The Solution Mining Research Institute—an Update

Horace W. Diamond, Jr.
Morton Salt Division, Morton Thiokol, Inc.
Chicago, Illinois, USA
President (1983) Solution Mining Research Institute
Woodstock, Illinois, USA

ABSTRACT

The Solution Mining Research Institute sponsors research projects and technical meetings in the areas of dissolution theory; well drilling, completion and logging; subsidence and cratering; cavern utilization and rock mechanics. The projects completed since the Fifth Salt Symposium or currently underway are described. A bibliography of SMRI reports since 1976 and an index of recent meeting papers are provided.

INTRODUCTION

The solution mining industry has undergone a dramatic change in the last few years. Previously the primary focus was on producing artificial brine to recover a mineral, usually salt. Today, much of the industry is focused on creating caverns that can be used for storage; the brine may even be a waste by-product. The activities of the SMRI have been similarly redirected.

RESEARCH

Dissolution Theory

Over the years, a major undertaking of the SMRI has been the development of a computer program that numerically simulates cavity leaching in a salt formation. The work extended over a number of years and involved several investigators. The basic model, a computer program named SALT77, was completed in 1977 and presented by Ahmad Saberian at the Fifth Salt Symposium. Two enhancements have since been prepared: the first is SALHYD, which is SALT77 plus the calculation of the hydraulics; the second is SALGAS, which is the SALT77 program plus calculation of the hydraulics plus calculation of the amount of gas needed to maintain a constant level for a gaseous pad (nitrogen). These programs are available from the SMRI.

The SALT77 model is based on dissolution rates for a fluid at a temperature of 75°F. Under some circumstances the fluid temperature may be significantly different, for example, solutioning a small cavity with cold water at a high injection rate. Experimental work has been done to determine dissolution rates at other temperatures, specifically

Temperature, °F	Salinity, %
43 to 127	72.8
75 to 120	88.4
40 to 150	96.8

The data are now being compiled and will be published shortly, along with a description of the experimental procedure and an empirical temperature/dissolution rate relationship. The SMRI has not decided whether to modify the SALT77 program and the related models to reflect the effect of different fluid temperatures.

Another leaching model has been independently developed by Intercomp. Both the SMRI and Intercomp models have their proponents, and the SMRI has retained Dr. Devraj Sharma to prepare a comparative evaluation. Dr. Sharma's report will be issued shortly.

Cavern Utilization

A survey is now underway to obtain data on existing solution mined caverns in salt domes. The survey will provide data on the ranges and norms for parameters such as cavern dimensions, depths, salt roof thicknesses and pillar thicknesses between caverns. This information will be useful in designing new caverns, evaluating existing caverns and planning expansions of existing cavern complexes. The project will be completed by the fall of 1983.

Storage cavern owners and operators undergo various certification steps before using caverns for storage. A survey is now underway to determine current practices for certification and to determine whether it would be appropriate for the SMRI to develop standards for cavern certification. This work will also be finished by the fall of 1983.

Another area being investigated is determining what

happens if a well is plugged after a cavern has been filled with a fluid. This problem is particularly pertinent in conjunction with the possible use of storage caverns as a final repository for liquid toxic waste. Due to the rheological properties of salt, convergence will occur and there will be an increase in the pressure within the cavern. Some experts have expressed fears that after a period of time a fracture will occur at the roof of the cavern or at the base of the last cemented casing, possibly resulting in an escape of the liquid into the biosphere. The study has just been authorized and will be completed in 1984.

Subsidence

The SMRI has researched the mechanisms, causes, methods of detection and methods of prevention of subsidence above solution mined cavities in salt.

Mechanisms and Causes. In order to understand the mechanisms and causes, four subsidence areas above solution mined caverns in salt have been investigated at two different locations in Hutchinson, Kansas. They are

1. North sinkhole, Cargill Salt, formed in 1954
2. South sinkhole, Cargill Salt, formed in 1974
3. Well #57, Carey Salt, formed in 1978
4. Well #50, Carey Salt, formed in 1978.

All four sinkholes were investigated by drilling and coring a number of holes in their vicinities. The investigation of the Carey sinkholes was a cooperative venture with the U.S. Bureau of Mines.

The four sinkholes can be divided into two groups. The south sinkhole at Cargill was the only one with a chimney and the crater was 55 feet deep. At the other three, no chimney formed and the craters were 10 to 25 feet deep. In all four instances, the salt had been completely dissolved from the cavity roof. The shale above the roof was then exposed to water and brine, which softened and cracked it.

For the three sinkholes that did not have chimneys the initial salt cavities were thin. The cavities were filled with insolubles and materials that stoped from the roofs, forming rubble piles. The overlying shale beds failed by sagging but came to rest on top of the rubble piles before they broke and lost their continuity. Overburden movements were restricted primarily to downward subsidence without the overburden material piping into the cavities.

The south sinkhole at Cargill that had a chimney was formed from a cavity that was originally much thicker. When the overlying shale sagged, it broke up before it reached the rubble pile and a chimney formed to the surface. The sand and gravel overburden piped laterally and downward into the broken shale in the chimney.

While these studies have described the mechanisms, information is lacking about the salt roof thickness required to insure a stable cavity. Information is also lacking as to what mechanisms might have triggered the collapse, because in all four of the subsidences, the brine wells around which the subsidences occurred had been out of service for at least one year prior to collapse. The effect operating procedures might have had on the stability of these caverns, for example, reverse circulation, is also unknown.

To provide further insight it was decided to investigate the cavity around well 56 at Carey where no subsidence has occurred. Well 56 is a part of the nine-well gallery that includes wells 50 and 57. Well 56 is located about 300 feet from well 57. It is understood that well 56 was used for injection but never operated with reverse circulation (i.e., never operated with injection down the tubing). The area around well 56 has been stable to date. (The results of this study were published in the summer of 1983).

An alternative hypothesis for sinkhole formation has been proposed by two SMRI members who are not convinced that present theory satisfactorily accounts for sinkholes that formed some time ago at Detroit, Michigan and Windsor, Ontario. They have proposed that consideration be given to a secondary mechanism operating after cavity enlargement and areal downwarping of overlying rocks have occurred. They suggest that stresses develop which fluidize over-lying sand layers to form a slurry of sand and water. The slurry attains sufficient density to migrate down minor cracks and joints to the cavity if a route for brine displacement is available. The slurry has a low stacking angle such that the fluid migrates long distances laterally. This results in undermining significant volumes above the cavity but below the surface. Surface collapse then follows and "clusters" or satellite craters are formed.

A paper has been prepared on this hypothesis; inasmuch as it conflicts with the hypothesis that has been presented for the subsidences that occurred in Hutchinson, Kansas it is hoped that the current drilling of Carey well 56 (the one that did not subside) will provide insight so that these conflicting theories may be reconciled.

Surveys for Detecting and Measuring Subsidence. There are a variety of methods available to the solution mining industry to detect and measure subsidence. No one method is best for all situations. In structuring a subsidence detection and measuring system, factors such as rock structure, depth of cavity, climatic conditions, surface structures and cost need to be considered.

In recognition of this the Solution Mining Research Institute has sponsored two papers on detecting and measuring subsidence. These two papers provide guidelines for preparing and conducting field surveys. The papers are written for managers of brinefields and field engineers as well as for surveyors. It is hoped that the reader can learn from them the principles, capabilities and limitations of the different methods of field surveying techniques. The papers are also intended to provide sufficient details on monumentation, survey network layout and data analysis so that a field engineer with some experience in surveying methods will be able to either conduct a survey program or evaluate the quality of surveys by others. For surveyors

who are undertaking the work as a departure from their routine land surveying activities, the papers are intended to explain the reasons for the surveys and define the accuracy required.

The two papers are "A Manual on Ground Surveys for Detection and Measurement of Subsidence Related to Solution Mining," October 1982 by Kam Wong, Professor of Civil Engineering University of Illinois, and "Surveys for Detection and Measurement of Subsidence," January 1981 by Thomas B. Piper, Staff Geologist, Manager Subsurface Technology—BASF Wyandotte Corp., Wyandotte, Michigan. The Solution Mining Research Institute does not advocate any one method; the user must decide which method is appropriate for the particular situation.

Other Projects

In conclusion let me briefly review a number of other projects.

KWIC Index. A Key-Word In Context (KWIC) index of salt related literature has been prepared. The index contains documents relating to

- thermo, mechanical and physical properties of salt
- analysis methods (rock mechanics and mining)
- solution and mechanical mining practices
- post mining storage activities
- subsidence and other environment related data
- cavity stability data
- geology and hydrology of evaporite brines.

