

Effect of proppant on maintaining permeability in fractured shale

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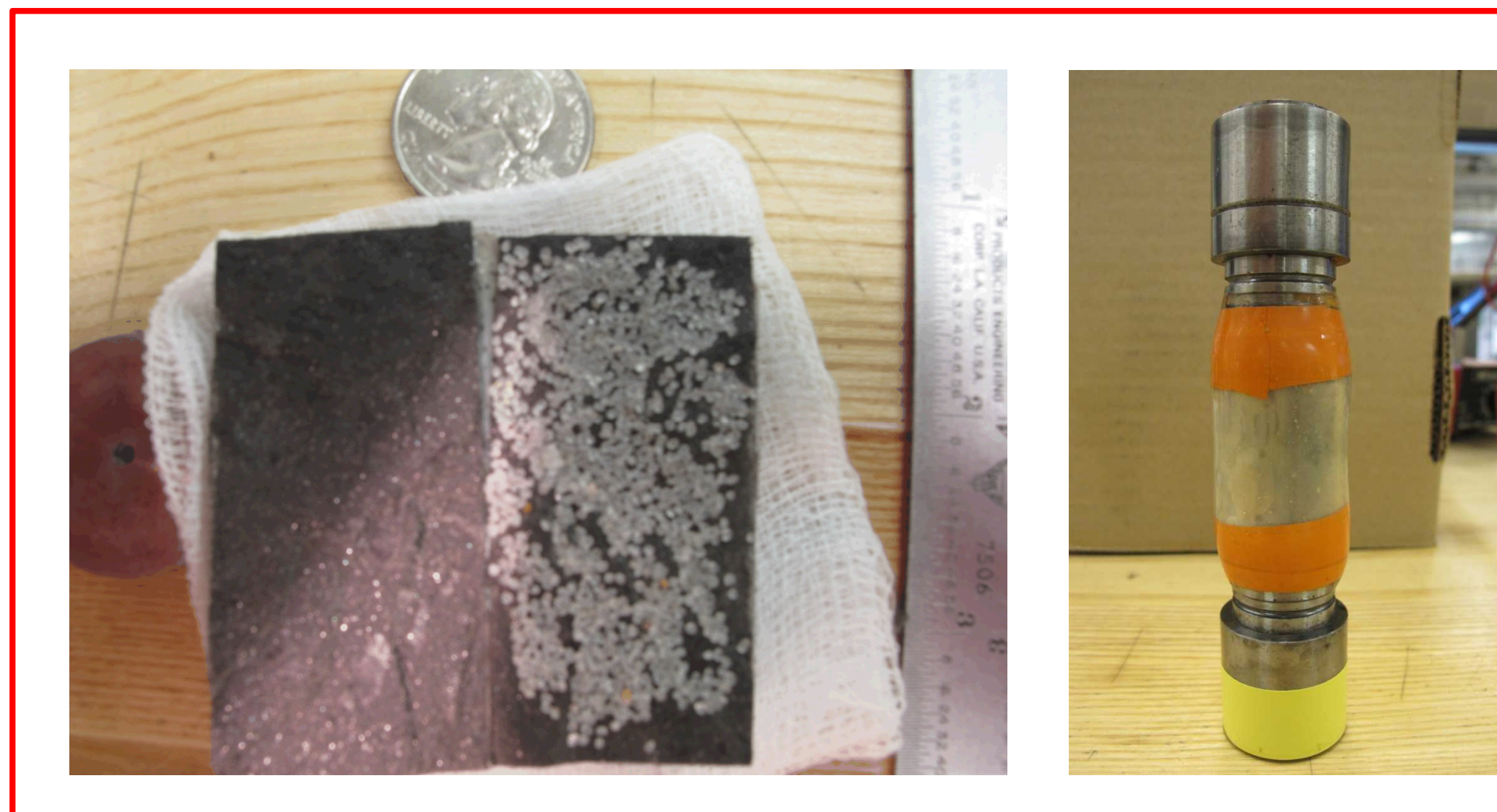
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Testing

- 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.

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.



