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Geomechanical Modeling to Predict Wellbore Stresses and Strains for the Design of Wellbore Seal Repair Materials

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1) Project Overview

The 3D wellbore model examines the resulting impacts various loading scenarios on a wellbore casing structure. This computational model is based on one used for evaluating the effect of slip along a bedded plane on a steel/cement casing structure (Arguello et al. (2009), Sobolik et al. (2011)). The model includes steel casing(s); cement surrounding the casing(s); and formation rock around everything. Displacement boundary conditions arising from slippage along the interbeds in the global mine excavation model are imposed on the boundaries of the wellbore model to simulate shearing and parting along a bedding plane cutting through the well axis. The bedding is treated as a "slip surface" at the top or bottom of a layer. The results of this model are used to inform our development and testing program estimates of conditions to be experienced by repair materials.

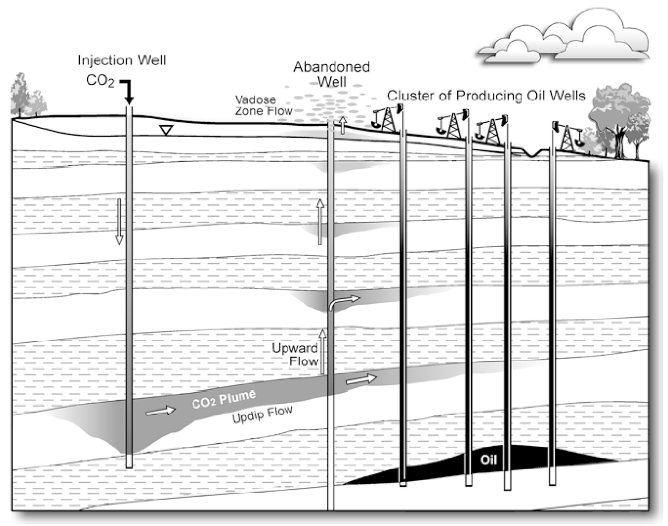


Figure 1. Gasda, S., M. Celia, and S. Bachu, 2004. Spatial characterization of the location of potentially leaky wells penetrating a deep saline aquifer in a mature sedimentary basin. Environmental Geology. Vol. 46, 6-7, 707-720.

2) Goals and Objectives

(1) Develop and test ***nanocomposite seal repair materials*** suitable for expected wellbore environments that have ***high bond strength*** to casing and cement, ***low permeability*** and ***high fracture toughness.***

-These materials will have superior properties compared to conventional materials to permit improved wellbore seal repair, contributing to the program's goal of 99% storage permanence.

-Success criteria: Materials shall have superior properties and characteristics compared to conventional materials.

Polymers	Nanomaterials					
	Neat	CNTs	Nanoclay	Nanosilica	Nanoalumina	Graphene NP
Polysulfide siloxane epoxy	C	C	C	C	C	U
Novolac epoxy	C	C	U	C	C	U
Siloxane epoxy	P	P	P	P	P	P
SBR latex/cement	P	P	P	P	P	P
Reference repair material (Microfine cement)	P (without nanomaterials)					
C: Completed testing	U: Undergoing testing		P: Planned testing in coming quarter			

Figure 2. *Matrix of nanocomposites being developed in this project. The matrix will test a suite of epoxy resins with varying loadings of neat epoxy, carbon nanotubes(CNT's), nanoclay, nanosilica, nanoalumina, and graphene NP.*

(2) Evaluate the effectiveness of developed materials to repair flaws in ***large lab-scale annular seal systems under*** conditions expected in wellbores.

-Evaluation and understanding of the expected performance of these materials to repair flaws within sealed wellbores will lead to more confidence in the ability to ensure 99% CO_2 storage permanence.

-Success criteria: The degree to which system permeability to CO_2 is reduced after repair, cost, material availability and ease of use compared to conventional materials.

