Effect of Fiber Dimensions on Particle Settling Dynamics in Viscoelastic Fluids

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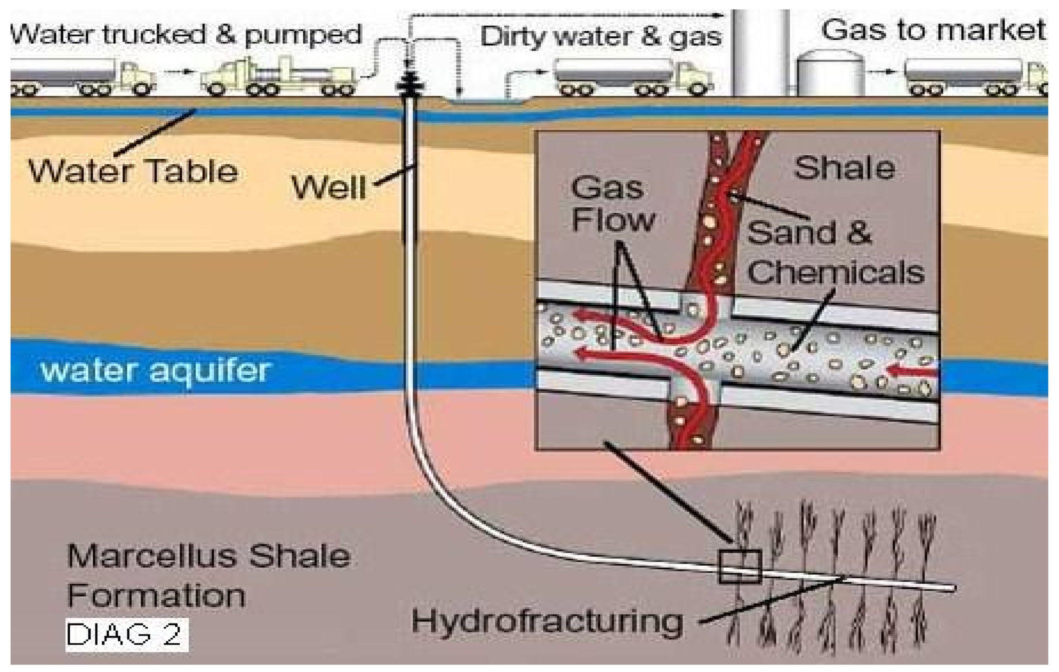
Introduction



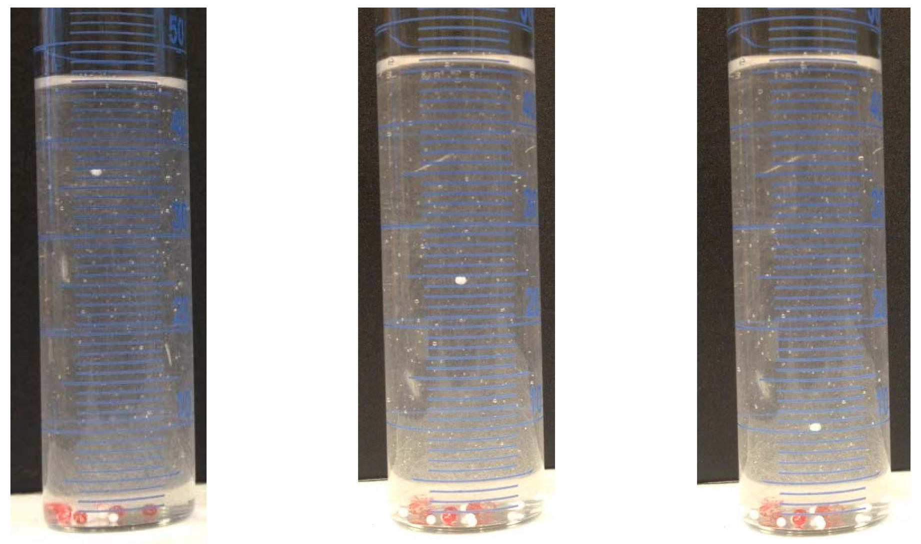
- Hydraulic fracturing ("fracking") is a hydro-carbon capturing method that involves pumping high pressure fluid to fracture shale and release trapped natural gas.
- To keep the fractures open, proppants are added to the fracking fluid, which is composed of mostly water and small amounts of cross-linker and other additives.
- Some of these chemical additives are hazardous, particularly the cross-linker sodium tetraborate.
- It has been found that adding fiber into the fracking fluid enhances its ability to suspend proppants while still retaining the rheological properties of the fluid, reducing the need for cross-linker.

