National Aeronautics and Space Administration

Shear History Extensional Rheology Experiment II (SHERE II) Microgravity Rheology with Non-Newtonian Polymeric Fluids

Aditya Jaishankar,[1] Simon Haward,[1] Nancy R. Hall,[2] Kevin S. Magee,[3] Gareth H. McKinley[1]

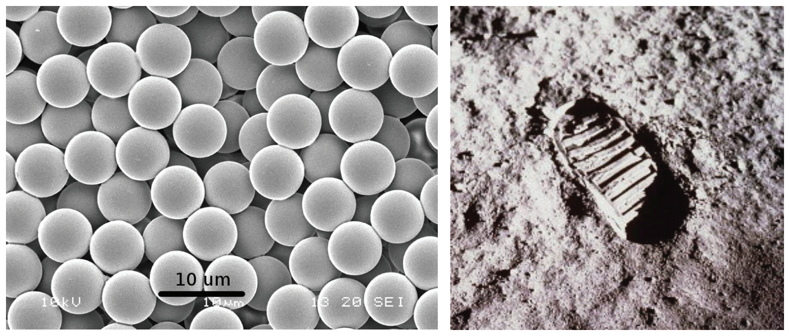
[1]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139
[2]NASA Glenn Research Center, Cleveland, OH 44135
[3]ZIN Technologies, Middleburg Heights, OH 44130

Introduction

- The primary objective of SHERE II is to study the effect of torsional preshear on the subsequent extensional behavior of filled viscoelastic suspensions.
- Microgravity environment eliminates gravitational sagging that makes Earth-based experiments of extensional rheology challenging.
- Experiments may serve as an idealized model system to study the properties of lunar regolith-polymeric binder based construction materials.
- Filled polymeric suspensions are ubiquitous in foods, cosmetics, detergents, biomedical materials, etc.

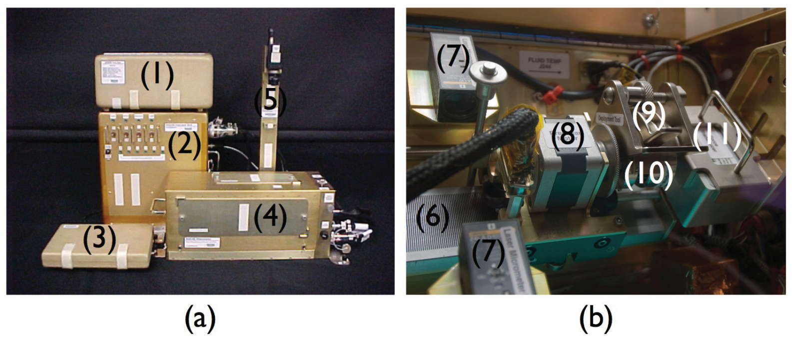
Model Fluid and Experimental Hardware

- The SHERE II test fluid consists of a dilute solution (0.025 wt.%) of 2.25×10^6 g/mol polystyrene (narrow polydispersity) in oligomeric styrene mixed with 6 μm poly (methyl methacrylate) microspheres.

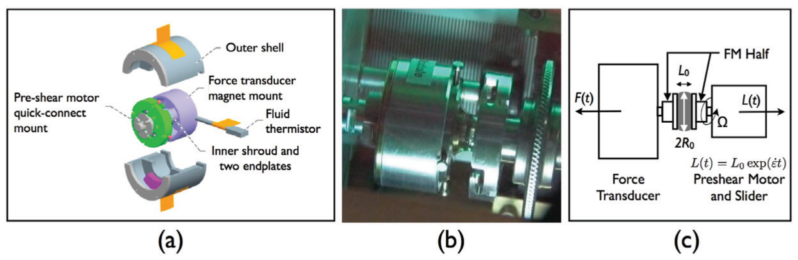


6 micron PMMS beads (left) were used to simulate the lunar regolith (right).