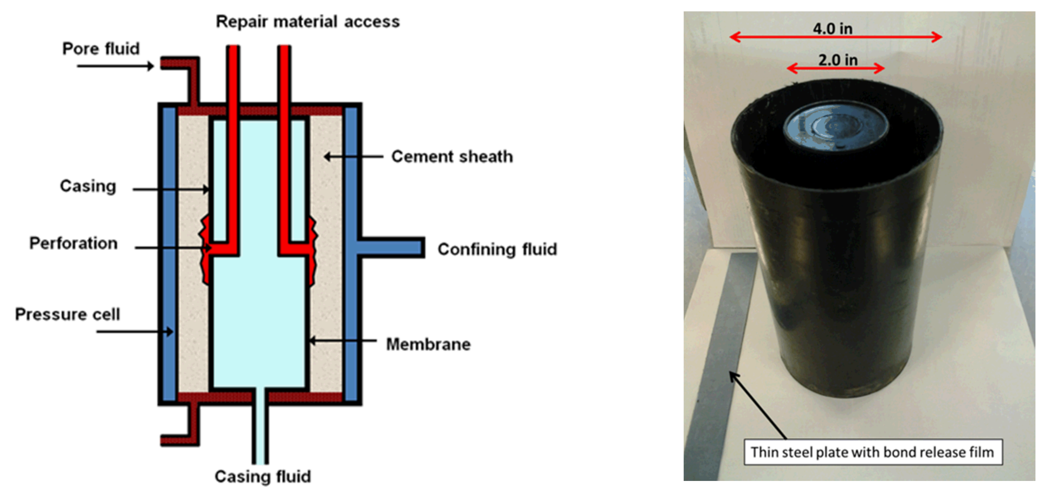


Figure 3. *Lab-scale seal system testing. From all candidate nanocomposites, those with the most promising material properties will be chosen for bench-scale testing in a wellbore mock-up.*

3) Predicting *In-Situ* Wellbore Stress and Materials Response

3D Geomechanical Wellbore Modeling

Wellbore modeling is being used to ***quantify the stresses and strains*** that seal repair materials will face in the wellbore environment. Material properties of developed nanocomposites will also be used as input for the wellbore model to ***predict the response of synthesized nanocomposites.***

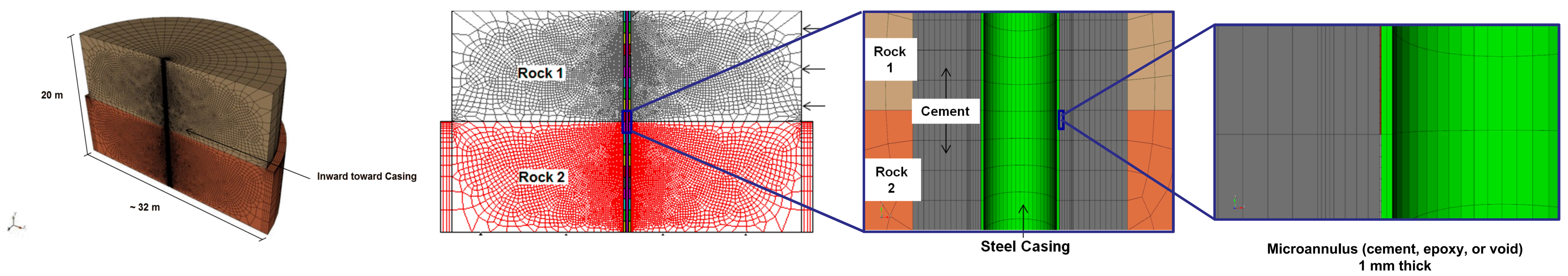
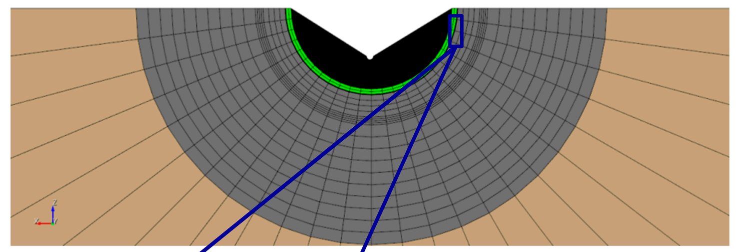


