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Can Nonhazardous Oil Field Wastes Be Disposed of in Salt Caverns?

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ABSTRACT

Solution-mined salt caverns have been used for many years for storing hydrocarbon products. This paper summarizes an Argonne National Laboratory report that reviews the legality, technical suitability, and feasibility of disposing of nonhazardous oil and gas exploration and production wastes in salt caverns (1). An analysis of regulations indicated that there are no outright regulatory prohibitions on cavern disposal of oil field wastes at either the federal level or in the 11 oil-producing states that were studied. There is no actual field experience on the long-term impacts that might arise following closure of waste disposal caverns. Although research has found that pressures will build up in a closed cavern, none has specifically addressed caverns filled with oil field wastes. More field research on pressure build up in closed caverns is needed. On the basis of preliminary investigations, we believe that disposal of oil field wastes in salt caverns is legal and feasible. The technical suitability of the practice depends on whether the caverns are well-sited and well-designed, carefully operated, properly closed, and routinely monitored.

INTRODUCTION

This paper provides a summary of a study recently completed by Argonne National Laboratory on the legality, technical suitability, and feasibility of disposing of nonhazardous oil and gas exploration and production wastes (referred to hereinafter as oil field wastes) in salt caverns (1). The author of this paper served as project manager for the study and was assisted by Deborah Elcock, Mary Raivel, Dan Caudle, Robert Ayers, Jr., and Ben Grunewald.

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U.S. SALT DEPOSITS

There are two types of subsurface salt deposits in the United States: salt domes and bedded salt. Figure 1 shows the location of U.S. salt deposits. Salt domes are large, generally homogeneous formations of salt that are formed when a column of salt migrates upward from a deep salt bed, passing through the overlying sediments. Salt dome deposits are found in the Gulf Coast region of Texas, Louisiana, Mississippi, and Alabama.

Bedded salt formations occur in layers bounded on the top and bottom by impermeable formations and interspersed with nonsalt sedimentary materials having varying levels of impermeability, such as anhydrite, shale, and dolomite. Unlike salt domes, bedded salt deposits are tabular deposits of sodium chloride that can contain significant quantities of impurities. Major bedded salt deposits occur in several parts of the United States. There are 16 states in which salt occurs in sufficient quantity to be mined by either excavation or solution mining or recovered through solar evaporation.

SALT CAVERN FORMATION

Salt caverns are formed by injecting water that is not fully salt-saturated into a salt formation and withdrawing the resulting brine solution. Figures 2 and 3 show the main features of salt cavern construction for caverns in domal salt and bedded salt, respectively. These figures are not drawn to scale or intended to show detailed construction features.

The petroleum industry has constructed many salt caverns for storing hydrocarbons. In an attempt to provide guidance for designing and operating hydrocarbon storage salt caverns, several organizations have developed standards and guidance documents (2), (3), (4).

USE OF SALT CAVERNS

The most common use of salt caverns is production of salt, which, in turn, enlarges the caverns. The postmining uses of caverns are hydrocarbon storage, compressed air storage, and waste disposal.

The earliest storage of hydrocarbons in bedded salt caverns occurred in the 1940s, with storage in salt dome caverns beginning in 1951. Some of the products that have been stored are propane, butane, ethane, ethylene, fuel oil, gasoline, natural gas, and crude oil. In 1975, the U.S. Congress created the Strategic Petroleum Reserve (SPR) program to provide the country with sufficient petroleum reserves to reduce the impacts of future oil supply interruptions. The SPR consists of 62 leached caverns in domal salt with a total capacity of 680 million barrels.

In the United States, waste disposal in salt caverns has been limited. In Texas, the Railroad Commission of Texas (TRC) issued six permits between 1991 and 1994 for disposing of nonhazardous oil field waste in salt caverns. The U.S. salt mining industry disposes of impurities removed during the brine purification process in caverns. Limited cavern disposal of wastes is occurring in Canada, Mexico, the United Kingdom, Germany, and the Netherlands.

REGULATORY CONSIDERATIONS

On July 6, 1988, the U.S. Environmental Protection Agency (EPA) published a list of those oil field wastes that were exempt from regulation as hazardous wastes under Subtitle C of the Resource Conservation and Recovery Act (RCRA) (53 FR 25477). On March 22, 1993, EPA issued clarification of the 1988 determination, adding that many other wastes that were uniquely associated with exploration and production operations were also exempted from RCRA Subtitle C requirements (58 FR 15284).

