ENVIRONMENTAL IMPROVEMENTS IN MINERAL PROCESSING AND EXTRACTIVE METALLURGY (M. A. Sánchez, F. Vergara and S. H. Castro, Eds.) University of Concepción

SALINITY GRADIENT SOLAR POND TECHNOLOGY APPLIED TO POTASH SOLUTION MINING

Catherine T. Aimone-Martin
New Mexico Institute of Mining and Technology, Socorro, New Mexico, USA

Mary-Alena Martell
Sandia National Laboratories, Carlsbad, New Mexico, USA

ABSTRACT

A solution mining facility at the Eddy Potash Mine, Eddy County, New Mexico, United State of American (USA) has been proposed that will utilize salinity gradient solar pond (SGSP) technology to supply industrial process thermal energy. The process will include underground dissolution of potassium chloride (KCl) from pillars and other reserves remaining after completion of primary room and pillar mining using recirculating solutions heated in the SGSP. Production of KCl will involve cold crystallization followed by a cooling pond stage, with the spent brine being recirculated in a closed loop back to the SGSP for reheating. This research uses SGSP as a renewable, clean energy source to optimize the entire mining process, minimize environmental wastes, provide a safe, more economical extraction process and reduce the need for conventional processing by crushing, grinding and flotation. The applications of SGSP technology will not only save energy in the extraction and beneficiation processes, but also will produce excess energy available for power generation, desalination, and auxiliary structure heating.

INTRODUCTION

Salinity gradient solar ponds (SGSP) are large reservoirs of saline water that collect and store thermal energy (Hull et al., 1989). The pond consists of three layers, shown in Figure 1, viz., an upper convection zone, the stable gradient zone, and the bottom thermal zone (also referred to as the storage zone). In the gradient zone, salt content increases with depth. Water in the gradient cannot rise because the salt content of the water above is less and is therefore lighter, and the water below has a higher salt content and is heavier. Thus, the stable gradient zone suppresses convection and acts as a transparent insulator, permitting sunlight to be trapped in the hot bottom layer producing temperatures that can exceed 94 °C (200 °F). Convection between layers is prevented by controlling density differences, thereby minimizing heat loses and maintaining pond

DISCLAIMER

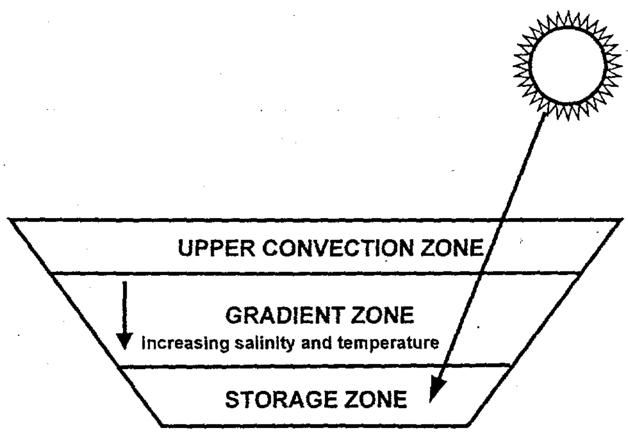

Figure 1 Schematic of a solar pond

stability. Pumping brine from the storage layer through a heat exchanger or an evaporator removes the heat for industrial applications. Useful demonstrations of solar ponds include the production of industrial and agricultural process heat, pre-heating for higher temperature industrial processes, electrical generation and desalination (Hull et al., 1987).

Solution mining of evaporites, such as halite, potash, and soda ash (sodium carbonate) has been attempted in the past. Techniques employ drilling injection and production wells to produce salts from relatively thin beds at great depths (e.g. 1000- to 2000-m from the surface) or develop large caverns for the subsurface storage of crude oil, petrochemicals or industrial wastes. The efficient dissolution of mixed salts can be achieved by first heating the solution to obtain proper solubility relationships. The energy required to heat the large volumes of water needed for mixed-salt solutioning is often cost-prohibitive. However, by utilizing SGSP technology, a low cost source of heated brine can be applied to salt extraction.

This paper describes the commercial process that will be used to apply salinity gradient solar pond technology for the efficient recovery of potash at the Eddy Potash Mine (EPM) in the Carlsbad Potash Basin, New Mexico, USA. This project will incorporate clean, renewable, low-cost energy to demonstrate the potential to extend the mining life of USA potash reserves at a cost lower than conventional mining. This project will be the first of its kind in the USA to merge two innovative, cost-effective technologies that promise to improve industry productivity and economic competitiveness.