Objective

This research aims to explore the optimal fiber dimension for reducing proppant settling velocity in fracking fluids. The goal is to minimize the required cross-linker concentration and reduce the negative environmental impact of fracking.

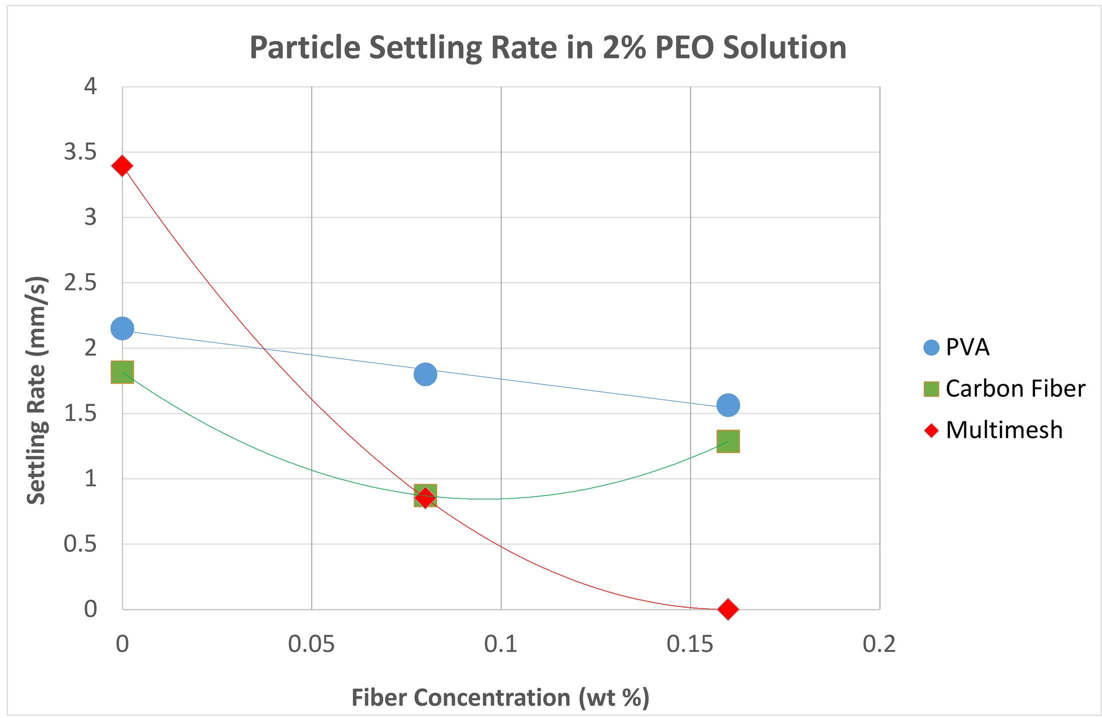
Experimental Methods

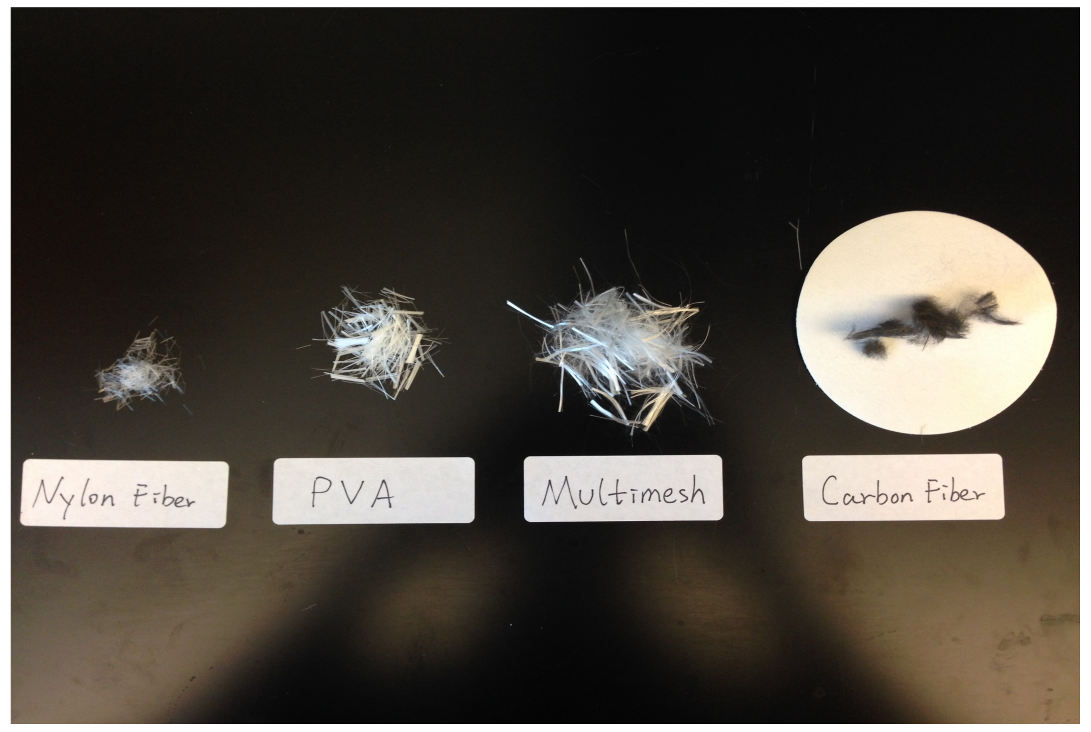
- Samples of hydraulic fracturing fluid were prepared by making Hydroxypropyl Guar (HPG, 0.5 wt%) solution.
