**Analysis of stress related to gel volume expansion**

The bulk stress created by the CO2-triggered volume expansion of PNNL fluids was determined to range between 130-410 psi (8-28 bar) depending on temperature and fluid flow rates, with higher temperatures and lower flow rates achieving higher stress values. This bulk measured stress is predicted to be lower than the stress generated at the microscale, i.e., at the fracture networks. Localized pressures resulting from a combination of capillary action, local changes in solution properties, and/or the significant elastic energy present due to the volume expansion process, all occur at the micron or sub-micron scale (1-4). These localized pressures are difficult to assess experimentally and are the primary source of additional stress generated by PNNL fracturing fluids. As a result, significantly lower effective stress (up to an order of magnitude) is required to create fracture networks in highly impermeable rock with PNNL rheoreversible fracturing fluids as compared to control fluids. A comprehensive study using micro-scale mechanical modeling is proposed to determine these localized pressures and predict/optimize fracture propagation. This study is of great significance to apply PNNL rheoreversible expanding fracturing fluids in the field.

**Proposed modeling study on fracture propagation by PNNL rheoreversible fracturing fluids (Additional budget required: $70K)**

It has been demonstrated beyond doubt that aqueous solutions containing amine-based polymers, such as polyallylamine (PAA), and then injected with CO2 repeatedly create fracture networks in highly impermeable rock samples at measured overpressures (effective pressure) that varied in magnitude but were always significantly smaller (1/2 to 1/10 depending on confining P/T) than effective pressures measured with the control solution (which does not contain PAA). This has been observed for several rock samples from two different EGS reservoir (Coso and Newberry) in a wide range of confining temperatures and pressures and suggests that the mechanism(s) by which a PAA solution fractures the rock is not the same as the mechanism(s) that cause fracture (or in some cases, no fracture at all) in the control experiments. In particular, it implies that the PAA solution, as it expands volumetrically, accesses pores or very small cracks that were not exploited by the control solutions. The process of the PAA solution expanding and accessing new volume in the rock would result in smaller bulk overpressures in the PAA experiments (which was observed) and is consistent with cracking in similar materials such as concrete (see, for example, Charpin and Ehrlacker 2012)1. The fracture mechanism(s) in the experiments performed with PNNL rheoreversible expanding fracturing fluids, which may be driven by a combination of capillary action, local changes in solution properties, or the significant elastic energy present due to the volume expansion process, all occur at the micron or sub-micron scale. These microscale phenomena and the local forces or stresses they generate were not measureable with currently existing equipment and are difficult to assess experimentally. To the best of our knowledge there are no reported experiments capturing the microscopic process involved in fracture formation due to gel expansion. However, modeling of fracture mechanisms on a similar process, Alkali- Silica Reaction (ASR), has been reported. It has been hypothesized that microscopically a network of microcracks propagates because of swelling of reactive sites where amorphous gels are created and these microcracks play an important role in the macroscopic expansion.1-3 A number of researchers have modeled ASR-related fracture mechanics.2-3 Due to the similarity between ASR and PNNL expanding fracturing fluids, we propose to model fracture formation generated by PNNL expanding fracturing fluids using micro-scale mechanical models. The outcome of this study will be of critical importance for the optimization and application of PNNL novel rheoreversible fracturing fluids in reservoir stimulation.

References

1. C. Laurent, and A. Ehrlacher. "*A computational linear elastic fracture mechanics-based model for alkali–silica reaction*." Cement and Concrete Research 42.4 (2012): 613-625

2. M. Moranville-Regourd "*Modelling of expansion induced by ASR—New approaches*." Cement and Concrete Composites 19.5 (1997): 415-425

3. M. Alganaggar, G. Cusatis and G. Di Luzio “ *A discrete model for alkali-silica-reaction in concrete”* VIII International Conference on Fracture Mechanics of Concrete and Concrete Structures (2013): 1-12