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.

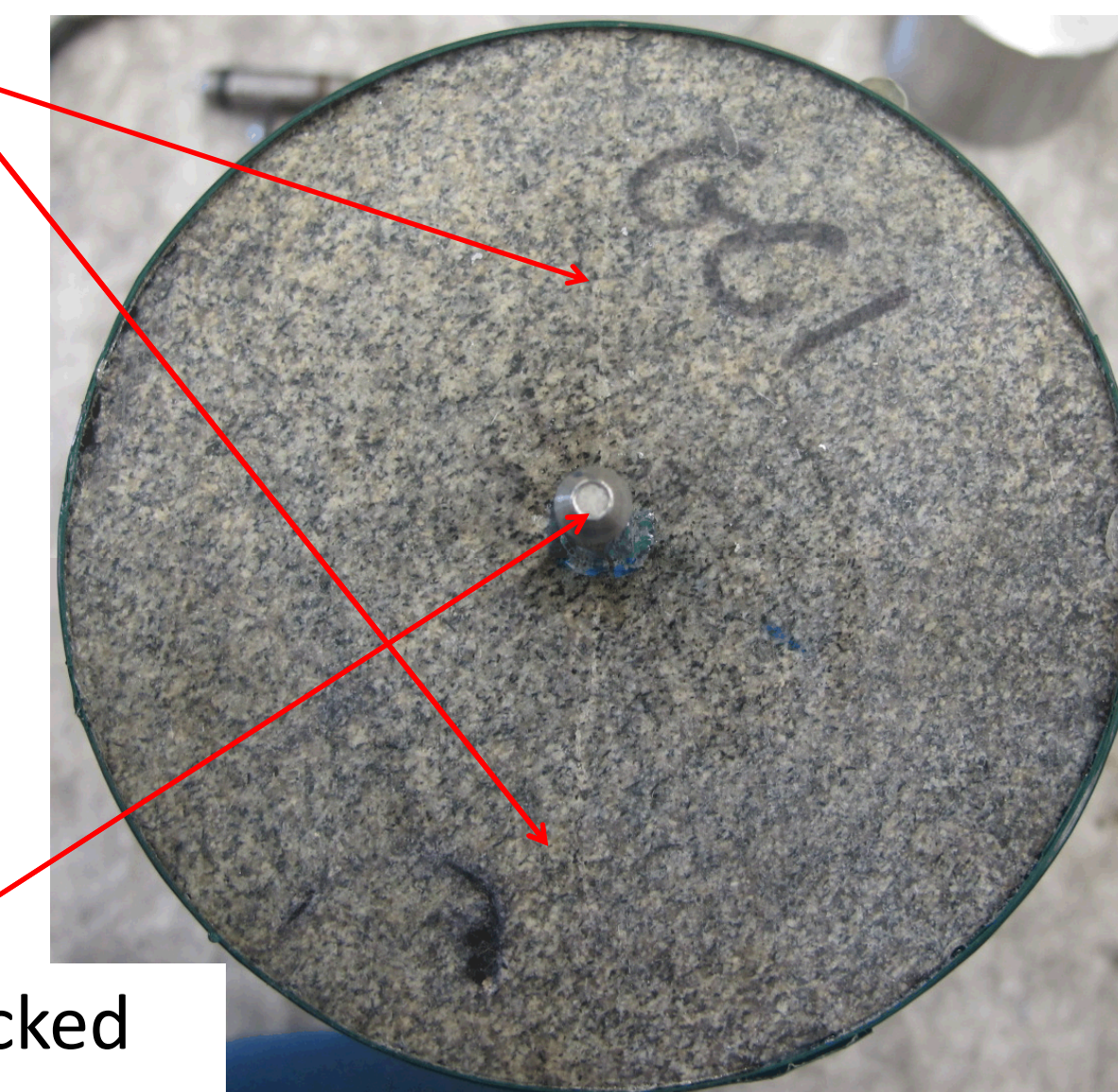
ARPS Equation

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

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.

Hydraulic Fracture



Proppant packed into borehole.

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.

