TECHNICAL ISSUES FOR CHEMICAL WASTE ISOLATION IN SOLUTION-MINED CAVERNS IN SALT DOMES

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INTRODUCTION

Many factors can be assessed to judge the technical merits of chemical waste isolation in solution-mined caverns in salt domes. Our investigation indicates that certain factors have primary importance, including the geohydrology, the engineering considerations, and the stability of the geologic isolation system, the cavern, the cap rock, and the surrounding strata. To a major extent, all these factors are interrelated and interdependent.

Initially, the domal system including cap rock, salt stock, and surrounding domed strata must be mapped to a level of detail generally not available in public sources and in the geologic literature. The most reasonable postulated release scenarios envision waste transport by ground water. Thus, the direction and rates of ground-water flow are critical. Ground-water flow is influenced by the rock matrix, which includes depositional systems, sand-body geometry, and fault patterns.

The cap rock is a focal point of many domal processes and is a particularly dynamic region of a salt dome. Studies on cap-rock properties may answer whether salt domes are undergoing uplift or dissolution. The cap rock plays a pivotal role in either promoting or retarding dome dissolution and cavern stability. Further domal studies must concentrate on defining (1) geometry and structure of cap rocks, (2) cap-rock lost-circulation zones, (3) geometry, structure, and stratigraphy of salt stocks and salt caverns, (4) salt-cavern stability, and (5) domal geohydrology. In the following sections, we discuss various issues that should be addressed to judge the technical merits of chemical waste isolation in solution-mined caverns in salt domes.

DOMAL GEOLOGIC SYSTEM

Definition of the geologic system is without doubt the first step in assessing the effectiveness of waste isolation in solution-mined caverns in salt. Precise mapping of the geometry of salt structures, their internal and external structure and stratigraphy, and the domal geohydrology is mandatory. We intend to do detailed studies of domes on the basis of data availability and intrinsic interest. The program involves detailed mapping of the cap rock, salt stock, and surrounding strata. Geologic literature and data are abundant for certain domes, but characteristically only for the shallow zones of salt structures. It is often difficult to judge the quality of published literature and structural interpretations of original data for those domes in which the original sources of data are not provided.

Salt Stock

Assessing the suitability of salt domes for long-term isolation of toxic-chemical waste requires more than a literature search. Detailed mapping of salt structures requires investigations of borehole geophysical logs through salt, investigations of deep boreholes near the salt stock, and study of salt cores from individual domes.

In addition to better mapping of the whole domal geologic system, we intend to derive some statistical methods to place confidence limits, standard deviation, or both on the contours used to map various aspects of domal geology. This is especially critical for domal geometry because the accepted industry standard is to place caverns within 300 to 500 ft of the edge of the salt stock.

We intend to study salt cores collected by the Strategic Petroleum Reserve program from Bryan Mound and Big Hill salt domes. With these and other available salt cores, we hope to use salt structure and salt stratigraphy to aid in obtaining a better understanding of properties affecting salt-stock geometry, structure, cavern geometry, and cavern stability.

Recent model studies of salt domes and salt-stock stratigraphy have raised the possibility that the margins of salt domes may actually be large downturned overhangs perched on a relatively thin salt pedestal (M. P. A. Jackson, personal communication, 1984). On the basis of studies of the stratigraphy and structure of salt cores, especially of multiple sets of core from a single dome, we may be able to map the characteristic flow patterns within a salt stock that give rise to the large overhangs.

Conventional reflection seismic data are generally unable to sufficiently locate the margins of domes. A new tool, magneto-tellurics, is promising. By mapping telluric earth currents, the margins of salt stocks may be more precisely defined because of the large contrast in electrical properties between the salt stock and the surrounding strata (Geotronics, Inc., Austin, Texas).

Cavern Stability

The three primary factors that affect the stability of salt caverns are pressure, temperature, and cavern shape (Fenix and Scisson, Inc., 1976). Precise techniques for predicting cavern stability may still be beyond the state of the art. In many respects, the problem revolves around defining the in situ state of stress within a salt dome.

The difference between the hydrostatic pressure within and the lithostatic pressure outside the cavern is probably the primary parameter affecting cavern stability. The depth of the cavern determines lithostatic pressure. Lithostatic pressure increases at about twice the rate of hydrostatic pressure exerted by a cavern filled with brine. Natural gas caverns are prone to have stability problems because of their great depth (4,000 to 6,700 ft) and rapid changes in internal cavern pressure owing to gas cycling by pressure release. The first natural gas cavern in a salt dome was constructed in Eminence salt dome in Mississippi. According to SAI (1977) and Dreyer (1982), the cavern underwent unacceptable closure of 30 to 40 percent in the first year.

The plasticity and strain rate of rock salt increase with increasing temperature and depth (Carter and Heard, 1970; Dreyer, 1982; Heard, 1972). This increase in salt plasticity is generally cited as the rationale for requiring a lower cavern depth limit of about 5,000 ft to 7,000 ft.

Empirical parameters are used as guidelines when constructing most solution-mined caverns in salt. These parameters include the thickness of salt above the cavern, the thickness of salt between the cavern and the margin of the dome, the ratio of the thickness of salt (web) between caverns and the diameter of the caverns, and the ratio of the height of the cavern to the diameter of the cavern.

Formulas have been devised to predict the convergence of caverns; these formulas include shape, depth, pressure, temperature, and dimensionless salt material constants (Dreyer, 1982). When a formula was applied to the gas storage cavern at Eminence salt dome, Mississippi, the predicted amount of closure was an order of magnitude less than the actual closure measured after one year. This illustrates that although mathematical models to predict cavern shape and stability exist, their usefulness is questionable.