- Test fluid preparation and its ground-based rheological characterization was performed at Massachusetts Institute of Technology (MIT) using a TA Instruments strain-controlled ARES rheometer. The onboard extensional rheometer and other allied hardware was manufactured by ZIN Technologies.



(a) SHERE hardware including (1) tool box, (2) interface box, (3) keyboard, (4) rheometer, and (5) camera arm; (b) open view of the SHERE rheometer and (4) its components; (6) slider, (7) laser micrometer, (8) preshear motor, (9) fluid module deployment tool, (10) fluid module, and (11) force transducer equipped with lock-down fixture.

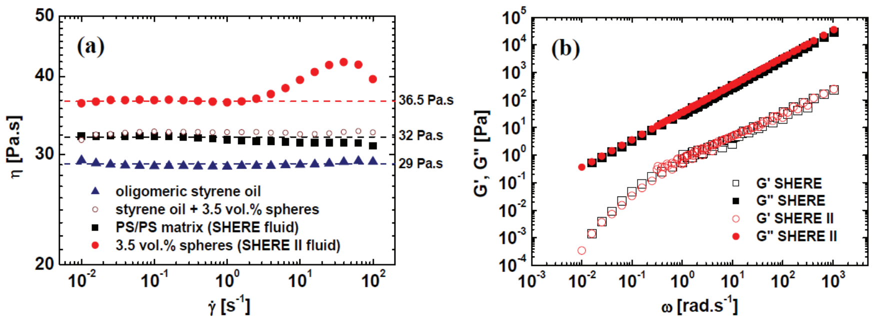


Exploded view of a fluid module (FM); (b) Exposed liquid bridge after FM deployment, and (c) schematic view of a deployed fluid column.

Results

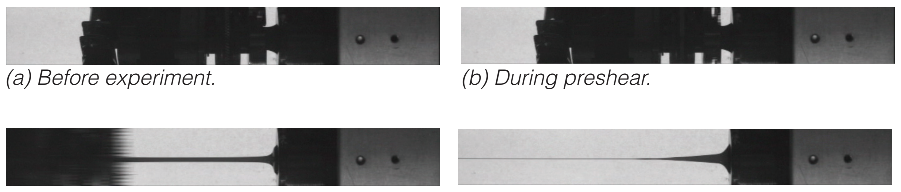
Shear Rheology

- The shear viscosity of the filled suspension is higher than that of the pure Boger fluid alone and is Newtonian over two decades of shear rate.
- The shear thickening seen at higher shear rates is possibly due to improved hydrodynamic interparticle interactions (Scirocco et al. 2005).
- Small Amplitude Oscillatory Experiments show that the fluid is dominated by viscosity.
- Addition of the particles leaves linear rheology unchanged.



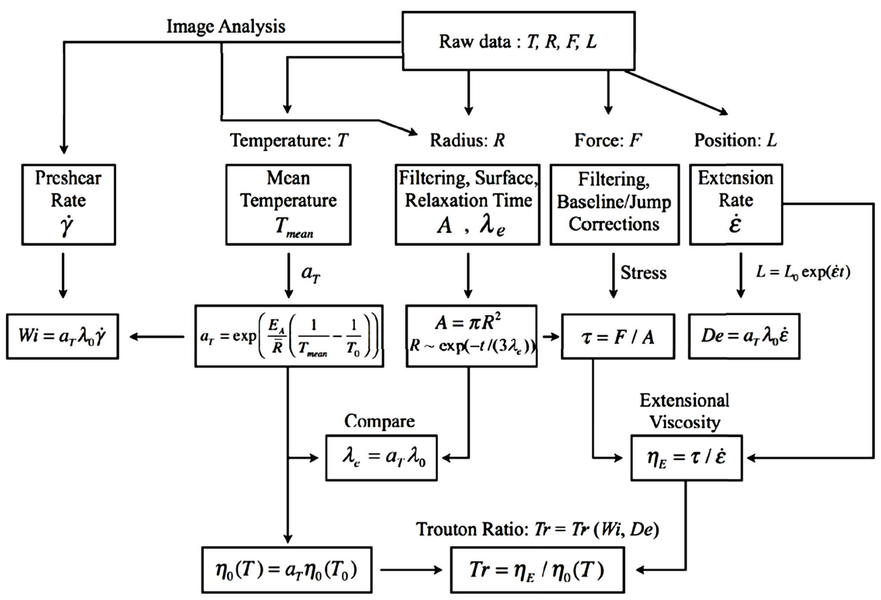
International Space Station (ISS) Onboard Experiments