References are from both the open literature and government supported laboratory reports. Due to the rather extensive literature on salt and funding limitations for the project, the scope of the index was limited by placing emphasis on literature appearing in the English language since 1959 and literature related only to the categories noted above. Furthermore, emphasis was placed on literature resulting from the U.S. nuclear waste disposal program.

Tiltmeters to Monitor Hydraulic Fractures. The solution mining industry would like to be able to monitor the path and progress of a hydraulic fracture as it occurs. Theoretical studies show that a hydraulically induced fracture produces a small displacement on the surface. Furthermore, displacement is characteristic of the attitude, azimuth and extent of the fracture. The displacement pattern also depends on the mechanical properties of the rock and the fracture width.

In December 1978, the Diamond Crystal Salt Company hydraulically fractured a connection between two wells. Tiltmeters were used in an attempt to monitor the fracture. For this application the tiltmeter is an extremely sensitive (approximately 1 microradian) instrument for measuring angular deviation from vertical. The device is enclosed in a torpedo-shaped housing about 6 feet long and 6 inches in diameter. It requires mounting in a vertical hole about 20 feet deep. Eight tiltmeters were installed approximately equally spaced on a circle concentric to the wells.

In his final report the researcher concluded the following:

> "Ground tilts associated with hydraulic fracturing and the early stages of cavity formation were measured at the site, although small—averaging between 3.0 and 5.0 × 10 to the minus eighth radian—the tilts associated with the fracturing were clearly documented on analog and digital records. Tilt changes that occurred after the start of injection of unsaturated brine were considerably greater. Ground tilts at the time of communication of the injection and target wells were consistent with tilts expected from a penny-shaped fracture with a radius of 180 feet, the distance between the two wells."

In the opinion of the SMRI membership the technique is highly theoretical and not amenable to practical, on-site application. No further work has been done.

Down-hole Treatment of Brine Impurities. For some brine producers, down-hole treatment of brine to reduce impurities could be attractive. It might cost less than above-ground treatment and would solve the problem of disposing of the waste sludge. A study is now underway to

- review and compile from published literature, patents, suppliers and users the effects of various additives on both food grade and nonfood grade brine
- determine whether additional research should be done in this field.

The study is scheduled for completion in the fall of 1983.

Microseismic Monitoring. The U.S. Bureau of Mines conducted field tests in Hutchinson, Kansas at the Carey Salt Company's brinefield during October, 1979 to determine the amount of detectable rock noise generated below the surface. The brinefield was selected because the two subsidence incidents that occurred in the summer of 1978 indicated that it might be unstable. This is the brinefield with wells 50 and 57 that has been described earlier in this paper.

They hoped to detect rock noise associated with degradation of the geologic strata over the solution cavities. During a two-day period 400 feet of paper records were made, representing about 10 hours of monitoring time. After full consideration of all available data, they concluded that no significant rock noises were generated because the formation was stable.

Potash Dissolution. A report has been prepared providing a general picture of the state of the art of potash dissolution. For a variety of reasons there is a scarcity of published material on in situ potash leaching. Only a few studies have been carried out. For competitive reasons,

companies involved in solution mining of potash, or have an interest in getting involved, generally don't publish their findings. Potash solution mining has yet to achieve the prominence that salt solution mining has achieved.

In the report the well-established relations for salt dissolution were used as the baseline and the available potash dissolution investigations were described in parallel. The similarities in dissolution principles do not make solution mining of salt and potash similar. In fact, there are significant differences.

The report also contains sections on potash solution mining by the multi-well, fracture connection procedure and on numerical simulation of potash leaching.

THE SOLUTION MINING RESEARCH INSTITUTE

In addition to sponsoring research, the SMRI meets twice a year. At these meetings technical papers are presented and the business of the organization is transacted. The business meetings are for members of the SMRI and the technical meetings are open. Research reports are distributed initially to members and one year later made available to the general public. Meeting papers are available at any time. Membership in the Solution Mining Research Institute is open to all organizations involved with solution mining. For information on the SMRI contact Mr. Howard Fiedelman, the Executive Director, at 812 Muriel Street, Woodstock, Illinois 60098, telephone 815/338-8579.