PROPOSED SOLUTION MINING PROCESS

A schematic of the proposed solution mining process is shown in Figure 2. The process uses the temperature-dependent solubility of KCl, shown in Figure 3 for jointly saturated NaCl and KCl, to assist with the hot dissolution and cold crystallization of KCl. The pilot facility

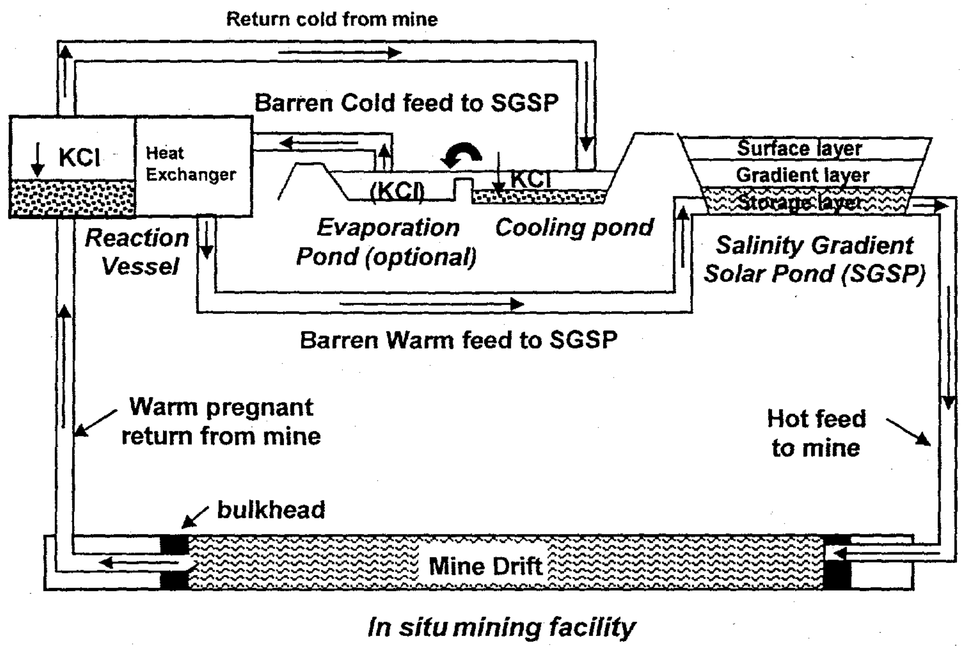

Figure 2 Proposed solution mining process and KCl production using a salinity gradient solar pond

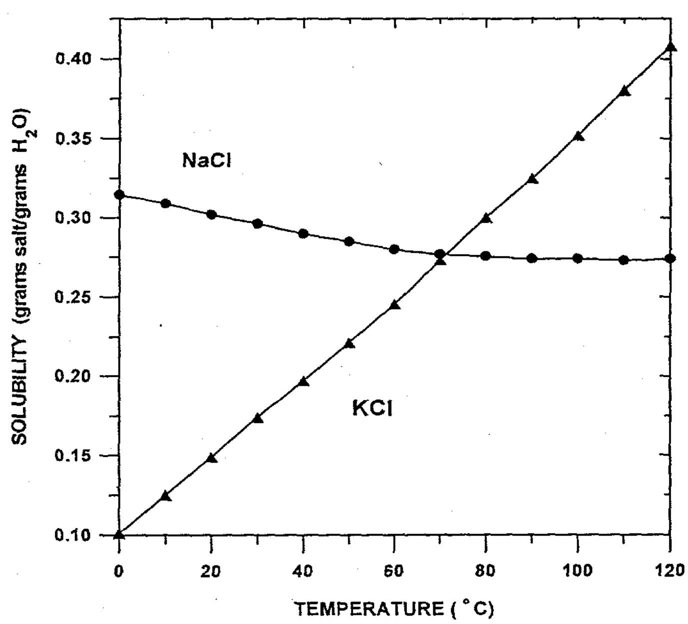

Figure 3 Solubility of NaCl and KCl in the system NaCl-KCl-H_2O

includes underground dissolution of KCl from pillars and other reserves remaining after completion of primary room and pillar mining using a hot, recirculating solution from the SGSP. The pregnant solution is pumped to the surface and flash cooled to force the crystallization of KCl product. The first stage of crystallization occurs in the reaction vessel, where a pure KCl product is expected to crystallize, based on an initial temperature difference. The second stage of precipitation occurs in the cooling pond, where KCl will be produced with minor amounts of NaCl. Waste brine (chiefly NaCl) from the cooling pond is sent to an evaporative pond to adjust brine saturation and density compatible with the SGSP feed requirements for pond stability. The evaporation process further provides the opportunity to investigate classical solar pond technology and the crystallization of the double salts as an alternative approach to evaporative cooling and KCl production. The barren brine from the evaporative pond is then pumped through a heat exchanger in the reactor vessel and preheated prior to being recycled through the SGSP. The heat exchanger, in turn, cools the solution from the mine forcing KCl precipitation while recapturing some of the heat that would otherwise be wasted. The entire process is designed to continuously reuse process brines. It is expected that 90% of the process water will be recycled while about 10% of the water will come from make-up brines extracted from existing mine site shallow wells.

