Effect of proppant on maintaining permeability in fractured shale

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Testing

- Specimens were manually fractured
- A mono layer of proppant was distributed onto the fracture face
- The specimen was reassembled and tested
- Testing consisted of:
  - Increasing temperature to 75°C at ambient pressure
  - Increasing pressure to 20.7 MPa (depending on loading cycle)
  - Increasing differential stress to 6.9 MPa.
  - Flowing water through the specimen to determine permeability with time.
- Specimens were periodically removed from the test system for imaging with an X-Ray CT system, to monitor the condition of the proppant and the fracture face.
- After imaging the specimens were returned to test conditions via the procedure above.

Abstract

A series of tests were performed on a manually fractured (subparallel to bedding) and propped (using quartz sand) shale plug to determine the extent to which the proppant fractured and the effect the proppant had on the fracture wall when subjected to reservoir conditions. The specimen was repeatedly subjected to reservoir conditions of 20.7 MPa confining pressure, 6.9 MPa differential stress and 75° C. While at reservoir conditions the sample permeability was measured. Periodically the specimen was removed from the test system and scanned with a X-ray micro computed tomography machine to visualize the fracture and proppant. Noticeable decrease in flow was observed with subsequent testing due to fracture closure. This can be attributed to observations of clay swelling, proppant embedment/fracture, and shale wall spalling leading to a decrease in effective fracture aperture. Flow induced particle transport clogged flow paths and impeded flow. It was observed that isolated grains tended to crush whereas continuous grain patches tended to fracture with little displacement and tended towards embedment.

Future Work

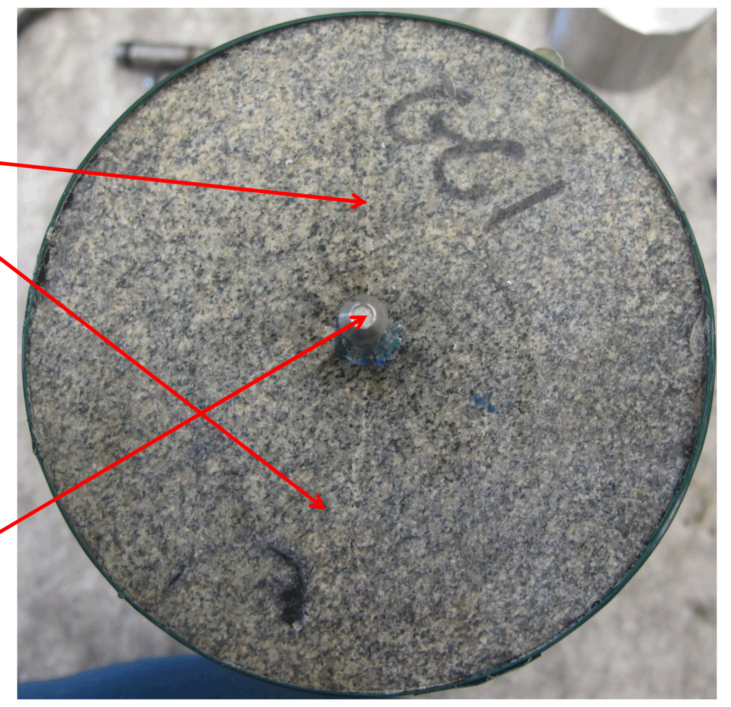
- Currently hydraulic fracture and prop tests are underway on Marcellus shale to determine the proppant distribution within the fracture from an injected proppant stream
- Proof of concept tests performed on granite have been conducted to ensure the fracturing system is viable.
- This data will be used to inform existing multiphase flow models which will then be parameterized to match the proppant distribution in the fracture based on injection conditions.