Cap Rock

Cap rock influences dome and cavern stability in a complex fashion. A complete study of cap-rock thickness, mineralogy, hydrogeology, distribution and thickness of lost-circulation zones, distribution of faults, and cap-rock resources is necessary to assess reasonably the influence of cap rock on dome and cavern stability. Cap rocks of domes in the Houston Salt Basin contain lost-circulation zones characterized by vuggy to cavernous porosity and by loose accumulations of anhydrite sand. Wells are completed through these zones with difficulty. Once completed, well casings and cements are subject to attack by corroding circulating fluids.

Lost-circulation zones probably are indicators of active salt dissolution. Anhydrite dissolution and volume loss during hydration to gypsum may also be important. Loose anhydrite sand accumulates at the cap-rock - salt-stock interface where salt dissolution, if present, will be most active. The cap rock at Barbers Hill salt dome contains a 25-ft-thick lost-circulation zone of loose anhydrite sand at the cap-rock - salt-stock interface. Cap-rock lost-circulation zones are one facet of cap-rock hydrology. The flow systems within lost-circulation zones must be carefully assessed because the lost-circulation zone is a likely release point for waste discharging from a solution-mined cavern.

Cap-rock lost-circulation zones neither occur over all domes nor do they occur everywhere on a single cap rock. Core of cap rock at Oakwood salt dome reveals a tight cap-rock -

salt-stock interface (Kreitler and Dutton, 1983). Cap rocks without lost-circulation zones are likely barriers to dome dissolution.

Many cap rocks are highly fractured by radial faults inferred to result from lateral extension owing to present or past dome growth. Lost-circulation zones may develop preferentially along these fault zones. The result of the influence of radial faults on cap-rock hydrology may be open pathways for ground water to enter the salt stock.

Surrounding Strata

Cavern stability may be enhanced or degraded by the nature of the strata surrounding the salt dome. Structural attitude, sand-body geometry, ground-water flow directions and flux, ground-water chemistry, and permeability of surrounding strata are all factors that must be assessed. Depositional systems and three-dimensional sand-body geometry will influence classic ground-water and water chemistry parameters. The implications of ground-water data can be understood better with a thorough knowledge of depositional systems and the rock framework.

The structure and stratigraphy of strata surrounding a salt stock provide a means of deciphering dome-growth history. Domes with a younger growth history are less stable than older domes because domes characteristically undergo an exponential decline in the rate of growth with time. Salt domes in the Houston Salt Basin are generally thought to be much younger than those domes in the East Texas Basin. Detailed patterns of growth history for domes in the Houston Salt Basin are unknown. In contrast, dome-growth patterns are relatively well known in the East Texas Basin (Seni and Jackson, 1983; Jackson and Seni, 1984). Patterns and rates of dome growth, history of erosion over domes, and regional patterns and history of growth faults and radial faults all need to be considered in assessing dome stability.

DOME GEOHYDROLOGY

Geohydrologic factors are a prime influence on both dome and cavern stability. Some geohydrologic variables that need to be quantified are three-dimensional analysis of hydraulic head, pressure versus depth within an aquifer, aquifer permeability, aquifer heterogeneities, shallow- and deep-aquifer chemistry, and the age of ground water. Questions that need to be answered are (1) what is the direction of fluid flow, (2) what is the travel time of ground water within a given aquifer, and (3) what is the flux through the aquifer?

Studies of long-term waste isolation often assume worst-case scenarios. If the outcome of the worst-case scenario can be tolerated, then an important safety criterion is satisfied. For disposal of chemical waste in solution-mined caverns, a likely worst-case scenario would entail waste leakage into a cap-rock lost-circulation zone where rates of ground-water flux, permeabilities, and possibly recharge are high. Lost-circulation zones at Barbers Hill salt dome have accepted 1.5 billion barrels of salt water since the beginning of storage at that dome. This water has since begun to leak from plugged and abandoned oil-field boreholes.

Ideally a three-dimensional steady-state ground-water flow model based on conservative values for system variables should be constructed for a candidate dome. System variables should include the regional and local ground-water circulation patterns, leakage coefficients, recharge rates, and heterogeneities and anisotropies within aquifers to account for the effects of faults and sand-body distribution.

ENGINEERING CONSIDERATIONS

Engineered barriers may be the weak link in chemical-waste disposal systems in salt domes. The burden of stability rests largely on the cavern. Casing strings, casing cements, and cement plugs all serve to isolate the cavern from the surrounding surface, cap rock, and salt stock. Problems with leakage from plugged and abandoned oil-field drillholes in salt domes indicate that these borehole-plugging devices become ineffective with time. One problem is corrosion by sulfate-bearing and saline fluids in cap rocks.

Borehole closure around the casing and cements is expected to improve the seal between salt and cements. But the directions and magnitudes of salt flow within the salt mass are unknown. Unidirectional lateral flow of salt within the salt mass could subject the plugged drillhole to unacceptable lateral shear stresses.

As currently conceived in the United States, nuclear waste isolation relies heavily on engineered barriers including resistant waste forms and encapsulation devices around the waste. Such barriers generally are not envisioned for chemical waste disposal. Solidifying chemical waste may be a desirable technique for preventing rapid ground-water transport of the waste; it could also minimize the potential for release of lithostatically pressurized waste liquids if drilling inadvertently breached the waste-filled cavern.

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TABLES

APPENDICES