EPA's Underground Injection Control (UIC) regulations define Class II injection wells as wells that inject fluids that are brought to the surface in connection with natural gas storage operations or conventional oil or natural gas production. Most but not all of the wastes exempted by the 1988 RCRA regulatory determination would meet the UIC program's criterion to be "in connection with" oil and gas production. Some wastes (e.g., hydrocarbon-contaminated soil) would not meet the UIC criterion. Although the EPA's description of wastes that are "uniquely associated" with oil and gas production under RCRA cannot be clearly applied to determining whether such wastes have been brought to the surface "in connection with" oil and gas production under the UIC Class II regulations, the waste in question (i.e., the soil) has been contaminated by wastes that have been brought to the surface. Efforts are currently under way to obtain clarification from the EPA on whether all exempted oil field wastes can be injected into Class II wells.

At the state level, only the TRC has formally authorized disposal of oil field wastes into salt caverns. The TRC has issued permits for six facilities, but as of May 1996, only four of these were active. In April 1996, the TRC released draft proposed amendments to TRC Rule 9, the regulation that governs injection into a formation not productive of oil, gas, or geothermal resources. Ten other states were contacted about their interest in disposing of oil field waste in salt caverns. Many of these states were interested in following the TRC program to see how it worked, but at this time, only New Mexico has received an application for disposal of oil field wastes in salt caverns. There are no apparent regulatory barriers to the use of salt caverns for disposal of most types of oil field wastes at either the federal level or in the 11 states discussed in this analysis.

TYPES OF WASTES TO BE ACCEPTED

The types of oil field waste proposed for disposal in salt caverns are those that are most troublesome to dispose of through regular Class II injection wells because they contain higher levels of solids. Wastes containing water that is not fully saturated with salt may increase the size of caverns because the unsaturated water will leach salt from the cavern walls. The presence of fresh water in wastes should not preclude their disposal in salt caverns, but the operator must account for the increased volume of the cavern and what effect it will have on such cavern siting parameters as distance to adjacent caverns and roof span or thickness. The solids-containing oil field wastes most likely to be disposed of in salt caverns include used drilling fluids, drill cuttings, completion and stimulation waste, produced sand, tank bottoms, and crude-oil- or salt-contaminated soil.

MONITORING AND RECORDKEEPING CONSIDERATIONS

It is in the best interest of both the regulator and the operator to know what types of wastes have been placed in the disposal cavern. The Interstate Oil and Gas Compact Commission (IOGCC) has published criteria that are intended to guide states in assessing and improving their regulatory programs for oil field waste management (5). While the IOGCC criteria do not specifically apply to disposal of oil field wastes by injection (which logically includes cavern disposal), they should be considered as a useful starting point for establishing monitoring requirements. It is appropriate to maintain long-term records of the source, quantity, and type of each batch of waste brought to the disposal facility.

CAVERN DESIGN AND LOCATION CONSIDERATIONS

Hundreds of salt caverns have been constructed and operated around the world. Most of these have been structurally sound and completely free from leakage or collapse. If cavern failure does occur, however, it can lead to contamination of surface water and groundwater. Caverns can fail through subsidence or collapse of the overlying material or through cracks resulting from increased pressures inside the cavern.

Reference (4) suggests several factors that should be considered for siting natural gas storage caverns. These factors are relevant for disposal caverns too.

- Distance to populated areas;
- Proximity to other industrial facilities;
- Current and future use of adjacent properties, including agriculture, which may withdraw large amounts of groundwater and potentially increase subsidence rates;
- Handling of brine or other displaced fluid;
- Proximity to environmentally sensitive wetlands, waters, and freshwater aquifers;
- Proximity to the salt boundary; and
- Proximity to other existing and abandoned subsurface activities (e.g., neighboring caverns for brine, gas, or hydrocarbons).

Another consideration for siting is the potential for seismic activity.

