Solution Mining Research—An Overview

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ABSTRACT

The Solution Mining Research Institute is a non-profit technical association of companies producing salt by dissolving, a technique known as solution mining. The Institute is the outgrowth of an organization founded in 1958 whose primary goal was to engage in research into technical matters of industry-wide interest and application.

The Objectives of the Institute are to serve as the technology center for industry, sponsor research projects, and bring interested people together on items of current interest. The work of the Institute is in the public domain and early publishing of results is a goal. Membership carries the right of contributing to the direction of research projects and proposing subjects for investigation.

INTRODUCTION

The importance of solution mining as a technique to produce brine to support chemical industries and evaporation plants based on salt has long been appreciated by managers and operators for its efficiency and low cost. This operation was largely taken for granted until about mid-century, at which time several aspects came into play which focused attention on salt wells and pointed up the need to apply technology to this activity: costs were rising, other uses for the cavities were becoming apparent, social impact and regulatory pressures were being felt, and cavity depth limits and production frontiers were being pushed. In addition, new techniques and technologies were being reduced to practice and new sciences such as rock mechanics and investigations into mass transfer and solution theory were being thrust forward through the application of computers. The need and the technologies had evolved upon which to base research into solution mining. The Solution Mining Research Institute was created for this purpose. This paper discusses the Institute, a technical association dedicated to the advancement of the technologies utilized in solution mining.

BACKGROUND

Before advent of the Institute, only sporadic research or engineering work had been done on aspects of solution mining by individual companies where the capability existed in-house. Some reports and papers had been prepared by outside researchers and writers. Examples familiar to the writer are salt cavity modeling experiments by C.A. Butler of Diamond Alkali Company in the 1940's, development of sonar for wire-line salt cavity measurements by I.C.I. and also by BASF Wyandotte's predecessor Wyandotte Chemicals Corporation in the 1940's, and publication of the book "Sodium Chloride," an American Chemical Society monograph. Work by Edward N. Trump on salt well cavity control led to issuance of a U.S. patent pertaining to a specific technique in the 1930's.

Recognizing the presence of salt well problems and the advantage of coordinating research capability, it was considered desirable to organize an inter-industry group to handle projects of practical value to all. By joint research, the services of the best researchers could be made available to the industry—a technical association was called for. The benefits of industry-wide input and development of the

technology center concept have resulted in a greatly expanded research effort.

As the result of conversations expressing this interest, an exploratory meeting was held in 1958 to propose establishment of a research association to investigate matters of a non-competitive nature. A delegation visited the American Petroleum Institute to learn how they handled research projects, budgeting and membership matters. This served to help in organizing a group interested in solution mining. The cooperation and guidance of API is acknowledged.

The following points derived from API conferences were considered to be significant:

1. All work done on an inter-industry basis must be open to the public and published as soon as possible.
2. Work is done in public or academic institutions in contrast to that being done in the laboratories of member companies to assure public disclosure.

Accordingly, it was agreed that an area of common interest could be defined for the initial effort: "To find or develop a precise method for delineating the boundaries of cavities resulting from solution mining of bedded salt", and the group was organized under the name Brine Cavity Research Group (B.C.R.G.) Eleven members were enrolled. However, the delineation of mature cavities in bedded salt resisted even the input of money and research effort. Several projects were undertaken (Appendix A), but it soon became apparent that other aspects of bedded salt production might be more productive ground for research effort; that salt domes warranted consideration; that to some the resulting cavity rather than the brine was the objective; and that to others, salt referred to other soluble minerals containing potassium chloride.

B.C.R.G. was terminated and the Solution Mining Research Institute was established in 1965. Solution mining was considered to be massive removal of a soluble mineral from its deposit by introduction of a suitable simple solvent, usually without chemical reaction. This definition contrasted with *in situ* leaching as is practiced in copper deposits where the material is selectively removed from its matrix by an appropriate solvent, frequently involving a chemical reaction and leaving the bulk of the matrix undisturbed. The purpose of the newly-formed Institute was to consolidate and improve the technology related to extraction of soluble minerals and of the related cavities by promoting basic research directed toward understanding and control of the mechanisms prevailing in the salt cavity environment.

Objectives were viewed as threefold: 1) To serve as the technology center for the solution mining industry by bringing together all those engaged or interested in extraction of minerals by the solution method or in utilization of the resulting cavity.

2) To sponsor and engage in research projects directed toward the following general objectives. A) investigate the basic mechanism operating in the cavity, the geometry of the cavity and appropriate controls. B) investigate earth movements resulting from creation of cavities and establish acceptable industry limits and standards for earth movements. C) investigate techniques, systems and methods for making direct and indirect measurements of cavities. D) sponsor other projects deemed worthy by the membership.

3) To bring people together to conduct the business of the Institute and to hear reports on results of research as well as other papers of current technical interest.

The Institute has progressed within this outline. Membership is now 26 (Appendix B) drawn from North America, South America, Mexico and Europe. Among its other achievements, it takes pleasure in assisting in the sponsorship of this symposium as it has others in the past. There are four papers being presented at this symposium discussing some of our sponsored research activities.

ORGANIZATION

The Institute has one staff member, an Executive Director, who handles the business of the Institute, arranges meetings and expedites research projects. We presently have the services of Mr. Horace Diamond, recently retired as Technical Director of Morton Salt Company, in this office. In his professional career, Mr. Diamond had extensive experience in many aspects of the salt industry. The Institute has the benefit of this background as well as his broad acquaintance with those interested in this work. The Institute also has consultants on retainer to serve as advisors in their field of specialty.

Other administrative activities of the Institute are carried out by representatives of member companies. A three-member Board of Directors is elected for staggered three-year terms. Other duties are assigned as required, for example, service as Chairman of the Technical Committee. The Technical Committee proposes and initiates research projects which are subject to approval of the membership. Other standing committees have activities indicated by their titles: Dissolution; Rock Mechanics; Legislation and Regulation; Publications; Drilling, Completion and Logging; and Membership. These committees change periodically as emphasis of research activity varies.

Meetings are held twice yearly. The business of the Institute is transacted and one or two days are set aside for presentation of technical papers on SMRI research projects and matters of current interest. The technical sessions are open to the public. The content of many of these sessions is not published except in the minutes of the meeting. There-

fore, attendance for the papers and contact with the speakers at the meetings is one of the advantages of attending meetings of the Institute. A list of some of the more significant papers presented at SMRI meetings is included as Appendix C.

RESEARCH ACTIVITIES

The principal areas of investigation and research by the Institute are listed in Appendix A which includes projects to date, title, principal researcher/institution and distribution of results. In the following discussion reference will be made to specific projects listed in Appendix A.

Cavity delineation. One of the initial goals of the Institute and its predecessor was delineation of the cavity resulting from salt production[1]. It was recognized that sonar techniques were effective in describing cavities in massive deposits such as the U.S. salt domes, but in cavities developed in bedded or deformed deposits, the absence of a clear sound path precluded employment of the sonar method[2]. Access and non-access (surface) methods were investigated. Access-method investigations were abandoned early because it was learned that use of other ranging than sound or development of a cavity-access survey vehicle was beyond the state-of-the-art at that time[3]. Non-access methods employing resistivity[3,5], gravity[11], seismic reflection and refraction techniques[22] were investigated experimentally in the laboratory and in the field[24].

Techniques designed to detect the cavity by surface measurements of stress changes[20], or elevation or lateral changes[19] have been investigated. Strain gauges in bedrock boreholes were installed and monitored[7]. A project is currently underway to outline and describe techniques for surface monitoring of overburden response to cavity development—i.e. subsidence[35].

Rock mechanics. Strain gauges installed in mines and bedrock boreholes provided for rock mechanics investigations by the Institute[7]. Further Institute sponsored work was done in the field of rock mechanics using finite-element techniques to define the competence of cavity-roof rock systems and the overlying layers and to define practical cavity limits[16,25]. A report was issued on the rock mechanics aspect of two related instances of sinkhole formation above cavities in the Michigan-Ontario area[31].

Use of a wireline downhole rock-properties log to monitor change in rock properties[30] over developing salt cavities is a continuing Institute project. It is directed to early warning of changes in rock properties over the developing cavity.

Subsidence. The Institute has investigated and issued reports on several instances of subsidence and sinkhole formation from the rock mechanics, cavity delineation and the social-impact points of view. An instance of subsidence in Michigan-Ontario in 1953 and 1970 was published in 1971[29]. A review of all subsidence occurrences in Kansas was published in 1976[28]. Additional work is being done in conjunction with the U.S. Bureau of Mines[33]. Work directed toward subsidence and sinkhole prevention was included in the discussions of cavity delineation and rock mechanics projects. Other projects proposed or underway include sonic monitoring of cavity roof noises both in salt wells and storage cavities[27].

Dissolution and cavity control. It was learned in the days of the cavity delineation project of the Institute and its predecessor, that determination or control of the cavity shape, particularly in bedded salt, must be predicated on an understanding of the salt dissolving mechanism operating in the cavity. Furthermore, that development of methods for cavity-shape control were necessary to properly develop a brine field to insure cavity stability and economic operation. Early work was directed to investigation of the dissolving of salt[1,12].