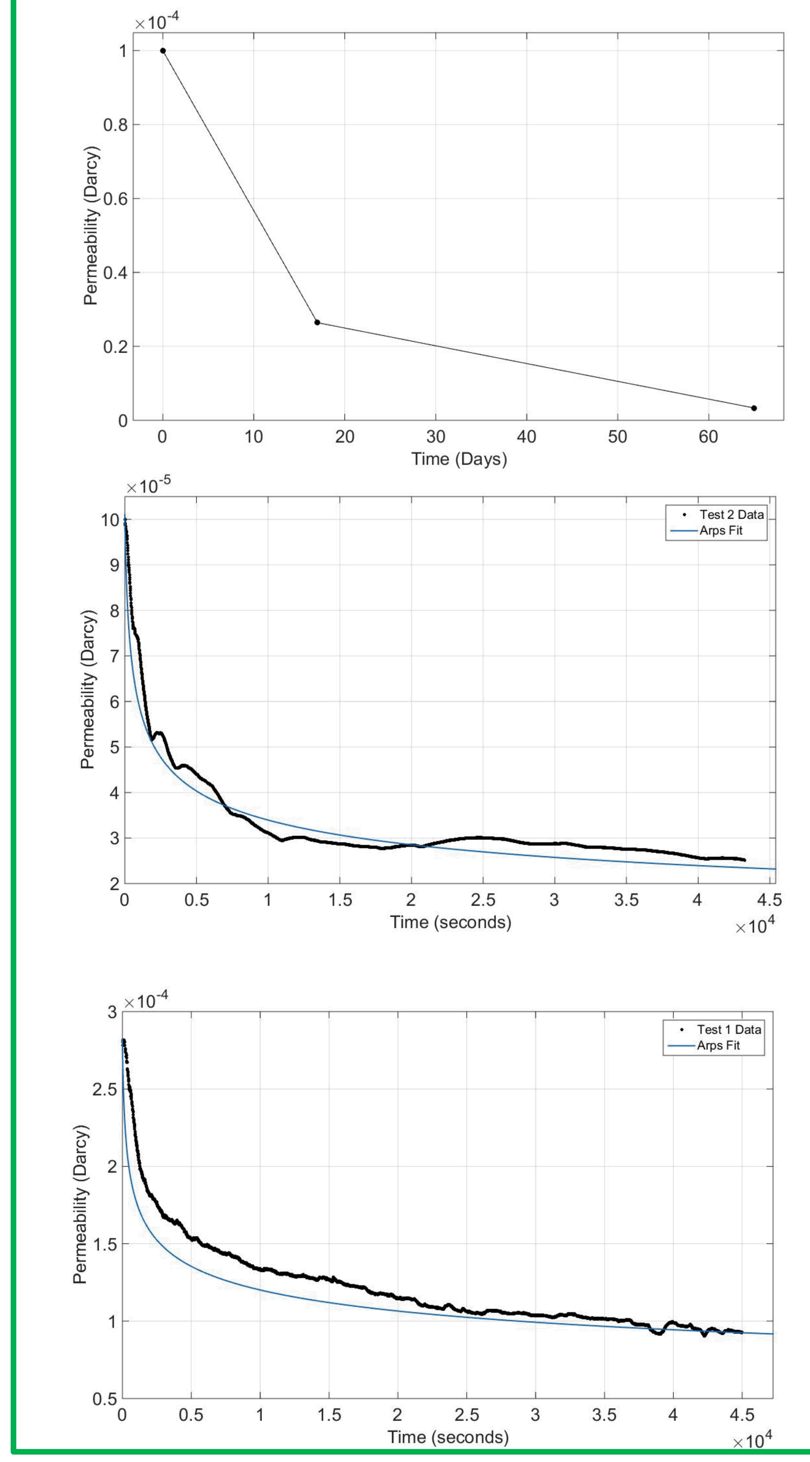
Mechanical and Permeability results

- Shale specimens showed little to no global deformation under the test conditions
- Permeability showed a strong similarity to field production data.
  - Permeability was initially high, and then decreased to a steady state with time.
  - Subsequent pressurizations showed progressive decreases in permeability.
  - Permeability was fit to the empirical ARPS production decline equation and showed reasonable agreement to production decline data.