Figure 4. *Simplified mesh (top left) was used to develop and test simulation code. The mesh includes well casing, cement sheath, void region, and rock formation. The void region or "Gap" can be represent a flaw (annular gap), intact cement, or epoxy.*



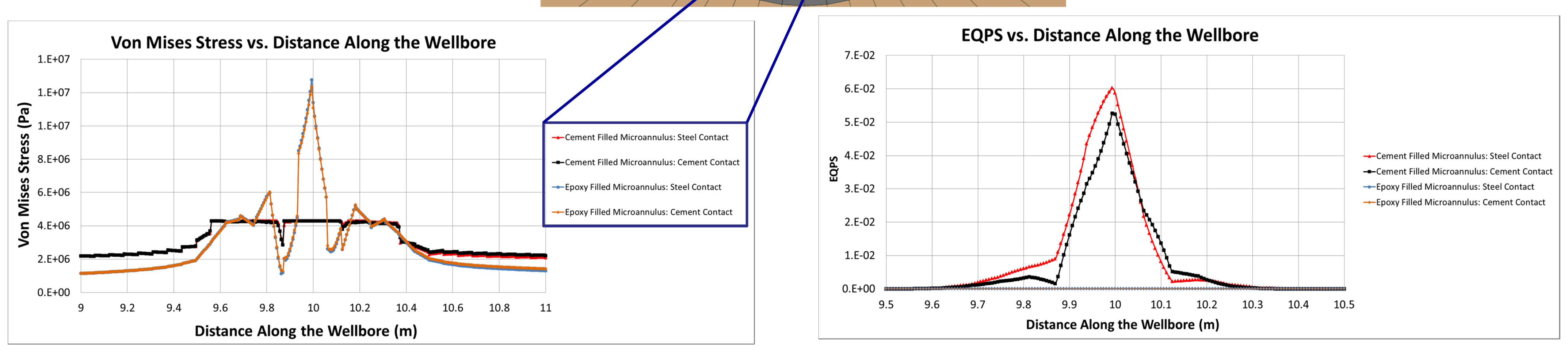


Figure 5. *Von Mises Stress and Equivalent Plastic Strain (EQPS) results plotted along the wellbore microannulus. The cases presented include the microannulus filled with cement and epoxy, analyzed on their respective contact surfaces.*