An experimental cavity was dissolved in an unused salt bed beneath the floor of a Detroit mine to verify laboratory results on dissolution and cavity prediction. The cavity was 5 m wide and 8 m high. The rock floor of the mine beneath which the cavity was created was 2 m thick. Samples and measurements were taken while the cavity was developing. It was ultimately pumped out to permit access for detailed observation. The resulting cavity confirmed predicted shape calculated from laboratory experiments[15].

Work on the dissolution mechanism and on cavity shape and control was conducted under Institute sponsorship at the Illinois Institute of Technology Research Institute under Dr. Richard Snow and at the University of Texas under the direction of the late Dr. Frank Jessen[8,12,26]. These projects resulted in research papers and graduate thesis reports. The Texas work is being continued under Institute sponsorship by A. Saberian Associates[32]. A discussion of these projects is the subject of a separate paper in this symposium. A computer program for cavity prediction based on this work is considered to be one of the major Institute achievements.

Well development. Connection of new wells in layered salt near the base of the deposit employing application of hydraulic pressures—a technique known as hydraulic fracturing—was investigated in order to improve performance and predictability[19]. Case histories were reviewed both from the rock mechanics and petroleum engineering point of view. Attempts were made to map the propagating fracture using microseismic methods[22,24] and research into directional control techniques was undertaken. Much work remains to be done to improve the operational and technological acceptability of this technique.

Legislative. The Institute has participated in or has been

invited to comment on the preparation of regulations covering salt and storage wells by several states and is presently working on comments concerning federal regulation of wells operating through zones of potable water. Institute participation in this activity is worthy because the entire spectrum of operations and most of the principal operators are included in Institute membership. It is appropriate that they should participate in the preparation of regulations affecting or serving as models for the entire industry.

Other activities. A sub-group of Institute members has sponsored research into application of electromagnetic waves and sonar techniques to mapping within salt mines. This work is being done under the direction of Dr. Robert Unterberger at Texas A&M University and is directed to investigation of the advancing front in a salt mine looking for test holes and water-filled fissures[18].

The Institute subsidizes speakers at its two yearly meetings in order to make available papers of current interest from solution mining and related technologies.

Vendors and suppliers are also invited to make presentations describing tools and techniques of interest to the members in their work. The Institute takes pride in its participation in this symposium and similar meetings where its stature and inter-industry scope serves to draw on wide representation.

The Institute is sponsoring preparation of a review of the state of the art of solution mining intended to be a compendium of all aspects of solution mining technology[36]. It also subscribes to a literature search service in the related sciences to provide members with information from publications from the scientific and technical literature.

SUMMARY

The Institute plans to proceed in the direction outlined in its goals and objectives to serve as a technical association of those interested in solution mining. Membership and attendance at the Institute's meetings is open to anyone sharing this interest. We welcome suggestions and guidance on research projects within the scope of the Institute.

APPENDIX A

RESEARCH PROJECTS, STUDIES, SPONSORED INVESTIGATIONS

Brine Cavity Research Group Projects 1958–1964

1. 1958 "Compilation of Brine Well Technology, Geology and Cavity Delineation Activities", M.W. Pullen editor.
2. 1959 "Suggested Program for Further Investigation into Brine Cavity Delineation". M.W. Pullen.
3. 1961 "Feasibility Study of Electrical (Resistivity) Methods for Underground Cavity Mapping". E.W. Ruhl (Pullen), Vitro Labs., West Orange, N.J.
4. 1962 "Physical Properties of Salt". 125 pp, M.W. Pullen, editor, BCRG.
5. 1962 "Field Experiments Employing Electrical (Resistivity) Measurements for Salt Cavity Delineation (Detection) at Silver Springs, N.Y." L. Scharon, Washington Univ., St. Louis, MO.
6. 1962 "Application of Shear Waves for Cavity Delineation". J.C. Cook, Southwest Research Institute.
7. 1963 "Detection of Cavities by Application of Strain Gauge Technique at Earth's Surface". C.L. Emery, CIM Consultants, Kingston, Ontario.
8. 1964 "Studies re Fluid Flow, Mass Transfer and Convection Effect in Salt Cavity". R. Snow, Illinois Institute of Technology Research Institute, Chicago, Ill.