ARPS Equation

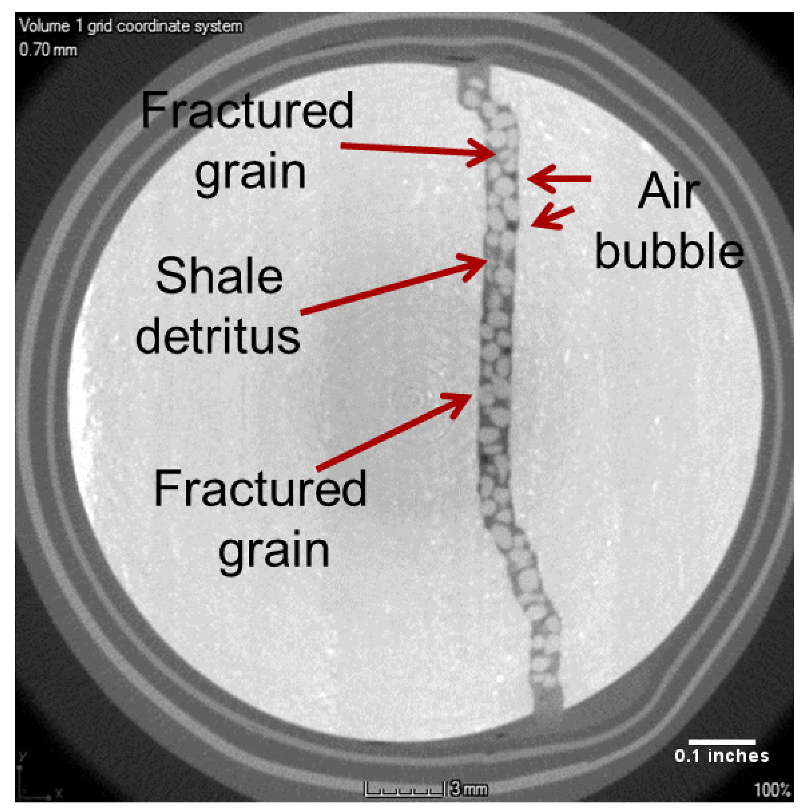
$$q_g(t) = \frac{q_{gi}}{\left[1 + bD_i t\right]^{1/b}}$$

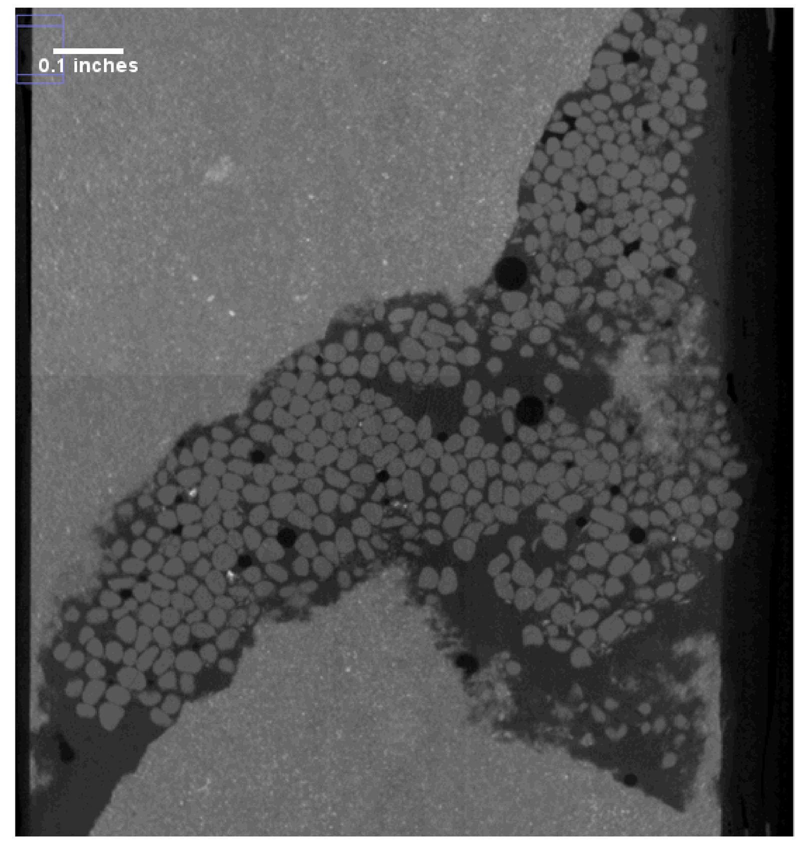


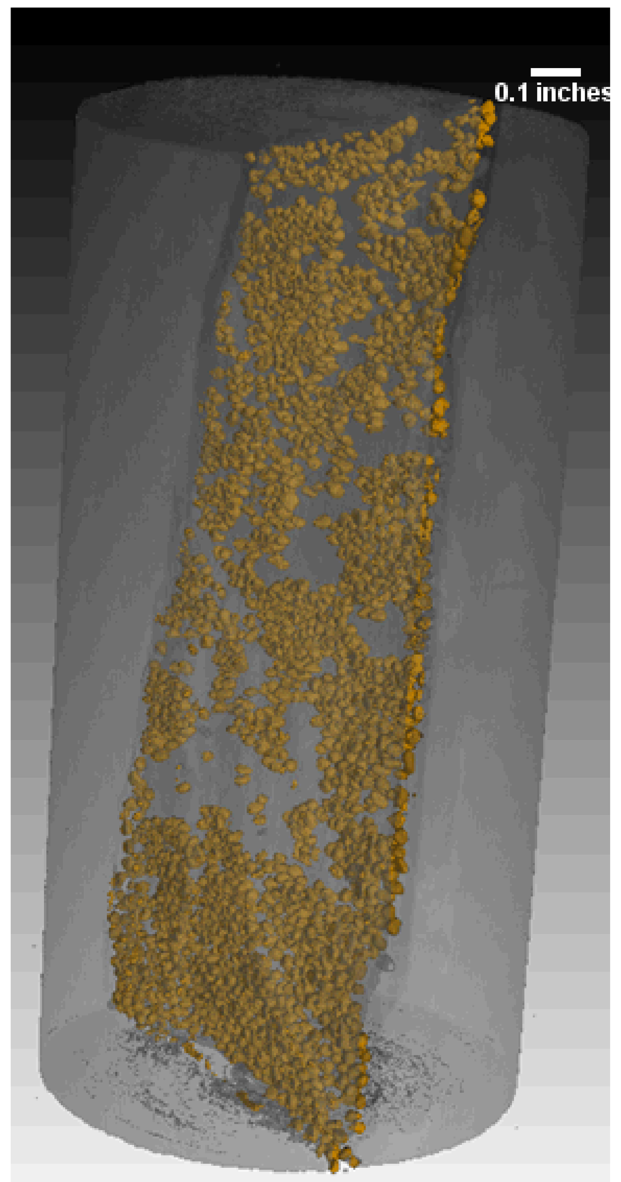


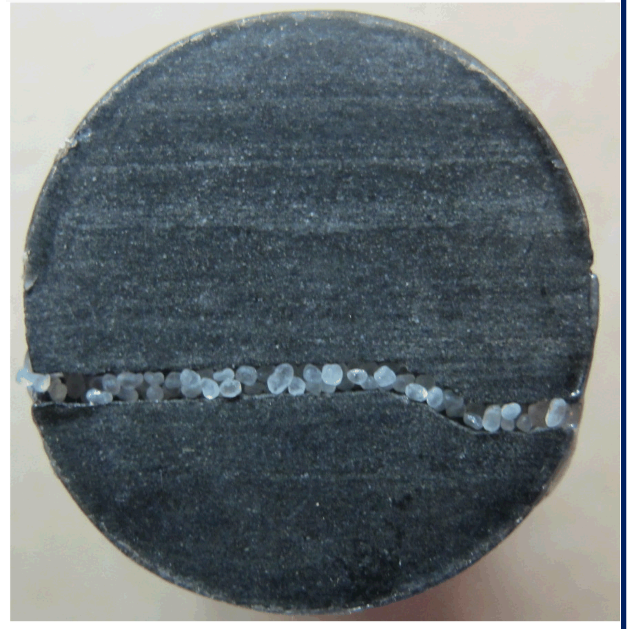
X-Ray CT results

- Monitoring the crack space with X-Ray CT proved to be invaluable in terms of determining what was affecting the permeability of the fracture.
  - Grain fracture was observed, and transport of the fractured grains caused clogging of flow paths.
  - Some grain embedment was observed, but it did not appear to be significant.
  - Fractured grains tended to be isolated, while embedded grains tended to be located in a pack of proppant.
  - Whole grains showed little to no motion after specimen was assembled
  - Fracture walls sloughed resulting in transport of shale detritus which also clogged flow paths.
  - Air bubbles were present in the fracture, even after multiple flow cycles, and a bottom up flow path. This indicates that the surface tension effects of the proppants and the shale fracture surface can trap gas within the fracture, but these should not affect permeability significantly.
  - The clays in the specimen did not appear to adsorb significant water, nor did they swell significantly.
- The first images were taken after only 18 hours under reservoir conditions, at which point all of the above features were visible in the fracture, indicating that deterioration of the proppant/fracture interface begins immediately after proppant injection.