Underground Solutioning Process

The solutioning will initially be conducted in a static mode (batch) followed by dynamic solutioning (continuous feed with convection) at various scales for the purpose of process modeling and optimization. Solution mining will take place near the No. 1 shaft at EPM within an existing low spot in the mine that will act as a natural sump for circulation of brines. The facility will require the isolation of the test volume spatially from the remainder of the very large EPM. Bulkheads will be constructed in a manner that is cost effective and compatible with the test duration. Conventional mining practices normally employ salt saturated concrete bulkheads for longer-term applications. However, for shorter duration tests, temporary bulkheads using lined salt berms may be applicable.

The volume of the excavation to be solutioned is 5000 m^3 and will be consistent with solar pond engineering design parameters to produce adequate brine flow rates and temperatures. Based on preliminary calculations, a 4047-m^2 (1-acre) SGSP with a storage layer slightly greater than 1 m in depth will provide the 5000 m^3 of hot brine feed required. Assuming a 10 °C temperature differential across the thermal layer (between the preheated feed to the SGSP and the hot feed to the mine), the maximum residence time for solutioning is expected to be 3 to 6 days for the initial batch feed process evaluation.

The underground facility will be carefully mapped and instrumented, and the solution process will be modeled. Geomechanical instrumentation will provide information on surface subsidence and rock displacements into the openings and will be important for the modeling and prediction of large-scale solution mining effects. Temperature and flow sensors will yield data needed for thermo-fluid dynamic modeling to accommodate scaling to any size process. Density-driven fluid dynamic computer codes, developed in support of the U.S. Department of Energy (DOE) Strategic Petroleum Reserve for the storage of crude oil and natural gas and applied to the solution mining of salt, will be adapted to include the temperature dependent solubility of potash, and fluid thermal response within the mine. Such modeling will allow process optimization and efficiency.

SGSP Construction

A prototype pond 4047-m^2 (1 acre), 3-m deep will collect and store solar energy and heat process brine for the underground solutioning of potash. The pond will be constructed with a double liner system comprising a 0.2-m layer of clay overlain with a 0.3-m thick layer of compacted salt. Clay (as process slimes containing kaolinite and smectite) is ideally suited for construction of an impervious base layer and is readily available on site as a waste product of potash processing. A moist crystallized salt layer compacted to form a dense, solid foundation for the SGSP will form the 0.3-m surface salt layer. Pond berms will be covered with a geomembrane tied into the compacted clay base to prevent lateral brine leakage. Heat extraction from the pond will be done by circulating hot brine from the pond through external piping into the mine.

BENEFITS OF SOLUTION MINING USING SALINITY GRADIENT SOLAR PONDS

Technology Benefits

This merging solution mining and SGSP technology will have application in two areas that include evaporite mining and the production of thermal energy for industrial process heat, power generation, and desalination. Solution mining is expected to cost 40% less than conventional extraction. Current mining costs are $66US/tonne. Preliminary feasibility studies have shown that solution-mining costs are expected to be $39US/tonne.

Solution mining offers a more efficient means of secondary mining and achieving close to 100% extraction of primary mined potash beds; translating this recovery to all reserves in New Mexico means extending the mining life by more than 25 years. Conventional mining recovery ranges from 60-65%, while secondary pillar mining can increase total recovery to as high as 90%. In comparison to solution mining, current methods used to mine potash reserves to high extraction ratios can be dangerous and the implementation of necessary ground supports systems can slow production and increase costs. Solution mining and evaporative cooling of brines represent processes that minimize worker exposure and hence, are deemed safer than conventional extraction. Once the underground environment is prepared for the introduction of solutions, only limited access to the underground will be necessary during extraction.

Additional benefits of using SGSP technology include the generation of power, desalinization, and developing aquaculture, with the production of marine fish and shellfish. Excess thermal energy derived from the SGSP can be converted to power with the use of a Rankine cycle engine that can, in theory, replace non-renewable electrical energy. Desalinization is desirable in the arid southwestern USA for potable water production from brackish ground waters as well as for surface water clean up of irrigation return flows and saline waste waters.