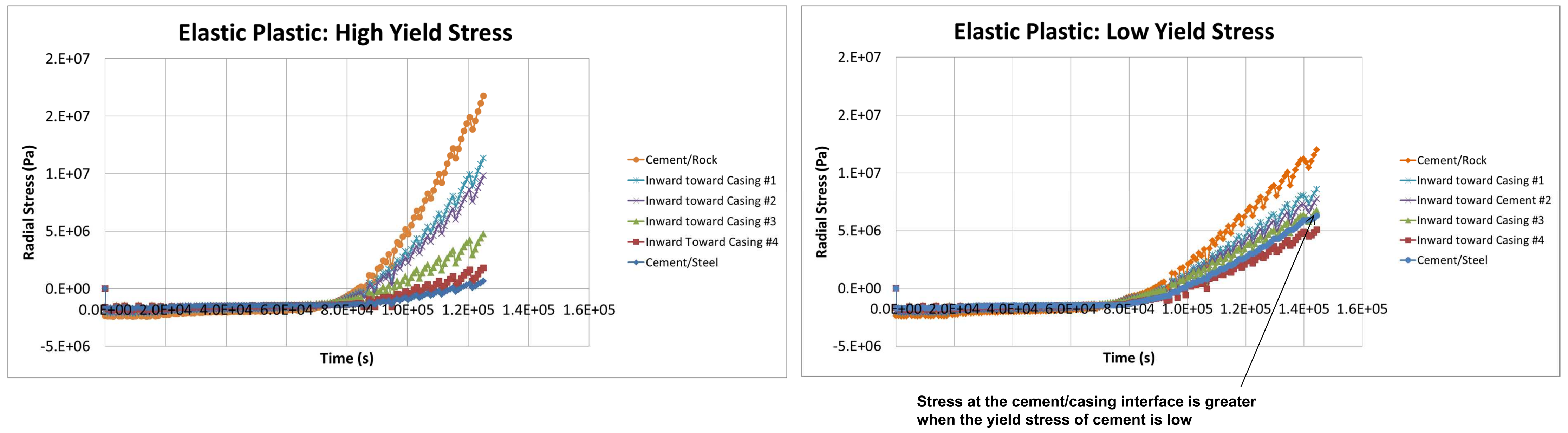


Figure 6. *Preliminary modeling results under elastic-plastic conditions indicate the importance of the yield stress model employed.*

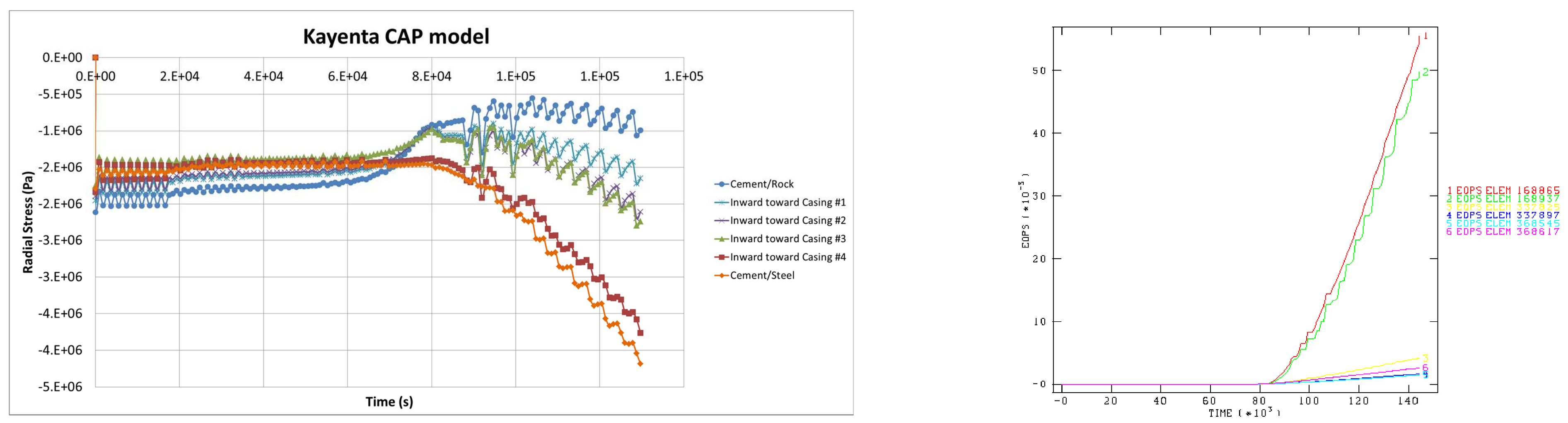


Figure 7. *The Kayenta model simulates Capped Plasticity (CAP). Plastic deformation is shown to remain compressive (negative values) as analysis proceeds from the cement/rock interface inward toward the cement/steel casing interface*

4) Optimizing Material Properties

Flowability is key for effective delivery of seal repair material

Flowability and ***bond strength*** are key material properties that are essential to correctly tune in order to make an effective seal repair. Material selection will take these properties, as well as fracture toughness and yield stress, into account to optimize for the best combination of material attributes. Wellbore modeling will be used to aid in the optimization process.

