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Particle transport in propagating hydro-fracture

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Hydraulic fracturing is a technique that involves injecting fluids into rock formations at high pressure to create cracks or hydro-fractures. While hydro-fracture can occur naturally during seismic events, hydraulic fracturing is a human-engineered process used to increase the permeability of low-permeability rock formations. This technique is widely applied in engineering applications such as oil and gas extraction, carbon sequestration, and geothermal energy production. Hydro-fracture tends to close due to the compressive stress from the surrounding rocks when fluid pressure decreases, which is unfavorable in applications, where maintaining open fractures is essential. To prevent fracture closure, particles known as proppants, are added to the fracturing fluids and co-injected into the hydro-fracture. Therefore, the effectiveness heavily depends on the efficient delivery to the desirable locations within the hydro-fracture. While the behavior of particle-laden fluids has been extensively studied, there is much less understanding of the particle transport dynamics within a hydro-fracture due to the complex interplay between fracture geometry, particle properties, and fluid flow characteristics within hydro-fracture. Exploring the impacts of various forces and factors that influence particle transport in hydro-fracture is crucial for accurately predicting the performance of proppants in fracture operations.

In the experiment, we introduce particles into fracturing fluids and induce a penny-shaped fracture in a PMMA cylindrical sample by injecting the fracturing fluids at high pressures. We visualize the particle transport process during hydrofracturing by high-speed imaging. The PMMA cylindrical sample is created using the stereolithography 3D printing technique, which uses ultraviolet laser light to cure liquid photopolymer monomers into a solid form. In the experiment, the sample is positioned horizontally, and the vertical hole is prefilled with a particle-fluid mixture. Water is injected into the vertical hole at a constant rate using a high-pressure syringe pump, gradually increasing the pressure to initiate a crack in the sample. The process is recorded from the bottom of the sample using a high-speed camera, enabling the identification and tracking of particles in the captured videos.

We demonstrate how fluid flow characteristics and fracture geometry jointly affect particle transport in hydro-fractures. Our findings reveal that particles closely follow the fracturing fluid flow until they are trapped by geometric size exclusion near the fracture tip, where the narrowing aperture prevents larger particles from passing through in water-driven hydro-fractures. Flow instability, characterized by vortex formation, further disrupts particle transport by entraining particles into swirls, altering their trajectories. In contrast, with viscous fluids such as glycerol-water mixtures, particle lag is negligible. Increased viscosity widens the fracture aperture and suppresses vortex formation, allowing larger particles to reach the fluid front with reduced disturbance. This work provides essential insights into the mechanisms governing particle transport in hydro-fracture, revealing how fluid viscosity, flow characteristics, and fracture geometry influence particle transport dynamics, which is important for optimizing proppant placement in hydraulic fracturing operations.

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