APPENDIX A

BIBLIOGRAPHY OF SOLUTION MINING RESEARCH INSTITUTE REPORTS 1976–1982

FILE NUMBER	AUTHOR(S) & TITLE
1976	
76-0001-SMRI	Saberian, A. The effect of water ascent velocity on salt dissolution rate, University of Texas (Austin), 24 pp.
76-0002-SMRI	Walters, R. F. Land subsidence in central Kansas related to salt dissolution, 144 pp.
76-0003-SMRI	Saberian, A. and A. L. Podio. The horizontal penetration of a buoyant jet stream in brine, University of Texas (Austin), 28 pp.
76-0004-SMRI	Saberian, A. and A. L. Podio. A numerical model for development of solution mined cavities, Symposium, Salt Dome Utilization and Environmental Considerations, Louisiana State University, November 22–24, 1976, 35 pp.
76-0005-SMRI	Myung, J. I. Laboratory model investigation for predicting roof failure using 3-D velocity logging technique, (Dissertation), University of Tulsa, 1976, 184 pp.
1977	
77-0001-SMRI	Thompson, T. W. and K. E. Gray. The development of hydraulically fractured connections between boreholes in salt, Interim Report No. 1, 60 pp.
77-0002-SMRI	Saberian, A. and A. L. Podio. Application of jet injection to salt cavity development, A. Saberian & Associates, Report No. 77-1, 22 pp.
77-0003-SMRI	Saberian, A. Cavity development in a three-layer bedded salt model, A. Saberian & Associates, Report No. 772, 26 pp.
77-0004-SMRI	Hendron, Jr., A. J., R. E. Heuer, and G. Fernandez-Delgado. Field investigations at Cargill sinkhole, Kansas, 35 pp.
77-0005-SMRI	Saberian, A. Salt dissolution in horizontal conduits, A. Saberian & Associates, Report No. 773, 28 pp.
77-0006-SMRI	Saberian, A. Cavity development in a five-layer bedded salt model, A. Saberian & Associates, Report No. 774, 20 pp.
77-0007-SMRI	Nieto-Pescetto, A. S. and A. J. Hendron, Jr. Study of sinkholes related to bedded salt production in the area of Detroit, Michigan, University of Illinois, 49 pp.
77-0008-SMRI	Podio, A. L. and A. Saberian. Optimization of solution mining operations, 56 pp.
1978	
78-0001-SMRI	Saberian, A. Accomplishments of SMRI-sponsored salt dissolution research since the Fourth Salt Symposium, 5th International Salt Symposium, 38 pp.
78-0002-SMRI	Unterberger, R. R. Sonar probing as a mining and tunneling tool. National Science Foundation Grant No. 76-21764, 98 pp.
78-0003-SMRI	Walters, R. F. Brinefield subsidence, June, 1978, Interpace Corporation-Carey Salt Division, Hutchinson, Kansas, 5 pp.
78-0004-SMRI	Thompson, T. W. and K. E. Gray. The development of hydraulically fractured connections between boreholes in salt, Interim Report No. 2, 31 pp.
78-0005-SMRI	Hendron, Jr., A. J., R. E. Heuer and G. Fernandez-Delgado. Field investigations at Cargill sinkhole, Final Report, Alfred J. Hendron, Jr. Geotechnical Engineer, 38 pp.
78-0006-SMRI	Kusnetsova, L. N. and V. S. Azev. The stability of gasolines stored in salt caverns, Unedited translation by Rebecca Barker, 10 pp.