- Average fracture aperture was reduced from 0.966mm to 0.914 mm over the duration of the entire test, approximately 90 hours.



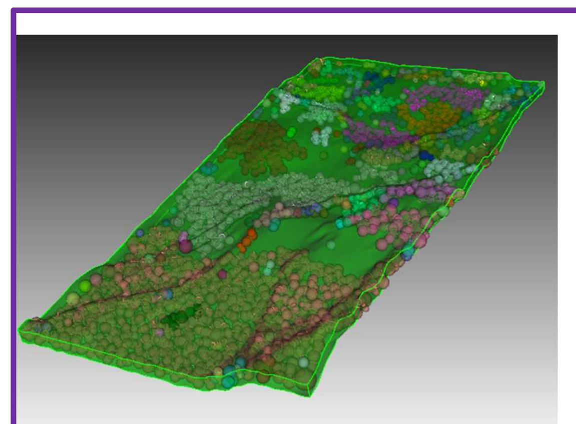


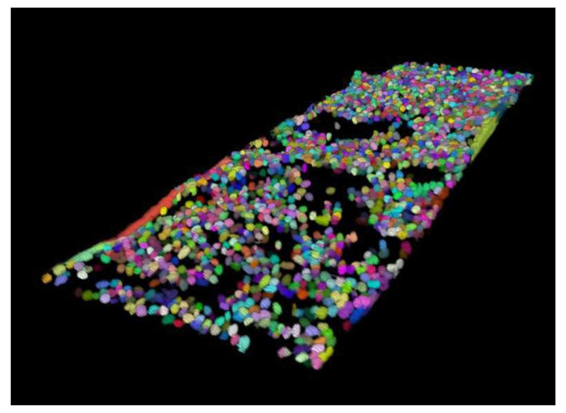




Conclusions

- Permeability of fractured shale depends on a number of factors
- Proppant placement and distribution is important, but there are more factors that affect permeability including the interaction between the formation and the proppant.
- Reduction of effective fracture aperture is the largest cause of permeability reduction. This is often due to particle transport causing clogging in high flow regions.
  - Particles seem to be most often generated by either proppant fracture or spalling of the fracture walls.
- With this particular shale, proppant embedment, and clay swelling do not appear to be a significant cause of permeability loss, but this is heavily dependent on the shale, and the type of clay it contains.
- Meshes were generated from CT data in order to model flow within the fracture and around the particles. This resulted in a high-quality mesh that still accounts for the particles.





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