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Elasticity vs. Viscosity influence on proppant carrying suspension properties in shale fracking fluids. A laboratory testing update.

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Abstract

Fluid viscosity has been established as driver for proppant suspension, following Stokes law. Laboratory experiments indicate viscosity is not the only driver for suspension, other parameters have been overlooked such as fluid elasticity, salinity as total dissolved solids (TDS) including divalent cations, temperature and polymer concentration.

Laboratory testing has been performed on both conventional anionic FR's, HVFR's and a proprietary non-guar related linear gel to evaluate suspension properties in a different perspective. Techniques included Rotational and Oscillatory Rheology, Multiple Light Scattering and Slot Test.

Results show that suspension of proppants is a time dependent process, based on the previous mentioned parameters within the fluid environment. Suspension could be very short lived as in the case of conventional FR's and some HVFR's. High TDS water salinity with high concentration of divalent cations is the dominant limiting factor for proppant suspension. Linear gel under analysis has been successfully formulated to go from minutes to hours.

Flow regimes to transport proppant from surface to bottom in front of the perforations change when inside the open fracture paths, this may lead to sedimentation making it harder to occupy a larger volume of open fracture volume.

Introduction

Proppant transport and placement during shale fracking operations have become a critical issue for fracture conductivity and well productivity. Proppant volume that occupies the total fracture created volume (Stimulated Reservoir Volume) is in many cases just a fraction of the later. This fact is an indirect way to account for proppant placement efficiency. Trend in operational practice shows higher pump rates (70-120 bpm) and larger proppant total loads distributed in steps of 1-3 pounds of proppant added (ppa). Under these conditions friction reduction requires to be in the range of 70-80 %. This operational practice is generally achieved in the field.

Suspension or proppant carrying capacity is poor in slick water, which has evolved from conventional low-cost polyacrylamides as friction reduction additives to current high viscosity friction reduction (HVFR's) additives. Moving several tons of sand from surface to downhole in front of horizontal casing perforations takes about three minutes due to the pumps action.

After passing the perforations to the fractures net, flow regime changes and proppant placement becomes an issue because of proppant settling, in procedures taking over one hour [1] . The model of "Sand Bank or Dune displacement" [2] appears in technical literature, supported mainly by Slot Tests. Unfortunately, this model cannot explain proppant behaviour in low permeability complex fractures, with questions about how proppant turn in corners with apertures with smaller widths and different directions.

Industry is looking for possible solutions to this problem and some proppant related technologies are emerging such as self-suspending proppants [3], ultra-light ceramic proppants [4] and smaller sized systems beyond the 100 and 200 mesh, known as micro proppants [5]. Experimental testing for settling currently under use are made in static mode (exception made for Slot tests), in other words, under gravity force G, in which parameters as particle shape, size, density, polymer fluid concentration and viscosity are correlated to create a data base [6]. Individual particles are followed by means of high-speed cameras or video devices in front of calibrated glass containers such as volumetric cylinders. Settling velocities are measured as foot/min. Table 1 [5] shows different reported settling speeds for different sand proppant sizes, including micro proppants.

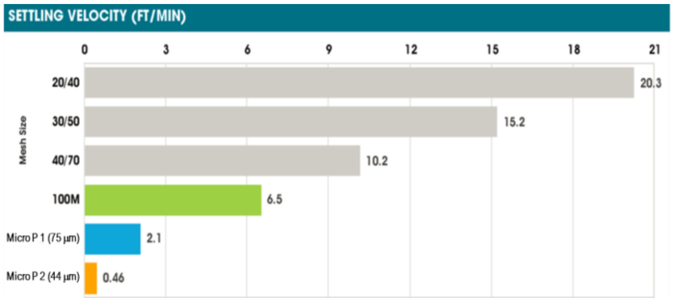

Table 1. Settling velocities measured in foot/min in water for different sand proppant sizes, Reference [5]

Laboratory Techniques Review

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Multiple Light Scattering (MLS)

A well-established technique in the areas of cosmetics, food, and petrochemicals. A desktop compact device, it works by pulsing an infrared light source into a sample glass cell, measuring the amount of light that is reflected (backscattering) and the amount transmitted straight through, which can be related to the concentration of the suspension (Figure 1).