Energy Benefits

Table I summarizes the energy benefits for integrating SGSP technology with solution mining. For the EPM yearly production rate of 440,920-tonne, an initial 20% savings in energy per tonne of product extracted can be realized by converting from conventional mining (e.g., 143 kJ/700 kJ). In addition, 5.7 $(10)^{12}$ kJ/yr of thermal energy could be generated in a full-scale 0.81-km^2 (200-acres) SGSP (Walton, 1999). By converting this thermal energy to power with the use of

Table I Energy Benefits of Applying SGSP Technology to Potash Solution Mining

Energy Source	Conventional Technology 10^3 (kJ/yr/tonne)	Proposed Technology 10^3 (kJ/yr/tonne)	Energy Savings 10^3 (kJ/yr/tonne)
Oil/Gasoline/Diesel	37	9	28
Natural Gas	335	335	0.0
Electricity	328	213$^{(1)}$	115
Solar Energy	0	<12,920> $^{(2)}$	
Total	700	557	143

(1) Utilization of solar energy would reduce this to 0 kJ/yr/tonne

(2) Energy available from this technology for industrial process heat in FY2002, calculated for an industrial size (0.8 km^2) SGSP (not included in the Energy Savings)

a Rankine cycle engine, the 213 kJ/yr/tonne electrical need for the entire mining process could be offset such that this technology would consume no non-renewable electrical energy. The proposed technology, reduced by 213 kJ and leaving 344 kJ, would thus provide an energy savings of 356 kJ. This represents a reduction of 51% in non-renewable energy.

Environmental benefits

Environmentally, the entire solution mining and KCl production operation can be conducted within existing facility boundaries with no new waste product streams. This confinement will totally eliminate disturbance of new lands or increased environmental impacts from operations. Electrical power requirements will be reduced or possibly eliminated with this technology. Solar heating and evaporative cooling are environmentally beneficial "green" technologies that represent renewable energy resources.

SOLAR POND TECHNOLOGIES DEVELOPMENT IN THE USA

Salinity gradient solar pond technology has been advanced in the USA at the El Paso Solar Pond project. This pond is a research, development, and demonstration project initiated by the University of Texas at El Paso (UTEP) in 1983 (www.cerm.utep.edu/solarpond/). It has operated since 1986 and has successfully shown that process heat, electricity, and fresh water can be produced in the southwestern USA using solar pond technology (Xu et al., 1992; Esquivel, 1992). The 3237-m^2 (0.8-acre) pond, operating at 85 °C (185°F), has been used to:

- deliver 300 kW of thermal energy as industrial process heat to Bruce Foods canning operations in 1986,
- produce up to 70 kW of power using an Ormat organic Rankine-cycle engine, delivered to Bruce Foods to augment electrical power needs in 1986, and
- produce 17.4 m^3/day (4,600 gal/day) of desalted water using a 24-stage, falling film low temperature desalting unit installed in 1987; in 1990 a second unit was installed to produce pure water from brackish water on a 24-hour basis.

ENVIRONMENTAL IMPROVEMENTS IN MINERAL PROCESSING AND EXTRACTIVE METALLURGY

Economics, education, and the lack of incentives have hampered widespread commercial development of SGSP technology in the USA. Most industries and utilities will only take the risks involved with a new technology if projected economic benefits are large compared to perceived risks. Current low oil and natural gas prices offer low cost and relatively risk-free options for energy supply, providing little incentive for exploration of alternative energy sources.

At current energy prices solar ponds represent a niche technology that make economic sense only under prescribed conditions. Specifically solar ponds provide lower cost energy if:

• low-grade heat energy (i.e., < 100°C temperatures) is required for an industrial process,
• salt to form the storage zone is readily available at low or no cost,
• low cost land is available, and
• the pond site is located in a high solar energy region,

all of the above exist for the proposed technology. As oil prices rise in the future, alternative energy sources such as solar ponds will become cost competitive under a wider range of conditions.

CONCLUSIONS

The basis for this research is to seek sustainable and environmentally benign methods to supply thermal energy for in situ solutioning of an existing underground potash mine and the processing of KCl product. Salinity gradient solar pond (SPSG) technology is one such option. A SGSP is a large reservoir of saline water that collects and stores low-cost thermal energy used for industrial process heat. This research integrates solution mining, mineral product crystallization, and SGSP technology to provide a safe, more economical secondary mining process. Excess renewable energy from this integration will be converted to electrical energy, used to desalinate water, and provide space heat. This project will be the first of its kind in the USA to commercialize SGSP technology in potash mining to improve productivity and economic competitiveness thereby extending potash reserves at a cost lower than conventional mining.

Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

REFERENCES

Esquivel, P. M. Economic Feasibility of Utilizing Solar Pond Technology to Produce Industrial Process Heat, Base Load Electricity, and Desalted Brackish Water. Master Thesis. The University of Texas at El Paso. El Paso, TX. 1992.

Hull, J. R., Nielson, C.E., and Golding, P. Salinity-Gradient Solar Ponds. CRC Press, Boca Raton, FL. 1989.

Walton, J. C., personal communication, University of Texas at El Paso Solar Pond, 1999.

Xu, H., Lu, H., Golding, P. and Swift, A. Experience with High Performance Solar Pond Operation for Electricity Production. Proc. of the American Solar Energy Soc. Annual Conf. Cocoa Beach, FL. 1992.