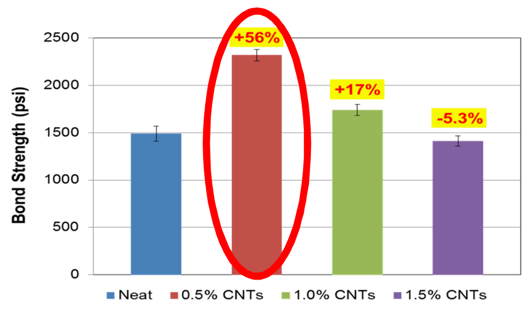


Figure 9. *Slant shear test results show a remarkable improvement in bond strength for 0.5% CNT loading.*

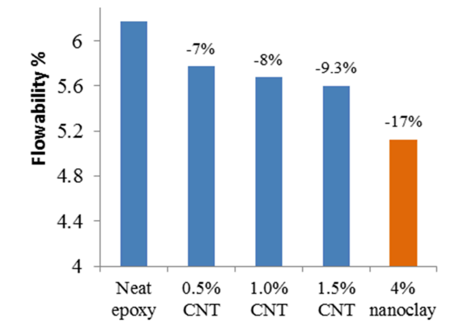


Figure 10. *Flowability test results show the negative impact of CNT's and nanoclay additions.*

Bond strength is key to restoring seal integrity

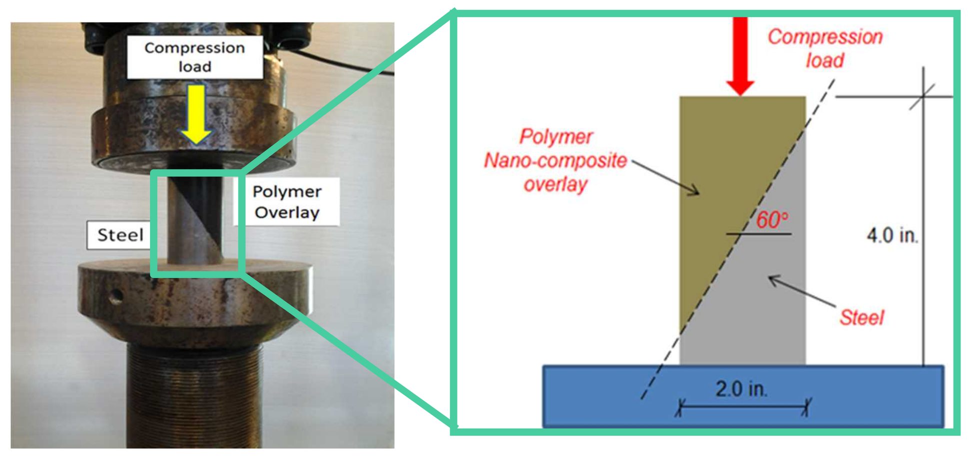


Figure 11. *Slant shear test performed according to ASTM C882 standards. The lower steel portion of the test cylinder is cut and sandblasted, and then overlaid with the epoxy in a mold for the test.*

5) Summary

A detailed wellbore model was developed that includes two adjacent rock formations shearing along their contact. The model was used to evaluate the response of the wellbore system (casing, cement, and microannulus), including the use of either cement or an epoxy in the microannulus to represent a repaired system. Model results indicate that an epoxy filled microannulus does not reach its yield stress whereas a cement microannulus experiences considerable yield which may lead to failure. Thus, under these conditions, a microannulus repaired with an epoxy based material would be able to better withstand wellbore conditions, suggesting improved zonal isolation. The wellbore model will be used to evaluate other scenarios, including a reservoir depletion case, in order to assess the expected wellbore conditions that a repair material will experience. These results will be used to inform our nanocomposite repair material development and testing efforts.

Acknowledgements

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References

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