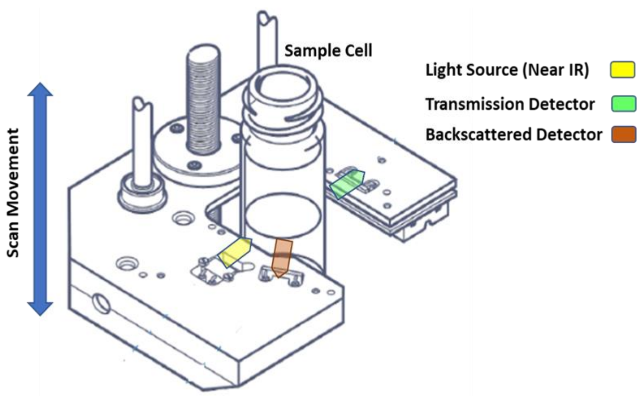

Figure 1. Cell arrangement and measurement principle in MLS.

In each scan the sensor takes readings of backscattering and transmission every 40 □m over the entire 55 mm height of the sample vessel, so it can reconstruct an animation of settling from real data (Figure 2), over the time lapse following how the suspension maybe changing as total settling, partial settling, or no settling. This test can be performed from 70-140 ºF. The quickest that scans can be taken is about every 30 seconds, but the interval can be set to any time greater than that. A particle front velocity and not an individual particle velocity makes this type of analysis ideal for calculating hydrodynamic parameters such as average front settling velocity from software installed on the equipment.

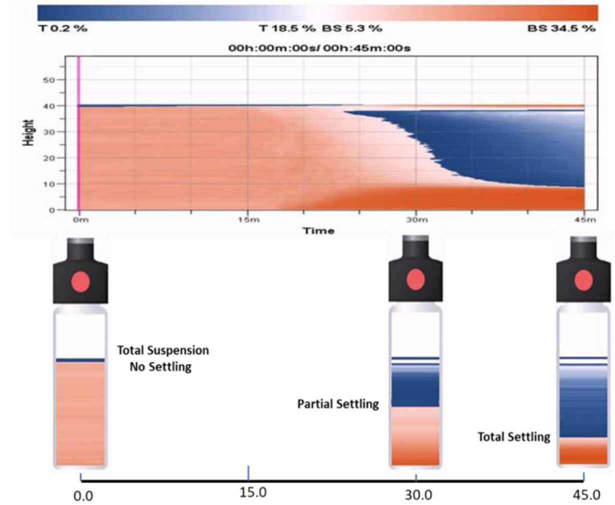

Figure 2. illustrates an example of output for a settling test of a linear gel polymer (non-guar) slurry mixed with tap water at a concentration of 1.70 gallons per thousand gallons (gpt) using a load of 2.00 pounds of proppant added (ppa) per gallon, sized as 100 mesh, at a temperature of 120 ºF. The proppant remains totally suspended for 20 min, then it begins a process of settling, seen as the accumulation of particles at the bottom, showing a darker orange color that corresponds to higher backscattered (BS) signal. The blue and light orange zones observed after 25 min indicate that sand proppant is settling first with larger particles (orange) following smaller particles (light orange), and upper part of cell is occupied mostly by the base fluid (blue).

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Effect of polymer concentration and polymer type on proppant settling using MLS

Two examples of settling tests were run with MLS technique to show simplicity in performing analysis and data interpretation. Increasing non-guar linear gel concentration from 1.60 to 2.00 gpt provides total suspension of 2.00 ppa 100 mesh proppant sand for one hour versus 20 min as seen in Figure 3. Blue zone is not observed because smaller sand proppant particles remain suspended.

