

KEM Research review, evaluation and interpretation

TITLE: Qualitative Risk Assessment of Long-Term Sealing Behavior of Materials and Interfaces (in) Boreholes

KEM Quality review

Description of the scientific quality of the results (team, research method, research results, quality of the products, ...), if needed external review result (project evaluation text website)

This project was envisioned as a literature-based review of the risk assessment of the long-term sealing behavior of abandoned boreholes. In addition to first identifying the key issues involved in borehole sealing, five specific research questions were identified, related to oilfield cement, steel casing, the micro-annulus, and plastic deformation of formations such as rock salt or claystone.

The 12-month project was contracted to EVO Energy Consulting, an oilfield consulting firm based in Texas, which specializes in drilling and completions of oil wells. The work was primarily carried out by Dr. Eric van Oort of EVO Energy Consulting, with Metarock Laboratories in Houston acting as a sub-contractor. Both of these organizations have extensive experience and well-validated track records in well engineering, and geomechanical testing, respectively.

The work involved extensive reading of journal articles, books, and standards from the oil and gas industry, civil engineering, and environmental science, along with many government reports from various countries. The project was completed in late 2021, and a 175-page draft final report was submitted to SodM on 16 October 2021.

The quality of the work performed in this project was very high. The literature review was extensive and comprehensive. The final draft report is very well written and effectively structured. The recommendations made as a result of the analysis will be useful to the oil and gas industry and government regulators. Overall, the project can be judged to have been a success.

KEM Evaluation of the results

Evaluation whether the research questions are addressed adequately (questions answered, precision and uncertainties on outcomes, potential consequences on current practice addressed, ..) (project evaluation text website)

The first stage of this project was aimed at providing a clear overview of the risk-critical elements and parameters that influence the long-term sealing capacity of boreholes. This goal was achieved, and the results are summarized in Chapter 2 (pages 11-36) of the final report.

The next specific question to be addressed was “how does the permeability of oilfield cement change over a long period of time (e.g. 100 to 500 years) and how does the change affect its sealing effectiveness?” It was concluded that the permeability of the cement itself is sufficiently low (micro-Darcy range) so as to not permit appreciable fluid flow through intact cement. Cement permeability does not seem to increase over time spans of tens of years, although data for time spans of hundreds of years are not available.

Question 3 was “How well is the steel casing, surrounded by cement, protected against corrosion? How is the corrosion rate affected by the change in permeability of the cement? Will the encased casing corrode in the long term? Can a corroded casing become a leak path?” The report concluded that steel casing is very well protected from corrosion for long periods of time when competent cement is well-bonded to the casing, but corrosion may occur if there is no cement or poor-quality cement in the annulus.

Questions 4 and 5 related to the long-term behavior of the micro-annulus that may exist between the cement and the formation. As pointed out in the report, “a micro-annulus represents a high permeability flow path ($k > 10$ mD) which bypasses the low-permeability cement matrix, thereby becoming an effective conduit for upward movement of fluids and gases to surface.” Some techniques that have been developed to artificially squeeze the micro-annulus closed are reviewed in the report. It is also emphasized that mud filter-cake must be removed from the wellbore during cement displacement, to avoid the filter cake interfering with the cement bonding to the rock formation, leading to the creation of a micro-annulus.

The discussion given in this section of the report is essentially correct, but referring to the “permeability of the micro-annulus” being > 10 mD (p. 47) is unclear. The micro-annulus is essentially a fracture, not a porous continuum, and does not have a permeability, although a “permeability” can be defined if the annulus geometry is known. Flow through the micro-annulus is proportional to the permeability–area product. This situation is analyzed correctly on p. 50, but the two discussions do not seem to have been harmonized.

The last specific question related to the possible ability of plastic formations such as rock-salt, claystone, or shale to form an effective seal around the casing. The report concluded that it is now accepted that time-dependent deformation (“creep”) of such rocks can fill the annular space and form an effective pressure-tight barrier. However, it was pointed out that it is imperative that the casing be designed to handle the stresses that will occur when the formation squeezes onto the casing.

Although the development of a risk assessment tool was not part of the work scope, the report does contain some general recommendations regarding well leakage risk assessment for onshore wells in the Netherlands. Several existing risk assessment approaches, including Watson & Bachu, DNV, IRIS-NORCE, and Heriot-Watt, were critically reviewed.

It was recommended that a simple qualitative scorecard approach with traffic light indicators should be developed, following the approach taken by Watson & Bachu. The limitations of such an approach, particularly due to the lack of data, were also highlighted. It was also recommended that certain quantitative aspects of the risk assessment approaches developed by Heriot-Watt and DNV are worth exploring.

KEM interpretation of the outcome

The interpretation of the results (consequences on methods/data to be used in practice, on risk instrument modules, on inspection procedures and operator procedures, ...) (project evaluation text website)

The motivation for this project was based on the understanding that over 1300 onshore wells have been abandoned in the Netherlands, and this number will increase significantly in the coming years. One of the potential hazards associated with abandoned wells is the possibility that hazardous gases will leak upwards through a well, and reach the surface. It is therefore imperative to develop a protocol for assessing the risk of such leakage, and being able to identify wells that may pose such a risk, and to identify methods to mitigate these risks.

Among the conclusions reached in this study are the following:

1. Cements that are typically used to plug abandoned wells have negligible permeability, and are not expected to deteriorate over relevant time scales.
2. Steel casing is also generally protected against corrosion by the cement, unless the cement is compromised by the existence of micro-annuli or other types of deterioration.
3. Micro-annuli may form due to cement shrinkage or from stress and thermal loads imposed during the lifetime of the well. These micro-annuli may serve as channels for the leakage of fluids to the surface. However, various chemical, biological, and physical methods exist to close up these annuli.
4. Rock formations such as salt or shale have the ability to creep and thereby close-up these micro-annuli.

A two-pronged approach to risk assessment was proposed, starting with a simple qualitative scorecard system similar to that developed in Canada by Watson and Bachu (2008), in conjunction with a quantitative probabilistic approach such as has been recently proposed by Johnson *et al.* of Heriot-Watt University, in which wells with incomplete and/or missing data can be represented by suitable “archetypes”.

Closure text for the website

A summary in simple terms of the goal, the outcome and impact on mining policies or toolboxes of the research project (project evaluation text website)

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