FILE NUMBER	AUTHOR(S) & TITLE
78-0007-SMRI	Saberian, A. Experimental studies of salt dissolution in horizontal fractures, A. Saberian & Associates, Report No. 7879-1, 48 pp.
78-0008-SMRI	Saberian, A. Numerical simulation of cavity leaching with compressible pads, A. Saberian & Associates, Report No. 7879-4, 33 pp.
78-0009-SMRI	Querio, C. W. and J. F. Gilbert. Diamond Crystal Salt Company hydrofracing of wells M-1 & M-2, 47 pp.
1979	
79-0001-SMRI	Hendron, Jr., A. J., G. Fernandez-Delgado and P. A. Lenzini. Field investigations of north subsidence area at Cargill, Kansas. Preliminary Report, A. J. Hendron, Jr., Geotechnical Engineer, 39 pp.
79-0002-SMRI	Hendron, Jr., A. J., G. Fernandez, and P. Lenzini. Study of sinkhole formation mechanisms in the area of Hutchinson, Kansas, A. J. Hendron, Jr., Geotechnical Engineer, (dated January 1979), 46 pp.
79-0003-SMRI	Sevenker, L. The Department of Energy strategic petroleum reserve, 42 pp.
79-0004-SMRI	Quast, P. and F. Crotogino. Compressed air energy storage (CAES) project, 26 pp.
79-0005-SMRI	Saberian, A. The effect of insoluble stringer dip angle on solution-mined cavities, A. Saberian & Associates, Report No. 7879-2, 28 pp.
79-0006-SMRI	Ghaboussi, J., R. E. Ranken, and A. J. Hendron, Jr. Finite element analysis of the time dependent behavior of solution caverns in salt, A.J. Hendron, Geotechnical Engineer, 99 pp.
79-0007-SMRI	Hendron, Jr., A. J., Fernandez, G., Lenzini, P. Study of sinkhole formation mechanisms in the area of Hutchinson, Kansas, A. J. Hendron, Jr., Geotechnical Engineer, (dated May 1979), 48 pp.
79-0008-SMRI	Saberian, A. Cavity shape alteration due to product displacement with cooler and/or undersaturated brine, A. Saberian & Associates, 32 pp.
79-0009-SMRI	Wood, M. D. Analysis of ground tilts associated with hydraulic fracturing and cavity formation in salt, M.D. Wood, Inc, 46 pp.
79-0010-SMRI	Walter, R. F. Surface subsidence related to salt-well operation, Hutchinson, Kansas, 1978, Walters Drilling Company, 32 pp.
79-0011-SMRI	Russel, J. E. Finite element models of caverns in salt, Texas A&M University, 29 pp.
79-0012-SMRI	Tillerson, J. R. Geomechanics investigations of Strategic Petroleum Reserve (SPR) crude oil storage caverns, Sandia Laboratories, 33 pp.
79-0013-SMRI	Mitchell, A. Compressed air storage, Fenix and Scisson, Inc., 8 pp.
1980	
80-0001-SMRI	Unterberger, R. R. Sonar probing as a mining and tunneling tool, Final Report, Texas A&M University, National Science Foundation Grant No. APR 76-21764, 55 pp.
80-0002-SMRI	Russell, J. R. Key Word in Context (KWIC) index of salt (with emphasis on nuclear waste disposal literature)—a literature search, Texas A&M University, 340 pp.
1981	
81-0001-SMRI	Saberian, A. Potash dissolution: state of the art, A. Saberian & Associates, 90 pp.
81-0002-SMRI	Hendron, Jr., A. J., G. Fernandez and P. Lenzini. Field investigations of subsidence areas at Carey Salt brinefield, Hutchinson, Kansas, A. J. Hendron, Jr., Geotechnical Engineer, 99 pp.
81-0003-SMRI	Piper, T. B. Surveys for the detection and measurement of subsidence, 60 pp.
81-0003A-SMRI	Wong, K. W. A manual on ground surveys for the detection and measurement of subsidence related to solution mining, 149 pp.
1982	
82-0001-SMRI	Stump, D., A. S. Nieto and J. R. Ege. An alternative hypothesis for sink development above salt cavities in the Detroit area, U.S. Geological Survey Open File Report 82-297, 1982, 63 pp.
82-0002-SMRI	Nigbor, M. State of the art of solution mining for salt, potash and soda ash, U.S. Bureau of Mines, OFR 142-82, 91 pp.
SALT 77	SMRI salt dissolution computer programs: SALT 77, SALHYD and SALGAS. (Listed here for informational purposes. These programs available from SMRI. For information contact Executive Director).

APPENDIX B

INDEX OF SOLUTION MINING RESEARCH INSTITUTE MEETING PAPERS 1979-1982

1979, OCTOBER 15—TORONTO

Mitchell, A. Compressed air storage.

Nieto, A. S. (D. Stump). An alternate hypothesis for the craters at the Windsor/Detroit area (A Synoposis).

Russell, J. E. Finite element models of caverns in salt.

Walters, R. Brinefield subsidence, June 1978, Interpace Corporation, Carey Salt Division, Hutchinson, Kansas. (Report File No. 78-0003-SMRI).

1980, OCTOBER 13-14—MINNEAPOLIS

Baumgardner, R. W. and A. D. Hoadley. Geology and hydrology of the Wink Sink, Winkler County, Texas.

