The role of geological barriers in achieving robust well integrity

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Abstract

Wells play a key role in the reduction of greenhouse gas emissions. They are not only a critical element in ensuring the permanent trapping of carbon dioxide (CO\textsubscript{2}) in deep subsurface permeable formations, but they are also being recognized as an important source of natural gas emissions (e.g. Kang, 2014).

The goal of well integrity is to minimize fluid migration from permeable formations through the use of barriers. Traditionally natural and man-made barriers have been regarded as separate and independent components: once the original impermeable layers such as shale or halite have been pierced by drilling, isolation must be restored by installing steel pipe and annular cement.

However this picture has been blurred by the growing recognition that a particular class of rocks can prevent and control fluid leaks through a well’s life, including the hundreds of years after abandonment. Creeping formations such as halides, mudstones and possibly ice can seal uncemented sections and large defects in the cement sheath. More importantly, the radial stress they exert reduces debonding and restores integrity once the cause of a microannulus has been eliminated; this makes the geological barriers self-healing, or robust.

If creeping formations are to become a fundamental element in well design and evaluation, they need to be properly understood and modeled. From an engineering point of view, the identification and characterization of geological barriers should provide four sets of constitutive properties:

- The ultimate radial stress exerted by the formation, as well as its anisotropy (i.e. its variation around the casing circumference).
- Mechanical properties of the formation to estimate leakage rates if the closure stress has been overcome and a microannulus is formed.
- A time scale over which the creep deformation can seal a given defect, or an uncemented section of the annulus.
- The type and extent of geochemical reactions, if any, between the formation and the leaking fluid.
This paper reviews the limited available evidence on the role and characteristic of geological barriers and adds new examples that have arisen from the study of well integrity at the basin scale. A simple model captures the essential characteristics of the formations’ behavior and allows identifying the key parameters that control the beneficial aspect of formation creep on well integrity. For a cross-section at a given depth, we model the well system (casing/cement / formation and the potential defects at the interfaces) under plane-strain condition. Modeling formation creep using viscoelasticity, we obtain the time of closure of a given set of defects between the formation and the steel casing. In the absence of defects, or when the defects have already been closed, we also obtain the time evolution of the radial stress clamping the interface. The intensity of such a normal compressive stress clamping the interfaces is the key parameter controlling the occurrence of micro-annulus induced by subsequent fluid injection, such as CO₂ injection, natural gas storage or reservoir stimulation (see Lecampion et al. 2013 for details).

We use both an analytical approach in the simplest case of an isotropic far-field stress and a boundary integral equations method in the Laplace domain to handle more complex configurations. Our method is notably agnostic with respect to the viscoelastic constitutive law chosen to model the geological formation time-dependent behavior. We notably discuss the impact of the choice of the type of constitutive law on the obtained results.

 Lastly, we discuss how the controlling parameters of the problem (in-situ stress, creep formation properties) can be measured or estimated from geophysical logs, geological and geomechanical information as well as active well tests. Our analysis aims at assessing the state of the art in the design and evaluation of geological barriers from a well integrity perspective. We also highlight the remaining questions to be answered by research.

References: