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Research Project Report
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An Investigation of the Integrity of Cemented Casing Seals with Application to Salt Cavern Sealing and Abandonment

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EXECUTIVE SUMMARY

BACKGROUND

Underground caverns developed in salt are a popular and economical method for the storage of oil and gas, the disposal of oil field and hazardous solid wastes, and the production of brine. Entry into these caverns requires the completion (cementing) of cased wells that extend from the surface through the nonsalt overburden and terminate at the casing shoe set in the salt above the cavern. Eventually, some caverns will be taken out of service and abandoned. A common method for abandonment is simply to pull or cut the hanging string and then to fill the inner casing or tubing with alternating intervals of concrete and cement grout.

The space left behind in an abandoned cavern generally contains fluid (e.g., brine). Over time, the fluid becomes pressurized because (1) the confined fluid tries to expand as its temperature rises to equilibrate with the temperature of the surrounding salt and (2) the volume of the cavern decreases through creep deformations of the salt, thereby compressing the confined fluid. An important question relating to cavern abandonment and operating caverns as well is how to establish a maximum cavern pressure while maintaining the structural integrity of the cavern sealing system; i.e., the salt surrounding the cavern, the cement seals and plugs, and the casing and tubing providing access to the cavern. Typically, the maximum casing shoe pressure allowed during the operational phase of a cavern is established by regulation using a stress gradient based on depth (i.e., 0.80 to 0.90 psi/foot). However, the fluid pressure in an abandoned cavern is likely to increase indefinitely because of creep closure of the cavern and may eventually approach or even exceed the lithostatic stress in the vicinity of the cavern. To date, there has been limited research to study the effect of high fluid pressures on the hydraulic and mechanical behavior of salt and virtually no definitive tests or analyses to investigate the effect of high fluid pressures on the integrity of plugged well casings.

In 1996, the Solution Mining Research Institute (SMRI) approved a long-term research program that focused on the uncertainties associated with Cavern Sealing and Abandonment (CS&A) issues. The initial efforts of the SMRI CS&A Research Program were the development of a comprehensive bibliography and a critique of the state-of-the-art in the understanding and practice of CS&A. As the research program developed, cooperative funding was obtained from the United States Department of Energy, and SMRI solicited proposals to pursue research in three key areas including:

1. Salt permeability testing under complex stress states
2. Hydraulic and mechanical integrity investigations of the well casing shoe through bench-scale testing
3. Geomechanical modeling of the fluid/salt hydraulic and mechanical interaction of a sealed cavern.

The bench-scale testing performed to investigate the integrity of the well casing shoe is the focus of this technical report.

TECHNICAL APPROACH AND SCOPE

In developing its solicitation to investigate the integrity of cemented well casings, the SMRI was particularly interested in the conditions of the casing/cement and cement/salt interfaces both initially after the casing was cemented into the salt and later after the interfaces were subjected to pressures approaching and even exceeding lithostatic conditions. In addition, the investigation was to provide information on the maximum pressures that could be applied to the interfaces; the location of any leakage paths that may develop; and the stress and deformation history in the salt, cement, and steel casing under conditions that simulate cavern sealing and abandonment scenarios. In response to these requirements, a technical approach was developed using bench-scale testing with a focus on

- Development and validation of an appropriate test configuration to simulate both the physical characteristics of a casing shoe set in the salt above an abandoned cavern and the state of stress in the vicinity of the casing shoe
- Testing to investigate the hydraulic and mechanical integrity of the casing seal at fluid pressures approaching and exceeding lithostatic stress
- Development of diagnostic techniques to assess the condition of the casing-cement-salt interfaces and the leakage rates through these interfaces
- Numerical analyses of the tests to predict deformations and stress states in the vicinity of the casing shoe.

Test Method and Configuration

A mock-up of the typical bench-scale test configuration is shown in Figure 1. The testing made use of large salt cores recovered from the Avery Island Dome, Louisiana, USA. These cores were machined to produce thick-walled, hollow cylinder test specimens with nominal lengths of 16 inches and nominal external and internal diameters of 12 inches and 6.5 inches, respectively. A steel casing (4.5 inches in diameter with a wall thickness of 0.25 inch) was cemented into the internal bore of each salt specimen, and the specimen was placed inside the pressure vessel of a large special-purpose test system capable of simultaneously applying load to all external surfaces of the test specimen and pressurizing the internal salt bore. The external stress and internal pressure simulated the in situ lithostatic stress and cavern pressure, respectively. The external stress was 2,000 psi in all tests, which corresponded to a cavern depth of approximately 2,000 feet. The internal pressure was increased in a step-wise manner, while a leak detection system monitored brine flow rates through the casing seal. The tests were terminated when the observed leakage rates were so high they could no longer be measured accurately.