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9. 1966 "Investigation Into Feasibility of Cavity Delineation Employing Access Devices". P. Constant, Midwest Research Institute, Kansas City, MO.
10. 1967 "Measurement of Surface Movements Above Stressed Salt Cavities Using Electric Transducers". F. Peterson, Stanford University, Palo Alto, CA.
11. 1968 "Application of Gravity Techniques to Salt Cavity Delineation (Detection)". R.C. Speed, Northwestern University, Evanston, Ill.
12. 1968 "Research Projects on Salt Dissolution, Cavity Prediction and Optimization". F. Jessen et al., University of Texas, Austin, TX.
13. 1968 "U.S. Bureau of Mines—Mines Research Center. Activities Applicable to Solution Mining". SMRI (Querio, Richner, Piper) 12 pp.
14. 1968 "Solution Mining Research Institute—Its Purpose and Research Efforts". Midwest Research Institute, Kansas City, MO 16 pp.
15. 1969 "Pilot-Scale Salt Cavity to Test Salt Dissolving and Cavity Development Theories". SMRI–IITRI–Univ. of Texas (Querio).
16. 1969 "Evaluation of Time-Dependent Material Properties on Prediction of Subsidence". K. Nair, Woodward-Lundgren Associates, Oakland, CA.
17. 1969 "Solution Mining Research". SMRI/A.E. Cummings editor, 13 Sections.
18. 1969 "Application of Electromagnetic Energy to Salt to Detect Discontinuities". R.R. Unterberger, Texas A&M Univ., College Station, TX.
19. 1970 "Review of Hydraulic Fracturing Techniques as Applied to Salt Wells". B. Haimson, University of Wisconsin, Madison, WI.
20. 1970 "Installation of Instruments in a New Brine Field to Detect Cavity Development (Dale, N.Y.)". SMRI (Querio).
21. 1970 "Research Practices & Procedures of SMRI". H.C. Helgeson, Northwestern Univ., Evanston, Ill.
22. 1971 "Review of Seismic Signal Enhancement Techniques (Using Filters) for Salt Well Applications," J. Bailey, Senturion Sciences, Tulsa, OK.
23. 1972 "Effect on Environment of Sinkholes at Two Locations in Detroit area, Michigan". K.K. Landes, T.B. Piper (SMRI).
24. 1973 "Appraisal of Seismic Technique for Mapping Fractures Induced by Hydraulic Pressures". M.N. Toksoz,

Massachusetts Institute of Technology, Cambridge, MA.

25. 1974 "Rheological Element Method (REM) Computer Technique for Rock Mechanics Studies". S. Serata, Serata Geometries, Berkeley, CA.
26. 1975 "Mass Transfer at the Salt-Brine Interface". G.C. Vliet, Univ. of Texas, Austin, TX.
27. 1975 "Field Tests to Investigate Micro-Seismic Detection of Roof-Rock Failure (Dale, N.Y.)". SMRI/L. Obert.
28. 1976 "Horizontal Penetration Studies—Buoyant Jet Stream in Brine". A. Saberian, A.L. Podio, Univ of Texas, Austin, TX.
29. 1976 "Land Subsidence in Central Kansas Related to Salt Dissolution". R.F. Walters/SMRI/Hendron.
30. 1976 "Use of 3-D Logging Technique for Predicting Cavity Roof-Rock Failure". J.I. Myung, Univ. of Tulsa, Tulsa, OK.
31. 1976 "Rock Mechanics Investigation of Two Sinkhole Events in the Detroit, Michigan area". A.J. Hendron/A. Nieto-Pescetto, Univ. of Illinois, Urbana, Ill.

Projects underway

32. 1976 "Research Projects on Salt Dissolution, Cavity Control and Development". A. Saberian, A. Saberian Associates, Austin, TX.
33. 1976 "Test Drilling to Determine Mechanism and Extent of Subsidence (Hutchinson, Kansas)". SMRI/USBu Mines/Hendron/Obert.
34. 1976 "Study of Field Data of Hydraulic Fracturing in Salt Wells". K.E. Gray, Univ. of Texas, Austin, TX.
35. 1974 "Survey Techniques for Detection and Measurement of Subsidence". SMRI/T.B. Piper.
36. 1977 "Solution Mining—State of the Art Review". SMRI/A.E. Cummings editor.