To minimize the chance for failure due to closure, collapse, or leakage, acceptable designs should be based on a geological review of the location that covers all features capable of affecting the cavern. Adequate studies should address regional stresses and strains; mechanical, chemical, and containment properties of the salt and confining rock formations; and structural anomalies, including faulting (4). The design should also consider potentially associated low-permeability zones and the effects of those zones on disposal operations (2). Detailed knowledge of the geology should be supported by adequate documentation. Operators should be able to demonstrate that the caverns they plan to use — either new caverns developed specifically for oil field waste disposal or existing caverns that are being converted — will remain stable in the future.

Following cavern construction and before waste disposal begins, inspection and testing should be conducted to verify the tightness of the cavern and to ensure that there is no hydraulic communication between the cavern and other caverns or elsewhere outside the salt formation.

During disposal operations, information on operation as well as measurements of subsidence and cavern integrity should be recorded periodically. Care must be taken to ensure against conditions that would cause the pressure at the cemented casing seat to exceed the fracture pressure. Emergency planning should also be undertaken to address accidental releases of brine or oily substances.

DISPOSAL OPERATIONS

Initially, caverns are filled with clean brine. Wastes are introduced as a slurry of waste and a carrier fluid (brine or freshwater). A carrier fluid that is not fully saturated with salt will eventually leach salt from the cavern walls or roof. Expansion of cavern diameter is generally not a problem as long as the anticipated degree of expansion is accounted for when designing the caverns. To avoid excessive leaching of the cavern roof, operators may intentionally introduce a hydrocarbon pad that, by virtue of its lower density, will float to the top of the cavern and keep the unsaturated carrier fluid from coming in contact with the cavern roof.

As the waste slurry is injected, the cavern acts as an oil/water/solids separator. The heavier solids fall to the bottom of the cavern, forming a pile. Any free oils or hydrocarbons that are associated with the waste float to the top of the cavern. Clean brine displaced by the incoming slurry is removed from the cavern and either sold as a product or disposed of in an injection well. When the cavern is filled, the operator removes the hydrocarbon pad and plugs the cavern. The remainder of this section provides greater detail on the disposal process and discusses issues related to disposal.

Fully saturated brine is a good carrier fluid, but it may not always be available or may be too costly. Using freshwater or brines that are not fully saturated as carrier fluids does not present major difficulties, however. Under this scenario, the operator would need to be aware of the effect the carrier fluids would have on additional salt leaching. Although the presence of freshwater should cause only a relatively small change in the diameter or height through leaching, under certain circumstances, the amount of additional leaching could reduce the intra-cavern distance, the distance to the edge of the salt formation, or the cavern roof thickness to a degree that would be considered undesirable.

There are three potential ways to fill the cavern:

1. The waste can be pumped down the tubing, and the displaced brine can be withdrawn from the annulus.

2. The waste can be pumped down the annulus, and the displaced brine can be withdrawn from the tubing.

3. The waste can be pumped down one well, and the displaced brine can be withdrawn through a second well.

The first scenario described above is the one most likely to be used. The heavier solids in the incoming waste will be introduced near the bottom of the cavern and will have a good chance of settling and remaining in the cavern. Some of the hydrocarbons rising through the cavern may become entrained in the displaced brine that is leaving the cavern, although most hydrocarbons will accumulate in a pad or layer near the roof.

As the solid components of the incoming waste fill the bottom of the cavern, an interface forms between the accumulated waste and the overlying brine, including a transition zone of brine that is mixed with the waste. Early in the life of a disposal cavern, brine is withdrawn hundreds of feet above the surface of the waste pile or the transition zone. The vast majority of the displaced brine will be clean. As the cavern fills, however, the transition zone brine may make up a larger proportion of the remaining cavern volume. At some later time, the brine withdrawn from the cavern will consist partially or completely of brine from the transition zone. The transition zone brine will be noticeably dirtier than the clean brine that was originally displaced from the cavern. The waste/brine interaction in the transition zone should have no effect on the nonhazardous classification of the brine or on the environmental suitability of cavern disposal. However, there may be unanticipated operational concerns and expenses.

Displaced brine is generally sold as a product or injected into brine disposal wells. As long as the brine is clean, either method of managing displaced brine can be practiced without additional treatment or handling. However, as the transition zone brine is displaced from the cavern, the operator may be faced with additional expense to clean up the brine before it can be injected underground for disposal. Solids-laden brine could clog the formation into which it was injected; typically such wastes are filtered prior to injection. Since most of the brine that is sold is used as a constituent of drilling fluids to drill additional oil and gas wells, the presence of waste components in the brine may not affect its salability.