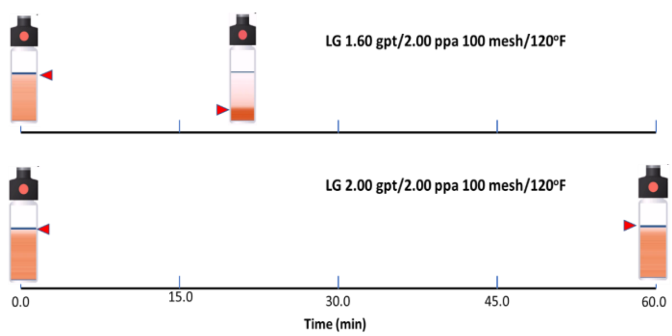

Figure 3. Effect of increasing polymer concentration with sand proppant suspension time.

Second example shown in Figure 4 makes a comparison of non-guar linear gel carrying capabilities versus a commercial High Viscosity Friction Reducer (HVFR) using three times more concentration (6 versus 2 gpt). It is evident the poor suspension properties of the later polymer type. Sand proppant settling is total within 15 min. No blue zone is observed due to opacity of HVFR direct emulsion.

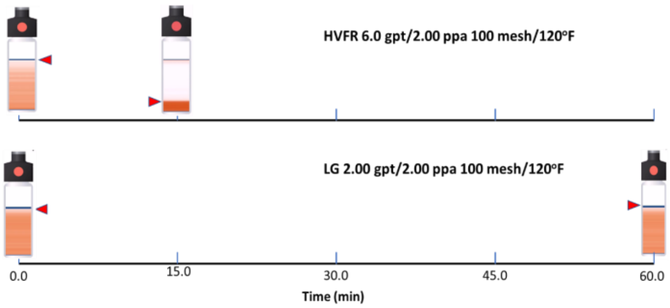

Figure 4. Effect of polymer type (HVFR vs LG) in sand proppant suspension time.

Slot Test

As MLS represents a static settling test, a dynamic approach to the suspension properties of proprietary LG polymer was performed using an arrangement for Slot test from a third-party laboratory (Figure 5). It simulates slurry flow into a fracture network. Testing assembly evaluates the ability of polymer systems to effectively transport proppant during the fracturing operations. The assembly consists of two parallel plates with a slot width of 0.25 inches, along with secondary and tertiary branches extending from the main slot. For each new branch, the width of the slot is decreased by 50%.

In each test, the slot was initially filled with neat polymer at the same concentration as the respective slurry. Five (5) gallons of slurry were pumped at 2 gpm through the slot without recirculation. A video follows up how proppant in the slurry settles or not in the period used. Total test time is about 2 minutes.

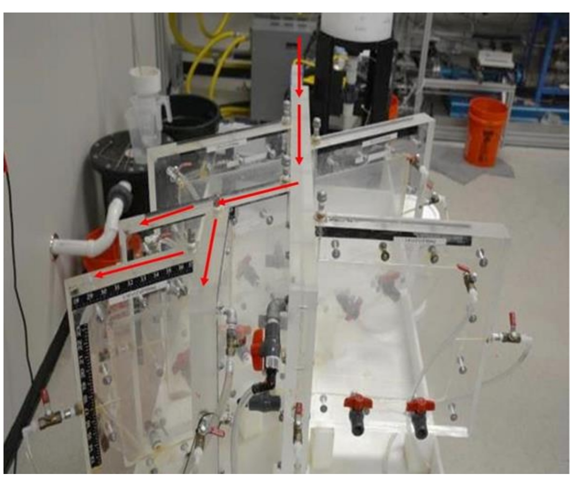

Figure 5. Slot Test assembly for dynamic suspension studies.

Frames from the video at the end of test show no proppant settling inside the assembly when flowing a 2.00 gpt LG polymer blend with a 2.00 ppa load as seen in Figure 6.

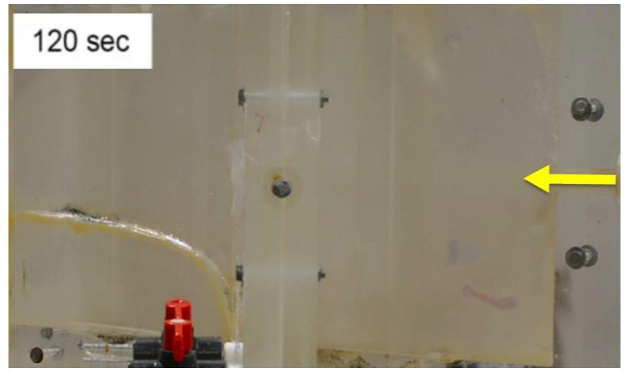

Figure 6. Slot Test of a suspension of 2.00 gpt LG slurry with 2.00 ppa showing no proppant settling.