- Chopped nylon fibers were added to the HPG solution and stirred vigorously with a magnetic stir bar until fully homogeneous.
- The samples were transferred to 100mL graduated cylinders and settling rate experiments were conducted by dropping a single sphere into the fluid and measuring the time it settles using a video camera.



Preliminary Results

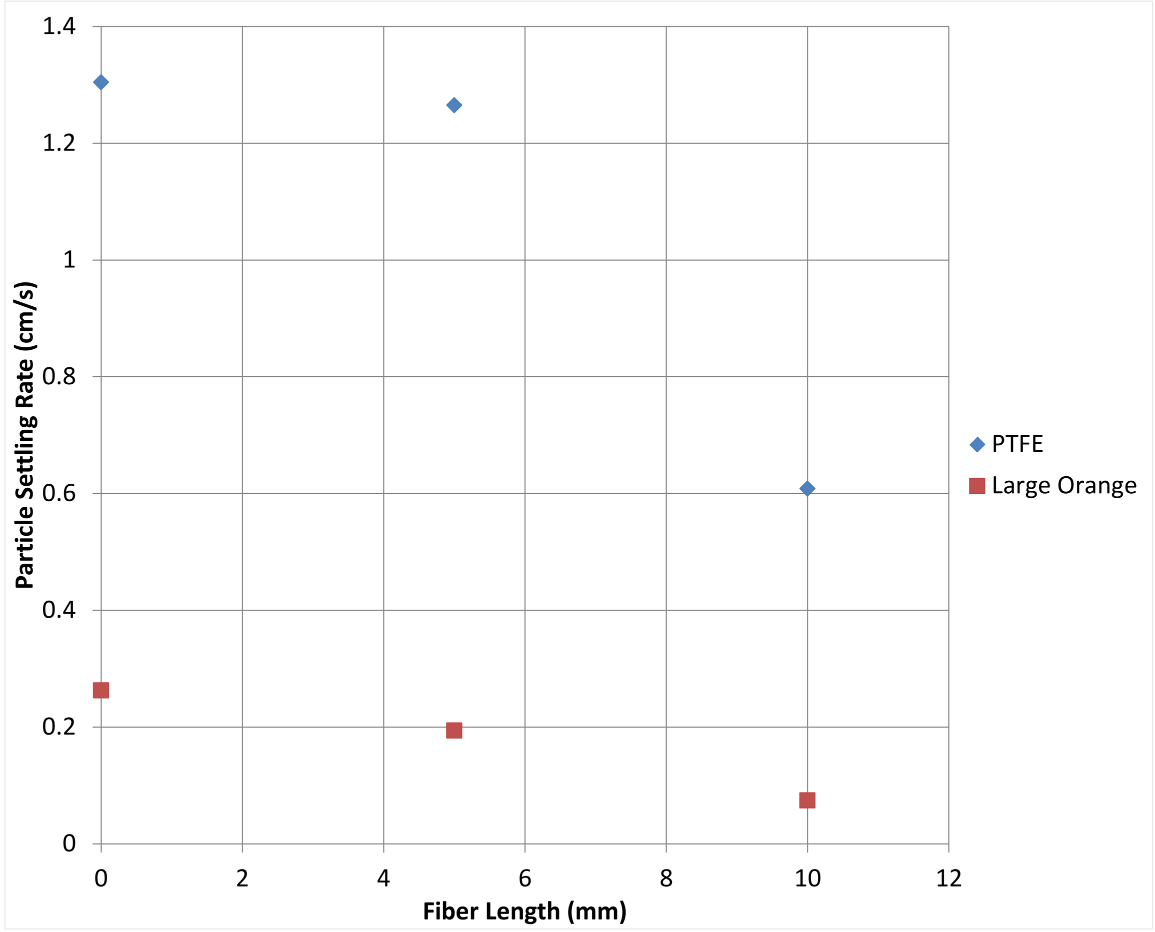
1. Settling rates vs. Fiber Concentrations for Different Fibers