Butler, W. J. and R. G. LaFortune. Preparation of former LPG cavern for high purity ethylene storage.

Bryson, W. R. Leakage of liquified petroleum gas from storage projects in bedded salt—An Update.

Harter, E. The loop storage project.

Henderson, J. Keller. Directional drilling A technique designed to connect salt wells.

Munson, D. E. and S. E. Benzley. Analytic subsidence using void-volume distribution functions.

Piper, T. B. Photographs of sinkholes and subsidence related to lowering of water table in Alabama.

Piper, T. B. Subsidence resulting from solution mining: Techniques for detection of subsidence and research into the mechanics of cratering.

Querio, C. W. Design and construction of solution-mined caverns for LPG storage.

Sevenker, L. An account of the Kermit, Texas Crater.

Sevenker, L. Subsidence experiments (Abstract).

Sharma, D., et al. Nuclear waste storage in excavated cavities within salt domes: postulated problems and theoretical analyses.

Thoms, R. L. Permeability of rock salt for compressed air energy storage.

Tichenor, J. H. Practical approach to subsidence monitoring in the Dale Brinefield.

Wright, R. Technical criteria for solution mining regulations.

1981, APRIL 27—CHICAGO

Goin, K. L. Analysis and leak tests of wells for new solution mined caverns at the Bryan Mound DOE-SPR storage site.

Mills, K. E. Specialized techniques in solution cavern shape control.

Van Fossan, N. Mechanisms of product leakage from solution mined caverns.

1981, OCTOBER 19-20—NEW ORLEANS

Arnold, R. Jamestown sulfate solubility inhibitor (SSI) (Abstract only).

Cabral de Mello, P. R. (Presented by J. F. Gray). Brineline and waterline cleaning.

Domingo, Arzani C. Cleaning brine lines by pigging techniques.

Giuainelli, J. J. and R. V. Carlson. Feasibility of solution mining for sodium carbonate at Searles Lake, California.

Goin, K. L. Experience in testing of solution mined storage caverns.

Henderson, F. Potential usefulness of satellite imagery for geologic/geotechnical assessments.

Holzhausen, G. Proposal for measurement and analysis of wellhead pressure transients for evaluation of hydraulic-fracture dimensions.

Piper, T. B. Horizontal drilling.

Russell, D. J. A re-examination of the processes of sinkhole formation, Windsor (Canada) brinefield.

Serata, S. Structural relationship between mine openings and solution caverns.

Sevenker, L. and E. W. Black. Asphalt injection for solution mine cavity roof control.

Stump, D. (Presented by T. B. Piper). An alternate hypothesis for sinkhole formation (Abstract only).

Thoms, R. L. Borehole closure in salt domes.

Warnick, C. D. An integrated digital logging and documentation system for the storage and solution industry.

1982, APRIL 19—ALBUQUERQUE

Bezfamilny, F. I. Brine storage reservoir 25mmb capacity—design and construction.

Ege, J. R. Surface subsidence related to solution extraction of salt.

Heitmann, N. A., et al. Drilling, cementing and testing of salt wells—A concern about details.

Klein, J. M. Safety interchange.

McCaleb, A. C. Special considerations for cathodic protection of well casings.

Serata, Shosei. Long-term deterioration of overburden formations above solution caverns and mine openings.

Thoms, R. L., et al. Tests on rock salt for compressed air energy storage (Abstract only).

Wunderlich, T. G., et al. Drilling, cementing and testing of salt wells—A concern about details.

1982, OCTOBER 4-5—MANCHESTER, ENGLAND

Dubois, D. Tests for tightness/containment in a cavity Leached in Salt, 10 pp.

Fischer, F. J. An axisymmetric method for analyzing cavity arrays, 21 pp.

Frydenberg, O. B. Natural gas storage project at L1. Torup, Denmark, 38 pp.

Gomm, H. and P. Streit. Solution mining technique in the brinefields of Schweizerhalle and Riburg of the United Rhine salines of Switzerland, 37 pp.

Hardy, H. R. Jr. Design and stability monitoring of salt caverns, 44 pp.

Miller, M. A state of the art light hydrocarbon storage facility, 78 pp.

Passaris, Evan K. S. Rock mechanics investigations for gas storage salt caverns at shallow and intermediate depth, 13 pp.

Wassman, T. H. Cavity utilization in the Netherlands, 8 pp.