Rotational Rheology

Rotational rheology profile for both proprietary LG (2-3 gpt) and commercial HVFR (3-6 gpt) were obtained with an automatic rheometer using API 13B procedure. LG polymer blend shows lower or similar shear thinning rheology as HVFR (Figure 7).

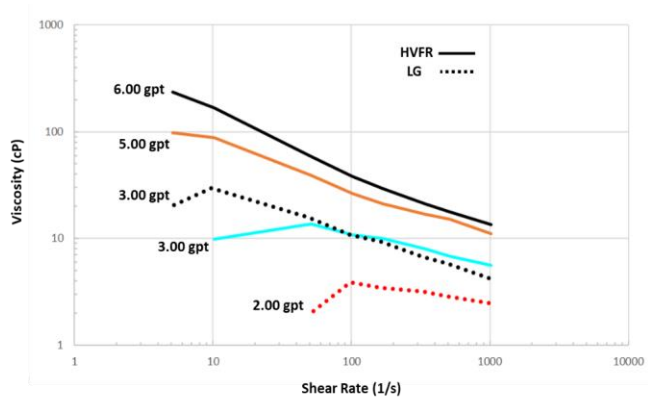

Figure 7. Comparative rheology profiles of LG blend and a commercial HVFR

Oscillatory Rheology

An oscillatory rheometer was used for specific rheological measurements of Elastic and Storage Moduli in the proprietary LG polymer . The viscosity was measured using couette geometry. The bob has a diameter of 26.663 mm, and the inner diameter of the measuring cup is 28.92 mm. The rheometer is equipped with a Peltier system, which can adjust temperatures from 104 to 400°F. Figure 8 shows the variation of G' and G" as a function of frequency at 150 ºF. This graphic demonstrates that the studied polymer blend sample formed strong gels as G' (elastic modulus) was greater than G" (viscous modulus) throughout the frequency range.

The crossover phenomenon did not occur with an increase in frequency. The polymer fluid (LG) shows a solid like behaviour, explaining in part how can a fluid with very low viscosity can be a good carrier for sand proppant.

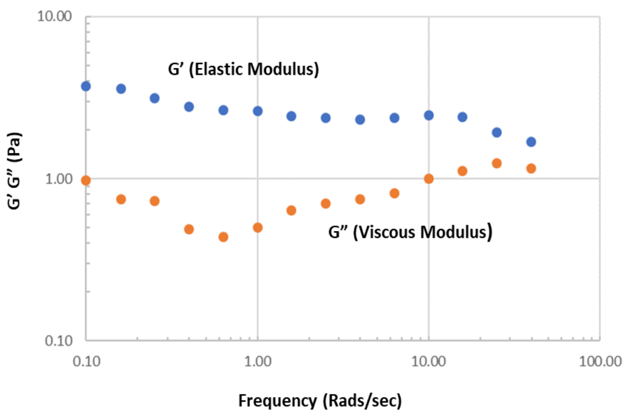

Figure 8. Oscillatory Rheology test of polymer blend sample with concentration of 17.85 ppt linear gel run @ 150 ºF, prepared with tap water as base fluid.

Conclusions

- Settling velocities calculated from MLS are 0.00853 ft/min in commercial HVFR (6.00 gpt) and 0.00565 ft/min in LG blend (2.00 gpt). If 2.00 or less gpt is used in HVFR, settling will be almost as fast as it happens in water.
- If proppant can be suspended (no settling) at least for one hour once it passes the perforations it could travel deeper along fracture paths increasing SRV.
- Elastic properties define suspension on viscoelastic fluids.
- Proprietary LG polymer blend fulfills requirements for frac fluids such as low viscosity and high carrying properties. Testing on friction reduction are underway and show promising results.
- MLS analysis shows to be very simple, accurate and reliable. Together with Slot tests should be use for settling experiments

Acknowledgments

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