APPENDIX B

MEMBERSHIP LIST

AKZO Zout Chemie
Boortorenweg 20, P.O.B. 25
Hengelo (0), The Netherlands
c/o G. Politiek

Azufrera Panamericana, S.A.
Apt. Post No. 1
Jaltipan, Ver. Mexico
c/o L.G. Gulvan

BASF Wyandotte Corporation
Wyandotte, MI 48192
c/o T. Piper

Billiton Delfstoffen B.V.
19 Louis Couperusplein
The Hague, Holland
c/o R. deVries

Canadian Salt Company, Ltd.
606 Cathcart Street
Montreal, Quebec H3B 1L6
c/o J. Mair

Cargill, Inc. Salt Div.
Box 1403
Hutchinson, KS 67501
c/o D. Robinson

Diamond Crystal Salt Co.
St. Clair, MI 48079
c/o C. Cronenworth

Diamond Shamrock Corp.
1100 Superior Avenue
Cleveland, OH 44114
c/o R.L. Fortune

Dow Chemical Company
409 Building
Midland, MI 48640
c/o D. Cella

FMC Corporation
2000 Market Street
Philadelphia, PA 19103
c/o A. McCue

Hooker Chemicals Corporation
Box 344
Niagara Falls, NY 14302

Imperial Chemical Industries, Ltd.
Box 13, Lostock Gralam
Northwich, Chesire, England
c/o G. Alvey

Kavernen Bau-und Betriebs-GmBH
Rahtensaustrasse 13,14
3 Hanover, West Germany
c/o H. Haddenhorst

Morton Salt Company
110 North Wacker Drive
Chicago, IL 60606
c/o M. Kallerud

Olin Chemicals
Box 178
McIntosh, AL 36553
c/o L. Sevenker

Pennwalt Corporation
4655 Biddle Avenue
Wyandotte, MI 48193
c/o R. Heineman

Rhone-Poulenc Compagnie Industrielle et Miniere
25 Quai Paul Domer
92 408 Courbevoie FRANCE
c/o M. Adolphe Beauvais

Sales del Istmo
Apdo Post 285
Coatzacoalcos Ver. Mexico
c/o L. Azuela C.

Salgema Ind. Quimicas S.A.
Caixa Postal 348
Maceio, Alagoas, Brazil
c/o L. Campos

Sifto Salt Div., Domtar Chem.
Box 7212
Montreal, Quebec H3C 3M3
c/o G.M. Camp

Solvay et Cie
33 Rue Prince Albert
Bruselles 5, Belgium
c/o R. Pissart

Texas Brine Corporation
2000 West Loop South
Houston, TX 77027
c/o L. Webre

Vereingte Schweizerische Rheinsalinenen A.G.
4133 Schweizerhalle, Switzerland
c/o L. Hauber

Class II members

Dames and Moore
7101 Wisconsin Ave., Suite 700
Washington, D.C. 20014
c/o R. Langill

Gulf Interstate Engineering Co.
930 Americana Building, P.O. Box 1916
Houston, TX 77001
c/o N. Van Fossan

Norsk Hydro Sales Corp.
800 Third Avenue
New York, NY 10022
c/o Ms. J. Andreu

APPENDIX C

SELECTED EXAMPLES OF TALKS AND PAPERS PRESENTED AT SMRI MEETINGS

"Rock Mechanics and Strata Control—Use of Plastic Strain Gauge Devices". C.L. Emery, 1963.

"Use of Sonar in Cavity Delineation". A.J. Myers, Dowell, 1963.

"Symposium on Use of Strain Gauge Techniques—Kingston, Ontario". C.L. Emery, 1964.

"Downhole Stereo Camera Applied To Salt Wells". G.M. Baker Co., 1964.

"U.S.G.S. Water Level Tilt Meter for Detection of Surface Effects of Ground Water Production". Francis Riley, 1966.

"Directional Drilling for Salt Well Connection". J.K. Henderson, 1969.

"Use of Electromagnetic Waves to Detect Discontinuities in Salt". R.R. Unterberger, 1969.

"Use of Recording Bore Hole Extensometer". T. Morgan, U.S. Bureau of Mines, 1971.

"Surface Electrical Potential Measurements to Determine Frac Direction and Length". C.L. Schuster, Sandia Laboratories, 1971.

"Precision Ground Measurement Using Aerial Photogrammetric Techniques". J.B. Strayle, DBA Systems, 1972.

"Application of Acoustical Holography to Underground Exploration in Salt". T.O. Price, Holosonics, Inc., 1973.

"Cleaning Brine and Water Lines with Pumpable Reamers". R. Urash/F. Gray, B.G. Harmon Co., 1974.

"Solution Mining Research Program, Saskatchewan Research Council". SRC/D. Storer, 1974.

"Federal Energy Administration Crude Oil Storage Program". P. Childress/FEA, 1974.

"Underground Storage Cavity Construction and Operation" H. Haddenhorst, KBB, 1975.