Monitoring of cavern pressure should be done before the cavern is filled with oil field waste, throughout the waste emplacement cycle, and, optimally, for some period of time after the cavern has been closed. To monitor cavern pressure after closure, a pressure transducer must be installed in the cavern at the time it is closed.

CLOSURE AND REMEDIATION

Although various industries have been operating storage and production caverns for years, the long-term behavior of caverns filled with oil field waste is unknown. Scientists have modeled cavern behavior, and engineers have conducted limited tests of closed brine-filled caverns. Most have studied liquid-filled salt caverns, although some have modeled hazardous waste disposal in dry caverns. The extent to which preliminary findings in these areas relate to the behavior of caverns used for oil-field wastes is not known. However, it will depend at least in part on the ratio of brine (or other liquid waste contents) to solids and on the densities of the solid wastes relative to those of the surrounding salt.

The general concern with sealing and abandoning a fluid-filled salt cavern is that the continued creep of the cavern can raise the fluid pressure at the top of the cavern to a value greater than that of the lithostatic pressure at that point. This condition can lead to a possible fracture in the area of the wellbore, allowing brine to be forced out of the cavern.

Space restrictions do not allow an in-depth discussion of the literature here. Readers are referred to the Argonne report (1) for more details. In one key study (6), the authors showed that the effect of geothermal heating, combined with the pressure from the creep of the salt formation, can cause internal cavern pressure to exceed lithostatic pressure within only two years. The authors conclude, however, that the predicted rate of brine pressurization is not high enough to result in fracturing of the salt.

A more recent study of the behavior of sealed solution-mined caverns suggests that the factors affecting cavern closure include not only brine heating and cavern creep but also rock salt permeability (7). More importantly, rock salt permeability, even if very small, allows some pressure release and leads to a final equilibrium pressure that can be substantially lower than the lithostatic pressure.

The Argonne report (1) provides a distillation of interviews with several experts in the cavern field on their opinions on long-term cavern stability. In summary, disposal of solids in brine-filled caverns will generally tend to enhance the stability of caverns. The degree of stability enhancement depends on the nature of the material. The interviewed experts generally believe that solids-filled caverns are unlikely to leak.

CONCLUSIONS

- This particular mode of disposal is in its infancy.

- There are no apparent regulatory barriers to the use of salt caverns for disposal of oil field wastes at either the federal level or in the 11 states discussed in this analysis. One area that would benefit from clarification is further EPA guidance on what types of wastes may be disposed of in Class II wells.

- The types of oil field wastes that are exempted from RCRA hazardous waste requirements are generally suitable for disposal in salt caverns. Many of these wastes are now disposed of in landfills or are land-farmed; these disposal methods pose environmental risks of their own.

- There are many variables to consider when siting, constructing, and operating a waste disposal cavern. The hydrocarbon storage industry has developed useful, detailed standards, guidance, and criteria for designing and constructing caverns; these are appropriate for waste disposal caverns, too. Hundreds of storage caverns have successfully been operated worldwide for several decades.

- There is no actual field experience on the long-term impacts that might arise from salt cavern storage of oil field wastes. The literature contains many theoretical studies that estimate what might happen following closure of a cavern. Although different authors agree that pressures will build in a closed cavern because of salt creep and geothermal heating, they do not specifically address caverns filled with oil field wastes. More field research and pilot studies on the effects of pressure buildup in closed caverns would aid our understanding of this subject.

- On the basis of this preliminary research, we believe that disposal of oil field wastes in salt caverns is feasible and legal. If caverns are well-sited and designed, operated carefully, closed properly, and monitored routinely, they represent a suitable means of disposing of oil field wastes.