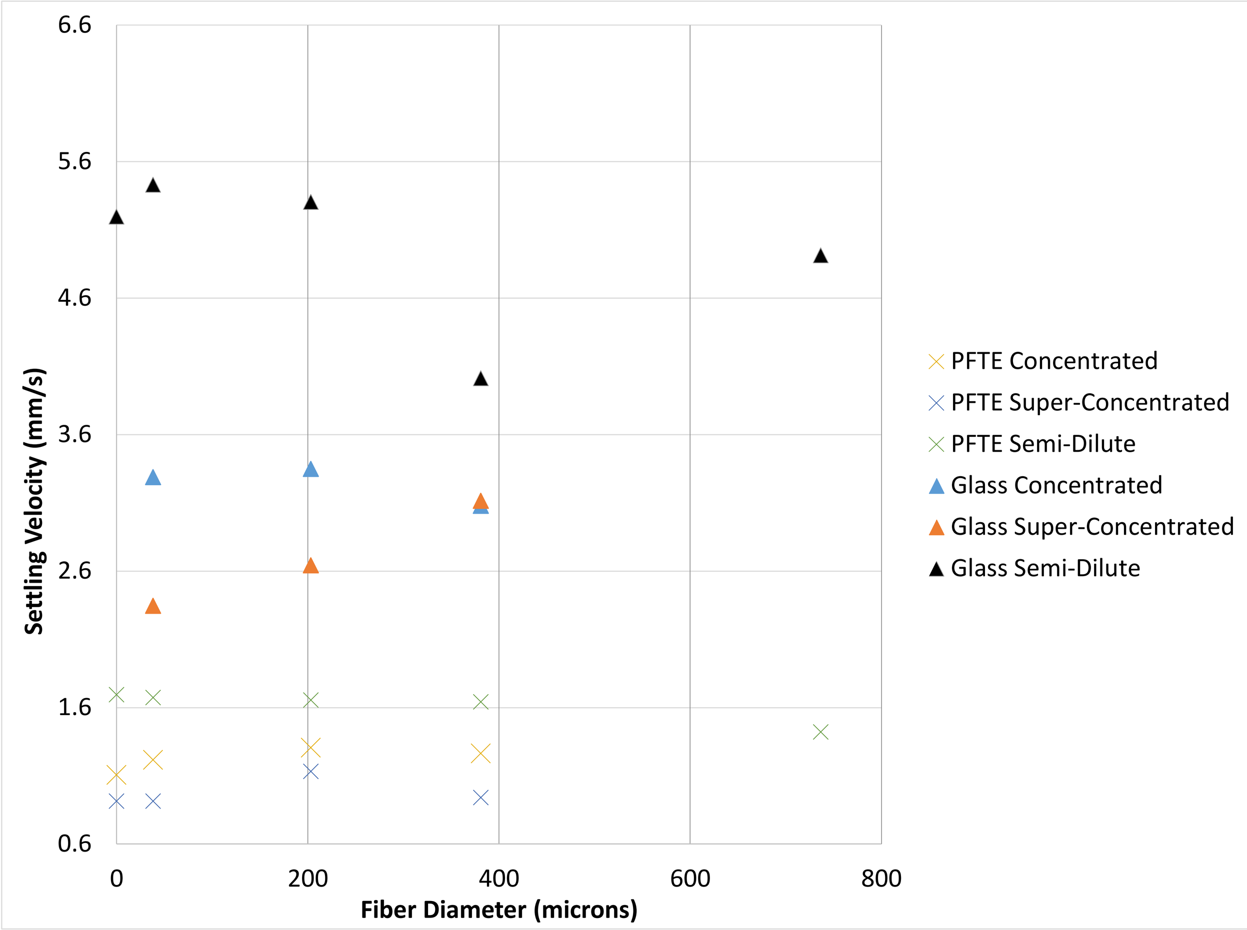


Experiment Results

2. Particle Settling Rate vs. Fiber Length

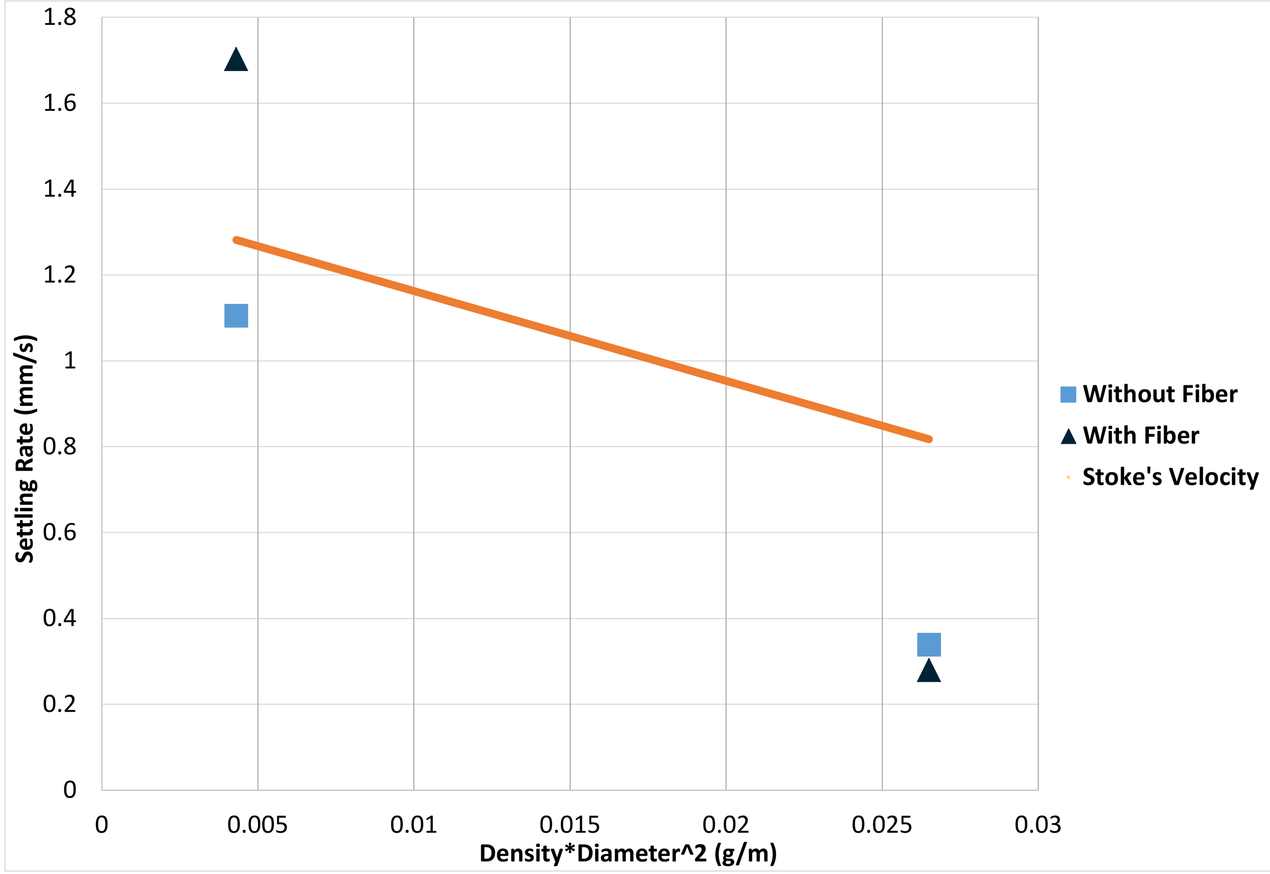


3. Particle Settling Rate vs. Fiber Diameter at Different Concentration Regime



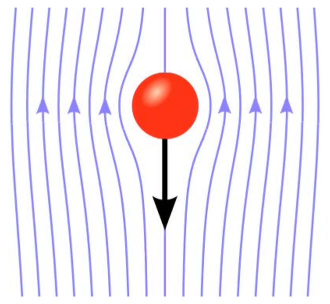
Settling Characterization

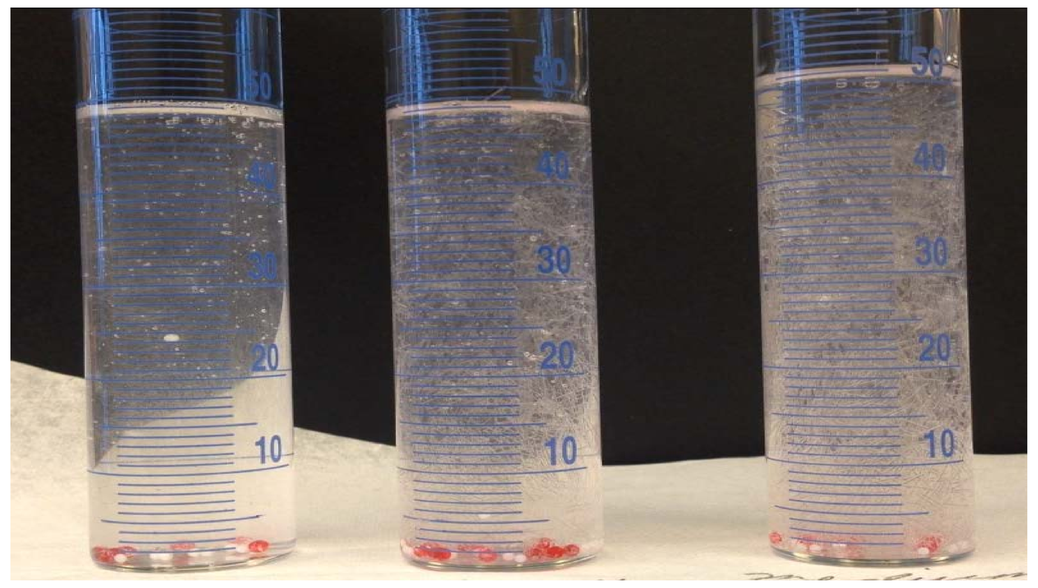
4. Experimental Settling rates vs. Stoke's Law Prediction



5. Settling Rate was modeled by Stoke's Law, Equation:

$$v_s = \frac{2}{9} * \frac{(\rho_p - \rho_f)}{\eta_0} * gR^2$$

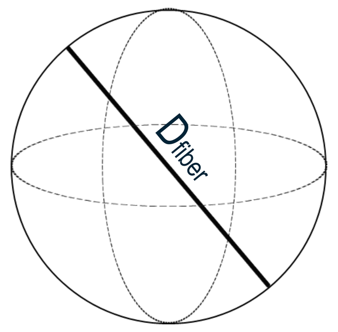




Computational Methodology

The fiber concentration regime is calculated by the following: a single fiber occupies a volume of a sphere whose diameter is the same as the fiber's length.

$$V_{fiber} = \frac{1}{6}\pi D_{fiber}{}^3$$



Fiber concentration regime (CR) is calculated by:

$$CR = \frac{V_{fiber} * N_{fiber}}{V_{fluid}}$$

