Revenue Canada. At the present time brine processing is not considered to be a mineral processing operation and is taxed at a higher rate. A petition, by Ward Chemical, is now before Revenue Canada for consideration of brine processing as a mineral processing activity. If the Ward Chemical petition is successful the tax rate for brine processing operations will be lowered.

2.6 Sensitivity Analysis

In order to amortize an amount of, for example, $50 million at 10 per cent interest over 20 years a minimum annual operating profit of $5.71 million must be achieved.

In order to determine the possibility of achieving such a cash flow it is necessary to examine the relative effects of varying the cost parameters for this proposed plant. The following table illustrates the effect on annual operating profit of variations in annual sales and operating cost.

Table 6

Annual operating cost: constant at $22.4 million

Sales variation	Annual Operating Profit $\$ \times 10^6$
+50%	+11.5
+25%	+5.9
0	unchanged at 0.160
-25%	-5.5
-50%	-11.1

Table 7

Annual sales revenue: constant at $22.6 million

Operating cost variation	Annual Operating Profit $\$ \times 10^6$
-50%	+11.4
-25%	+5.8
0	unchanged at 0.160
+25%	-5.4
+50%	-11.0

These results reveal that with either a 25 per cent increase in sales or a 25 per cent decrease in operating cost such an operation could achieve the annual cash flow necessary to amortize, over 20 years, the fixed capital investment of approximately $50 million.

Such an increase in annual operating profits could be achieved by improvements in one or both of the following areas as they affect the profitability of this operation;

1. Higher brine salinity: that is, the utilization of a brine with a higher content of calcium chloride and magnesium chloride thereby increasing the units of production and spreading the operating costs over a greater production base. In other words the operating costs for a plant are being applied to the processing of a smaller quantity of brine with a direct increase in the volume of salts produced.

2. Lower operating costs: solar evaporation of brines could replace the higher cost and more expensive to operate evaporators. Solar evaporation offers the additional benefit of upgrading a native brine thereby increasing the salinity of the feedstock and its economic viability.

The Great Salt Lake, the Dead Sea, and the California brine processing operations utilize solar ponding to concentrate their brine feedstock before it enters the plant. In addition, the Dead Sea magnesium ion content is approximately three times greater than that of the Alberta brine.(see Table 3)

Currently, in Canada, solar evaporation is used by several brine processing operations to upgrade the salinity of brine feedstocks. For example, in Saskatchewan, during the summer months, sufficient natural solar evaporation takes place in shallow lakes and ponds to permit brine processors to pump these enriched sodium sulphate brines into evaporating reservoirs where the solar process continues to raise the concentration of dissolved salts to near-saturation state. Lower temperatures in the fall cause differential crystallization to occur and crystalline product is harvested once the brine ponds become frozen.

A similar operation, by Potash Company of America at its Patience Lake mine in Saskatchewan, uses solution mining brines that are evaporated and precipitated in surface ponds to produce crystalline high-purity potash.

3.0 RESULTS AND CONCLUSIONS

3.1 Market Outlook

3.10 Calcium Chloride

The principal applications for calcium chloride in Canada are; as a road dust control agent, and as an agent to assist in roadbed compaction of contaminated sands and gravels. These will continue to be the prime uses for this product. Its growth in demand will be dictated by the level of activity in road construction in Canada. Expected annual growth in demand is in the range of zero to two per cent.

Two areas which may contribute to greater demand growth for calcium chloride are; newsprint deinking and crystalline sodium chlorate production. The anticipated boom in newsprint deinking has been slow to develop, however, an increase in recycling of deinked papers is expected to foster growth in demand for calcium chloride as a water conditioning agent. Calcium chloride is used by producers of crystalline sodium chlorate as a purifying agent when precipitating calcium sulphate from sodium sulphate. The well established trend away from the use of chlorine as a bleaching agent in the manufacture of wood pulps should increase the future demand for calcium chloride.

Underutilization of established processing plant capacity is likely to remain a problem in Canada until increased market demand necessitates increased levels of calcium chloride production.

Overall demand is forecast to remain at or below current levels.

3.11 Magnesium Chloride

The demand for magnesium chloride is directly controlled by the demand for magnesium metal. With the current level of automobile sales remaining low, the overall demand for magnesium metal is forecast to decline in the near term. However, substitution of magnesium for aluminum and alloying of magnesium and aluminum in some car parts is increasing and this should stimulate demand.

Increasing use of magnesium chloride as a dust control agent may follow the development of admixed corrosion inhibitors.

The continued dumping of magnesium metal into Europe by the former U.S.S.R. will depress prices and prolong an oversupply situation.

Production and demand for magnesium compounds is expected to remain stable in the near term.

3.2 Alberta-specific Uses and Growth Areas

The production of magnesium chloride from brine represents a significant opportunity within Alberta. The preferred means of operating the idle magnesium smelter at Aldersyde, Alberta is with a combined feedstock of crystalline magnesite (magnesium carbonate) and magnesium chloride. With approximately equal amounts of each feedstock a zero-effluent system is established with respect to chlorine wherein the excess chlorine released by the decomposition of magnesium chloride is used to break down the magnesium carbonate and form additional magnesium chloride. In the past the production of excess volumes of chlorine was a significant problem for the smelter operator. In addition to environmental benefits the use of the two feedstocks represents a cost savings in that make-up chlorine purchases would no longer be necessary for the efficient operation of the smelter. Anhydrous magnesium chloride is the preferred form for use in the smelter.(28)

The potential to explore for and develop magnesite deposits in Alberta is considered, by the writer, to be high. Cambrian age carbonate rocks similar to those in which the rich deposits of the Cross River area of British Columbia occur are known to outcrop in Alberta. To date, no systematic exploration for high-magnesium dolomites appears to have been carried out in Alberta. In the event this exploration is successful it may be possible to reactivate the magnesium smelter with feedstocks derived entirely from within Alberta.

Solar ponding as a means of upgrading the salt content of brines to reduce operating costs may be feasible in Alberta. In the Coronation, Hanna and Oyen areas of southeastern Alberta summer weather conditions may be suitable for development of such an operation. Optimum solar ponding conditions in summer involve; high daytime heating by the sun, low relative humidity, low precipitation, significant wind velocity and freezing conditions in winter. Two additional benefits of operating solar ponds in this area are; the entire area is underlain by the Beaverhill Lake Formation which has been identified as a potential producer of high salinity brines; and the possibility exists to produce fresh potable water from solar ponding waste water in an area that is not currently irrigated and is in need of water. The choice of one of these locations would reduce transportation costs for moving raw brine from production wells to a processing plant. Additional research is required to evaluate this area for solar ponding operations.

3.3 Strategies for Development

The economic viability of establishing brine processing operations in Alberta depends upon the outcome of further research designed to:

a) Upgrade the salinity of feedstock brines either through solar evaporation or through the discovery of brines richer in calcium chloride and magnesium chloride than those discovered to date.

b) Lower the operating cost per unit of salt production to effect an increase in the profitability to a point where a large fixed capital cost debt can be serviced in a twenty year amortization period.

c) Develop new technology which will lower the cost of producing anhydrous grades of calcium chloride and magnesium chloride. This development may open new markets to these potential products and reduce the cost of transporting bulky salt solutions which contain large volumes of water.

Sales penetration in an industry characterized by a mature market, negative to flat demand forecasts, and underutilized processing facilities must be addressed with the full knowledge of the consequences of any actions. Caution must be applied when extrapolating current price structures too far into the future while attempting to gain market share from a dominant producer who appears to control the market. In addition, the full impact of the North American Free Trade Agreement (NAFTA) must be appreciated.

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