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## Hydrology of Brine Disposal in Caprock of Barbers Hill Salt Dome, Chambers County, Texas

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The Barbers Hill salt dome in Chambers County, Texas, is the largest LPG storage facility in the world, with 137 solution-mined chambers and a total storage capacity of 155,522,000 bbl (24,726,000 m<sup>3</sup>). These storage operations require an efficient system to dispose of the excess brines. A method of disposal has been developed whereby brines flow by gravity into lost-circulation zones in a caprock 1000 ft (305 m) thick at the top of the salt dome.

The east-west cross section in Fig. 1 shows the irregular configuration of the caprock and the thick section of uplifted sediments that rest on the flanks of the dome and have been a prolific source of oil.

The Burkeville layer (the shaded layer in the figure) is important because it separates the shallow Chicot and Evangeline aquifers, which contain fresh and slightly saline waters from the saltwater sands beneath. The Burkeville is principally a clay section and acts as a confining layer at the base of the Evangeline aquifer. The caprock plunges from a relatively flat surface in the central part of the dome down very steep slopes to depths varying from 2000 to 6500 ft (607 to 1980 m).

The total storage space in the caprock is estimated to be about  $1.4 \times 10^9$  bbl ( $2.2 \times 10^8$  m<sup>3</sup>), and the volume of brine that has already been

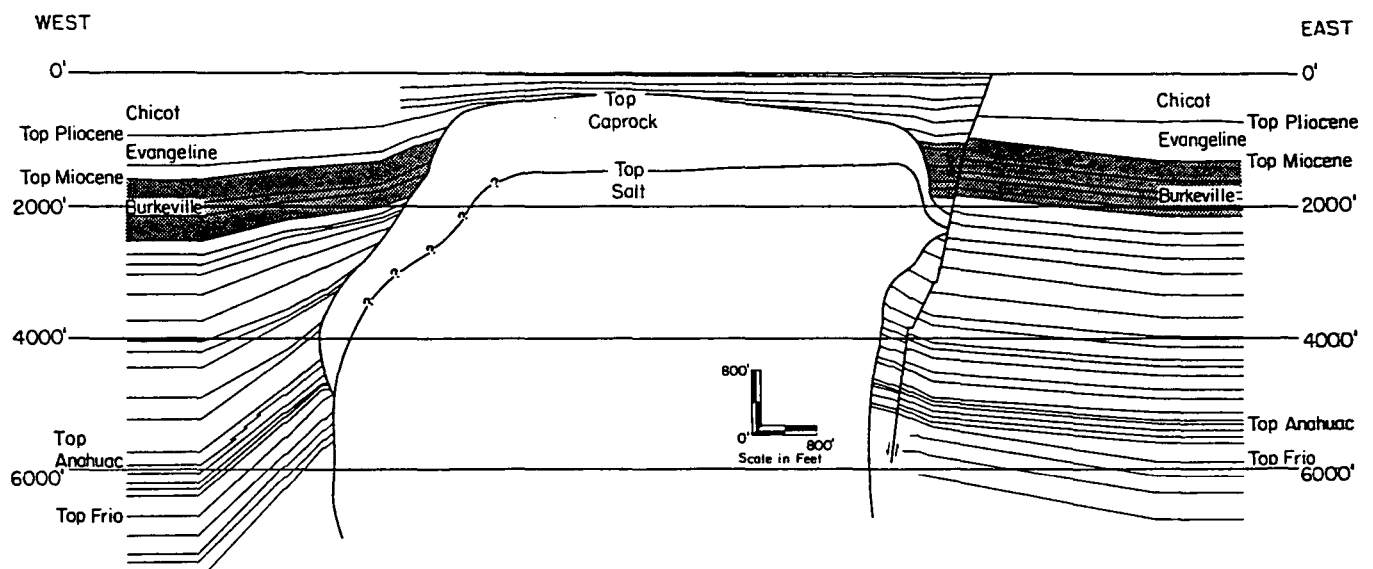


Figure 1. An east-west cross section of Barbers Hill salt dome and adjacent formations. [XBL 857-10653]

injected into the caprock is well over a billion bbl ( $1.6 \times 10^8 \text{ m}^3$ ). As the static fluid levels in the boreholes of caprock wells have not changed significantly since the start of disposal operations, it would appear that the caprock must be in hydraulic contact with a much larger underground flow system. It is therefore important to learn where the brine goes after entering the caprock and what the impact is of large-scale brine-disposal operations on the freshwater aquifers in the vicinity of the dome. A detailed investigation of the hydrologic properties of the caprock has been carried out to address these problems.

One of the first investigations on the hydrology of the caprock was to measure the effects of the brine disposal on fluid levels in the caprock system. Several months of observation proved that disposal anywhere on the dome had an almost immediate effect on water levels in any given observation well, indicating that the lost-circulation zones within the caprock are hydraulically connected.

## FIELD INTERFERENCE TESTS

A more quantitative investigation of the hydraulic properties and boundary conditions of the lost-circulation zones was carried out using field interference tests. It was assumed that the aquifer system within the caprock could be taken as having a circular shape, and the first question was whether a hydraulic test would reveal the boundary conditions that were controlling fluid movement. A solution for flow within a circular closed boundary with off-centered injection and observation wells was developed from the work of Carslaw and Jaeger (1959). Because the solution depends on well location, it was necessary to develop a set of type curves for the special case of brine injection and observation of the pressure effects at two available wells. Depending on the magnitude of  $a$ , the radial distance to the closed boundary, the pressure changes at the observation well follow the well-known Theis curve for longer and longer periods of time as the size of the circular system increases. Thus the point at which the data deviate from the Theis curve in an injection test is indicative of the size of the system. If the boundary is closed, each of the curves will reach a unit slope regardless of the size of the system.