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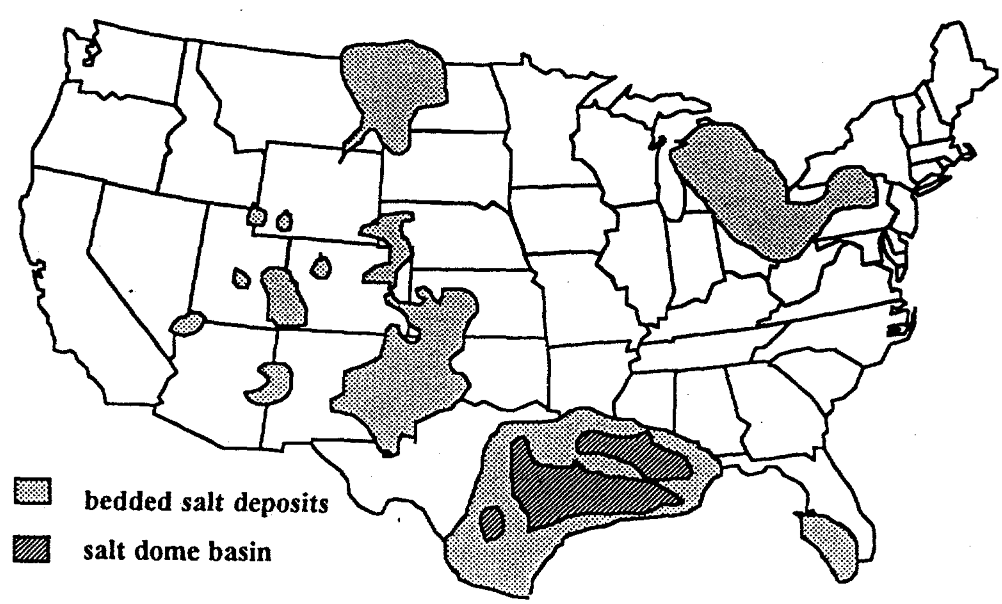

Figure 1 - Major U.S. Subsurface Salt Deposits

Figure 2 - Idealized Cavern in a Salt Dome Formation (not to scale)

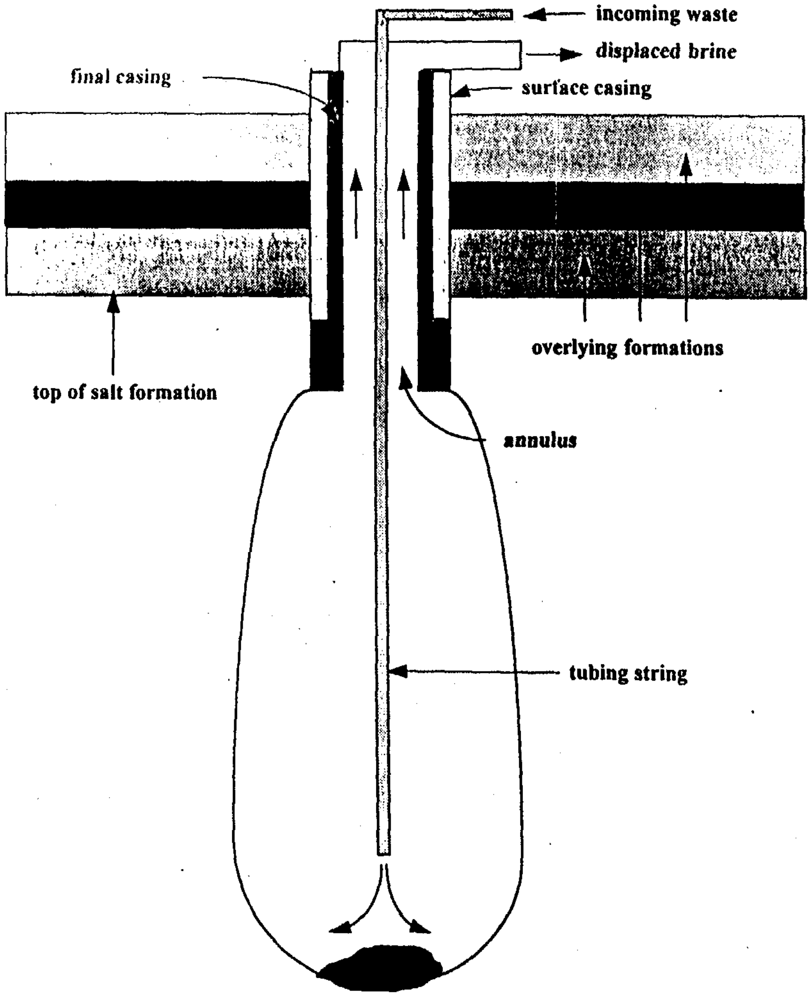

Figure 3 - Idealized Cavern in a Bedded Salt Formation (not to scale)