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Long-Term Evolution of a Sealed Cavern

by

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1 EXECUTIVE SUMMARY

When a brine-filled cavern is sealed and abandoned, its pressure builds up due to two main phenomena:

- (i) thermal expansion of the brine; and
- (ii) cavern creep.

The former —except perhaps in very deep caverns ($\approx$ 2000 meters) where cavern creep is extremely fast — is by far the predominant phenomenon during a period of several years or dozens of years (depending on the cavern size). When thermal expansion is disregarded, cavern creep leads to cavern shrinkage, at which point pressure builds up and, in turn, slows the cavern convergence rate, which becomes very small when brine pressure is close to lithostatic pressure.

With the possible exception of very deep caverns, the balance between cavern pressure and lithostatic pressure will only be achieved after several centuries. Due to the density difference between brine and rock salt, only an average balance can be achieved: in a high cavern, brine pressure will exceed lithostatic pressure by a significant amount at the cavern top. Fears have been expressed that this excess will lead to rock fracturing and/or a severe increase of rock permeability — in either case, leading to a large amount of brine seepage.

Theoretical considerations prove that this situation can be alleviated, provided that the salt exhibits some permeability to brine. In this case, even an extremely low rate of brine seepage (say, 1 m^3 per year) will prevent brine pressure from reaching lithostatic values.

Rock-salt permeability is extremely low (except perhaps for salt damaged by high deviatoric stresses); salt caverns, when correctly designed, can be considered to be perfectly tight and are probably the safest conceivable man-made hydrocarbon tank. However, salt permeability cannot be considered as null.

In order to determine the effect of salt permeability on cavern pressure build-up, Gaz de France and Ecole Polytechnique, supported by the Solution Mining Research Institute (SMRI), have performed an in-situ test. The Ez53 cavern of the Etrez site in France was selected for this test. In Spring 1982, the relatively small cavern (7500 m^3) was leached out in a bedded salt formation at an average depth of 950 meters. Thermal equilibrium has been reached in this cavern, whose mechanical and hydrological properties were determined in several previous in-situ tests.

When the cavern is opened and the well filled with saturated brine, the cavern pressure (at a depth of 950 m) is 11.2 MPa, while the lithostatic pressure at the same depth is 20.5 MPa. The objective of the test was to prove that when the cavern is sealed, the cavern pressure reaches a figure intermediate between these two values.

This figure was to be determined in situ by a step-by-step approach. First (see Figure 1), cavern pressure was submitted to a pressure slightly higher than the expected equilibrium value (14.35 MPa), resulting in a slow pressure decrease from March 27, 1997 (day 0) to November 20, 1997 (day 238). Then, pressure was lowered by approximately 1 MPa by withdrawing brine from the closed cavern, resulting in a slow pressure build-up from November 20, 1997 (day 238) to March 10, 1998 (day 348). Following this, cavern pressure was increased again by approximately 0.3 MPa by injecting fuel oil, resulting in a slow pressure decrease from March 10, 1998 (day 348) to June 16, 1998 (day 446).

From June 16, 1998 (day 446) to September 18, 1998 (day 540) several fluid movements were performed in order to check the fuel-oil volume, resulting in significant pressure changes. When cavern pressure is smaller than 13 MPa (days 446 to 468) pressure rate is positive; when cavern pressure is larger than 13 MPa (days 481 to 540), pressure rate is negative.

To correctly interpret these results, it was necessary to ensure that no (or very small) leaks occurred in the well itself. This objective was met by lowering the fuel-oil columns both in the annular space and in the central tubing. Accurate measurements of the differential pressure evolution (between the annular and tubing pressures at the well head) then allowed determination of fuel-oil/brine interface movement. This system has proven to be extremely effective.

Test results prove that, for the Ez53 cavern, the cavern creep and brine seepage balance when the cavern pressure is 13 MPa $\pm$ 0.1 MPa, a figure far below the lithostatic pressure of 20.5 MPa (see Figure 1). The estimated yearly brine seepage is 1.4 m^3, or 0.02% of the cavern volume.

This conclusion is a significant breakthrough in understanding the long-term behavior of sealed caverns: due to brine percolation through cavern walls, pressure in an abandonned salt cavern does not reach lithostatic pressure.

It must be noted that

- this result applies to a cavern leached out from a salt layer which contains interbedded insoluble layers
- the final equilibrium pressure, although still below lithostatic value, would be higher in a deeper or larger cavern.