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Evaluation of Salt Permeability Tests

by

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Executive Summary

Ecole polytechnique has performed 17 permeability tests on hollow spheres. The present study focuses on 5 tests selected by Ecole polytechnique and considered to be successful. The major findings are given below.

1. The Ecole polytechnique tests clearly prove that, at laboratory scale, an increase in salt permeability takes place when brine pressure at the cavern wall is roughly equal to the compressive stresses prevalent in the salt sample. These tests clearly confirm earlier tests performed on cylindrical samples by others groups (e.g., [1]).

2. One significant drawback of the Ecole polytechnique tests exists in the mathematical interpretation of test results. As long as stress state and pressure distribution in the sample are complex, quantitative modeling is difficult to interpret. For example, these tests only provide an "apparent" permeability, which is a type of average permeability at sample scale. They do not allow precise assessment of permeability changes at the very beginning of the test.

3. It is recommended that the next research step include a full-scale permeability test on a real cavern. A tentative analysis of evolution of cavity compressibility is provided to be helpful in this respect.

The following comments support the findings and recommendation.

1. Even small heterogeneities in the sample or flaws in measuring-system tightness may lead to erroneous interpretation in terms of permeability. Furthermore, petrographic surveys would be useful for verifying if the cavity size is large enough (compared to crystal size) to ensure the representativeness of such permeability measurements.

2. An analysis of transient characteristic time within the framework of poroelasticity supports the steady-state flow assumption made in the Ecole polytechnique report [2].

3. In order to erase small time fluctuations caused by the pressure regulation system, the author has computed permeability by the means of linear regression over a moving time interval. Results are shown on Figures 36, 37, 46 to 48, 58 to 60, 71 to 73 and 83 to 85. Based on Tests 7 and 17, it is suggested that the experimental set-up allows accurate measurement of apparent permeability higher than $10^{-21}\mathrm{m}^2$.

4. Data processing has been performed that takes into account the effects of reservoir compressibility. It also allows computation of apparent-permeability evolution during initial pressure build-up and the detection of an increase in reservoir compressibility (attributed to the salt softening associated with pressure build-up).

5. Test 3 is considered to be suspect: Results from Test 3 are not consistent with the results of later tests. It is noted that the Ecole polytechnique report [2] states that some electronic problems were encountered during the earlier tests. When Test 3 is discarded, the following is observed.

   - During the first 20 to 50 hours, apparent permeability decreases at constant applied pressure from about 10^{-18}m^2 to about 10^{-21}–10^{-20} m^2. This decrease cannot be attributed to the transient hydraulic state; it is thought to be due to a delayed plastic pore closure rather than recrystallization.
   - After this period, permeability increases when pressure builds up. This increase is small as long as the inner pressure exceeds the confinement pressure by less than 0.5–0.7 MPa. The enhanced subsequent increase is interpreted as the propagation of a damaged zone leading to failure when the inner pressure is higher than the confinement pressure by 1.3 to1.5 MPa. This view is supported by the concurrent cavity softening demonstrated by the reservoir compressibility analysis.

6. Permeability increase has been analyzed through four models within the framework of poroelastoplasticity. Analytical solutions have been derived. A semi-analytical method has been used to simulate the tests.

   - The widely used Walsh Permeability Model can be used as long as the effective state of stress remains compressive. Simulations have shown that, with the other parameters being set to constant values taken from the literature, the observed permeability increase during the first period can be modeled only if the Biot coefficient, b, is set to a value close to 1. Apparently, this is in disagreement with the theory of poroelasticity (in which b should be significantly less than 1 owing to the low porosity of salt), but it could be argued that b evolves with respect to the applied stress, as does permeability.
   - A set of parameters is provided for two models which reproduce permeability increases for Tests 13 and 16. These two models depend on the effective tangential stress $\sigma_t + P$:
     - The LMS ([1]) model formulation and the proposed set of parameters are provided in Section 4.3.2. The results of simulations and comparison with experimental data are shown on Figures 17 to 22.
     - The IUB ([2]) model formulation and the proposed set of parameters are provided in Section 4.3.3. The results of simulations and comparison with experimental data are shown on Figures 23 to 28.
   - The yield behavior is analyzed through a simple plastic model in which permeability is set to infinity as soon as plasticity occurs, keeping its initial value otherwise.

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[2] Institute fur Unteridisches Bauen

It is shown that elastic-limit pressure (at which plasticity occurs at the cavity wall), the ultimate pressure (at which sample failure is achieved) and the associated plastic radius depend on sample size. The set of chosen parameters is not optimized, and further investigation is needed. However, this preliminary analysis allows the progressive failure observed in the data analysis to be reproduced. This simple model is not able to reproduce the observed permeability increase, but the model could be improved by taking into account a non-linear evolution of permeability with respect to stresses — or strains — in the elastic zone. The author recommends using a finite element method for such a study.