Conclusions

1. Adding small amounts of chopped fiber to fracturing fluids significantly decreases particle settling rate in the fluid. This result can be applied to commercial fracking wells to reduce polymer and cross-linker concentrations and thereby reduce the pernicious environmental consequences of fracking.
2. Different fiber properties can have wildly different effects on the settling velocity.
3. Increasing fiber concentration reduces settling velocity.
4. For rigid fibers, settling rate is a weak function of fiber diameter, implying that it is best to minimize fiber diameters in commercial fracking wells.
5. Increasing fiber length decreases particle's settling velocity.
6. Stoke's Settling Law is not an appropriate model for predicting settling rates in fiber-laden fluids, because it ignores particle-fiber interactions and assumes the fluid is Newtonian.

Future Work

1. Determine the settling rate of a particle in a cross-linked fracking fluid system.
2. Explore the effect of a fiber's material properties (e.g. density, elastic modulus) on particle settling rate.
3. Find optimal fiber characteristics for commercial fracking operations.
4. Develop a semi-empirical model that will predict particle settling rate in fiber-laden fluid. Ideally, this model would take into account the geometric properties of the fiber.
5. Conduct settling rate experiments using actual proppants.
6. Investigate bio-degradable chopped fibers.

Acknowledgements

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References:
Macosko, Christopher W. (1994). Rheology - Principles, Measurements and Applications.. John Wiley & Sons.
Mezger, Thomas G. *The Rheology Handbook: For Users of Rotational and Oscillatory Rheometers*. Hannover: Vincentz Network, 2006. Print.