The first interference test was carried out with an injection rate of 1130 bbl/hour ( $0.050 \text{ m}^3/\text{s}$ ). To measure the effects, a sensitive quartz pressure gauge was placed in the fluid column in an observation well 1740 ft (530.4 m) away. Pressure buildup data were collected every 5 s for the first few minutes,

and the results are plotted in Fig. 2. It may be seen that for the first 2 min, the data in Fig. 2 compare very favorably with the Theis curve. After 2 min the data deviate significantly from the Theis solution, indicating that a boundary has been reached. Comparison with the type curves suggested that the case for  $a = 8000 \text{ ft}$  (2438 m) gives the best match with the field results. It may also be seen that after the data depart from the Theis curve, their slope is about  $30^\circ$ , well below  $45^\circ$ , the line that would indicate a closed boundary. This means that the highly permeable lost-circulation zones in the caprock are communicating through a leaky boundary to an outer region of lower permeability.

From the match point shown in Fig. 2, we obtained a transmissibility of  $4.4 \times 10^4 \text{ darcy}\cdot\text{ft}$  ( $1.3 \times 10^4 \text{ darcy}\cdot\text{m}$ ) and a compressibility factor of  $1.5 \times 10^{-5} \text{ ft/psi}$  ( $6.6 \times 10^{-7} \text{ m/kPa}$ ). Such a high transmissibility is consistent with field observations that disposal rates of up to 10,000 bbl/hour ( $0.44 \text{ m}^3/\text{s}$ ) have been possible in single wells for short periods under gravity flow.

Later it was decided that the investigation should be expanded to include the whole dome. A second interference test was carried out with an injection rate of 2690 bbl/hour ( $0.117 \text{ m}^3/\text{s}$ ). Fluid levels were measured at two observation wells, one at 1740 ft (530 m) and the other at 7100 ft (2164 m) from the point of injection.

In view of the leaky boundary condition that had been confirmed during the first interference test, it was necessary to develop type curves that could take into account the effect of the outer region on pressure changes within the caprock. Larkin (1963) has developed an analytical solution for this kind of problem that was modified for this study. Two sets of type curves were prepared for the analyses of data from the above interference test, one for each obser-

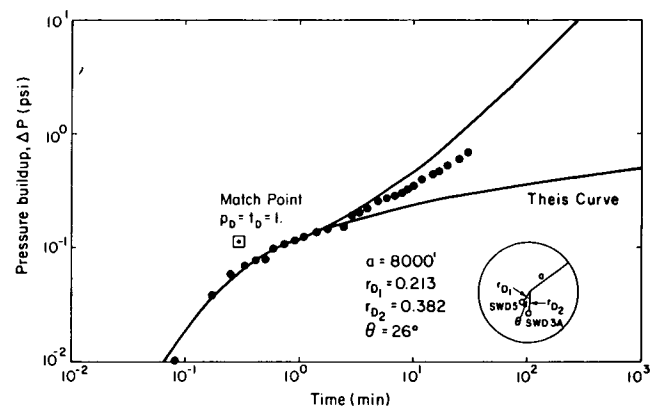


Figure 2. Comparison of results from interference test with the type curve for  $a = 8000 \text{ ft}$ . [XBL 857-10650]

vation well. Comparison of the field data with these type curves revealed that the ratio of the transmissibility of the caprock to that of the outer region is about 10.

Using the results of the previous tests, a mathematical model was developed to predict the fluid level response over large time periods. To validate the model, a 50-day controlled-injection test with variable flow rate was carried out. The observed data from this long-term test matched the predicted results satisfactorily.

## DISCUSSION AND CONCLUSIONS

The results of this work confirm what the industrial operators at Barbers Hill have known for a long time: the lost-circulation zones in the caprock of the salt dome provide an excellent disposal system. Not only do these zones accept high rates of disposal under gravity flow, but the caprock must be connected to an extensive system of permeable sands of enormous capacity. There is no evidence that the system is filling up, because there is no indication that present fluid levels have changed significantly from what they were 25 years ago.

The disposal system in the caprock has such a high permeability that the effect of the relatively less permeable formations outside the leaky boundary causes water levels everywhere to rise and fall together. The leaky boundary acts like a dam surrounding an open reservoir of water. Injection at any point within the reservoir will cause water levels to rise almost immediately everywhere.

The indicated radius of 8000 ft (2438 m) for the leaky boundary of the caprock should be taken only

as an approximation of the size of the inner region. However, it is important to realize that this distance from the center of the dome places the location where brine leaves the caprock far out on the flanks of the structure. This means that once brines start moving through the caprock, they flow down the steep flanks and out into the very thick section of sediments beneath the Burkeville (Fig. 1). This being the case, the natural paths of migration would tend to divert the brines away from the freshwater aquifers above the Burkeville.

The field tests have shown that barring mechanical failures, it should be possible to control the brine disposal system to avoid undesired environmental effects. Fortunately, an important characteristic of this disposal system is the immediate reaction of the fluid levels to a change in injection rate. This characteristic of rapid recovery means that controlling fluid levels at or below some desired level is a straightforward matter of operating procedures. By setting up a permanent system for continuous depth measurements in one or two brine disposal wells, fluid levels can be monitored and maintained at safe levels.

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