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Research Project Report
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Pressure Build-Up Test in the Etzel K 102 Cavern

by

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8 Summary

The objective of the pressure build up test in the Etzel K102 cavern was to gather in situ data and field experience from a long term test to form the basis for an official approval procedure for the abandonment of salt caverns which would be economically viable, technically prudent, pro-environment and rock-mechanically acceptable.

The boundary conditions were selected to allow pressure increase rates with an acceptable time/cost ratio which could be extrapolated to longer time periods. Top salt was at a depth of 694 m. The brine field cavity had a volume of approx. 233,315 m^3. The test equipment was designed if required to create a brine pressure gradient of G = 0.320 bar/m at the 13 3/8" cemented casing shoe of the final casing at a depth of 827.7 m. Taking into consideration a theoretical overpressure ΔP, which could build up above formation pressure in the roof zone of a sealed cavern, most of the existing cavern would have been sealed upon reaching a brine pressure gradient of G = 0. 320 bar/m.

Pressure build up in the test cavern started on 03.09.1990. Gradient step G = 190 bar/m was reached on 02.10.1990 after injecting approx. 500 m^3 of brine into the cavern. The second pressure build up step began after an 8 week observation phase and was finished on 02.01.1991 after injecting 134.4 m^3 of brine to reach a gradient of G = 0.205 bar/m. No pressure loss was observed during the subsequent observation phase.

Time delays occurred associated with the technical modification of the dosing pump system, and in particular because of the continuous micro-seismic logging, so that the third pressure build up phase did not start until 20.03.1991. The volume:pressure ratio during the pump phase began to shift towards larger and larger volumes of brine per pressure unit so that the third pressure build up phase did not reach a brine pressure of 82.36 bar (G = 0.219 bar/m) until after approx. 7 weeks of pumping on 21.05.1991 with the injection of 179.5m^3 brine. A technical cause for the pressure loss in the cavern was excluded after investigating the subsurface and surface equipment. Extrapolation to a stable pressure level of around 80 bar (corresponding to a brine pressure gradient of G = 0.217 bar/m) appeared plausible.

Pumping operations for the fourth pressure build up step (planned gradient step G = 0.235 bar/m) began after a two month observation phase. Although the volume:pressure ratio continuously rose compared to the third pressure step, the pressure increase rate dropped to 0 by 20.08.1991. The maximum gradient reached was initially G = 0.223 bar/m.

From this point on, the pressure in the cavern dropped gradually despite continued brine pumping.

An unscheduled oil/brine level survey was carried out in the cavern throat on 27.08.1991 to exclude any technical causes for the continuing pressure loss. The measurement revealed that no change in level had occurred since the previous measurement in July.

The pressure loss diminished during September at the same continuous pump rate. After reaching a minimum on 30.09.1991, the pressure began to climb again to reach its highest level of G = 0.226 bar/m on 09.11.1991, before dropping again. on 17.01.1992, a second minimum was observed for several days followed by a slight pressure increase after which a pressure corresponding to a gradient of G = 0.222 bar/m was measured in March 1992. Because of the risk of uncontrollable infiltration by penetration of the brine into the cover rock as a result of further pumping, the dosing pumps were switched off on 26.03.1992, and the cavern was sealed. A total of approx. 1654 m^3 of brine were pumped into the cavern during the fourth pressure build up phase.

Following the shutdown of pump operations, the pressure began to drop asymptotically to reach a gradient of 0 = 0.211 bar /m on 25.08.1992. This was followed by several test phases agreed in advance with the pressure build up test technical committee, the consultants, and the Bureau of Mines before the stepwise draw down of the cavern began in early February.

The return of the cavern to oil storage operations at the end of the pressure build up test required conversion of the cavern involving reduction to atmospheric pressure. The resulting balance between the volumes of injected and withdrawn brine revealed that approx. 50 % of the 2488 m^3 of brine pumped into the salt remained in place.

Sonar surveys were carried out in cavern K102 in 1989 before the start of the pressure build up test, and in 1993 upon completion of the test. The volume differences determined by the surveys lie within the range of measuring accuracy. Technical causes can be excluded as a reason for brine loss. One can therefore assume that the completion was properly functioning and tight during the whole period of the test.

From the observation that the internal pressure in the fourth pressure build up phase could not be raised despite pumping for months at a time, one can unequivocally conclude that brine impregnation took place during the fourth pressure build up phase.

This conclusion is confirmed by calculations of the secondary stress state surrounding the K102 test cavern, which take into consideration the load history of the cavern, the material behaviour of the rock salt, as well as the most realistic possible values for cover rock and rock salt density. Infiltration of the brine into the salt is therefore considered to be a fact when the internal pressure exceeds the main stress components acting vertical to the pressure direction. This criterium is already fulfilled at pressure gradient steps lying within the assumed primary stress state. At the same time, zones within the rock could be confirmed which limit the infiltration zones which means that the cavern being used for storage operations can be considered to be technically tight. This confirmation does not apply to a sealed abandoned cavern if infiltration zones are to be excluded when the relevant main stress components are several MPa higher than the expected internal pressure.

The only conclusion that can be drawn on the basis of the results of the pressure build up test, combined with the theoretical investigations discussed above, is that liquid is forced into the roof zone of a completely sealed brine-cavern as a result of temperature and convergence related pressure increase - the time frame is not yet determinable.

The pressure build up test has generated clear and convincing results which could not have been gained by theoretical studies or laboratory tests because the assumptions and conditions assumed for theoretical models always lead to idealisation of the actual long-term stress state affecting a salt cavern, and in the laboratory it is only possible to simulate simplified load conditions but not the actual stress state occurring in the vicinity of the cavern wall.