- The onboard experiments consist of three distinct stages: Preshear, stretch, and capillary thinning.
- Each test point is uniquely determined through the preshear rate $\dot{\gamma}$ and the stretch rate $\dot{\varepsilon}$ (Preshear time = 30 s). 25 different test points were measured during SHERE II operations.



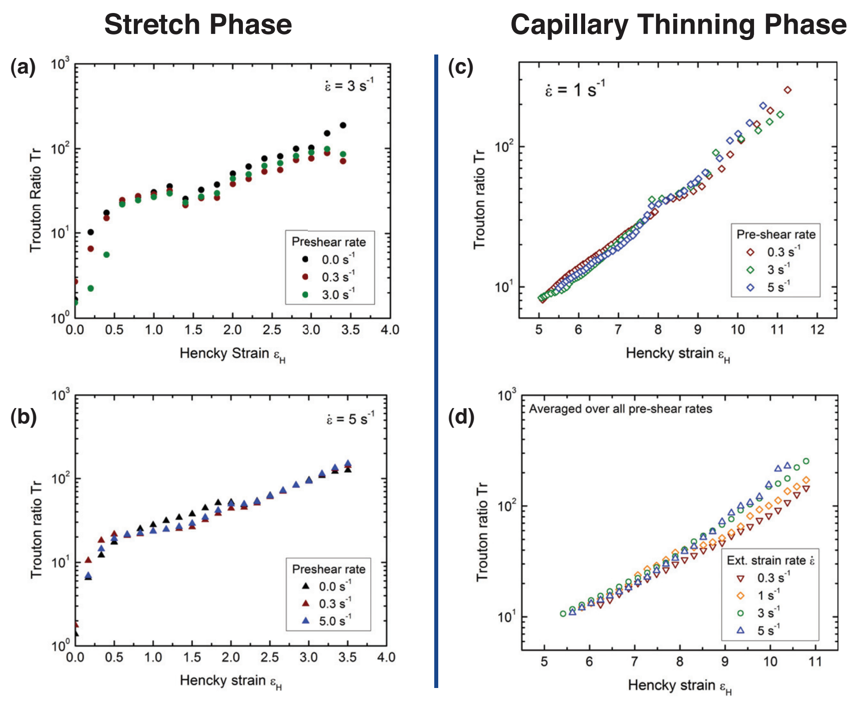
(a) Before experiment. *(b) During preshear.* *(c) During stretch (t = 0.87 s).* *(d) Filament thinning (t = 30 s).*

Snapshot of the fluid filament at the different stages of the experiment ($\dot{\gamma}$ = 3 s-1, $\dot{\varepsilon}$ = 0 s-1).



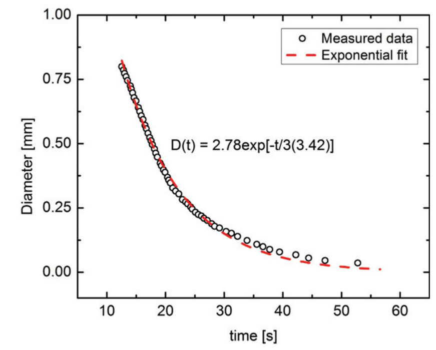
- Specialized algorithms were written to carry out the data analysis and calculation of the rheological parameters according to the flowchart above.
- From the elasto-capillary regime of the filament thinning phase, the relaxation time as well as the extensional viscosity of test fluid can be obtained.
- The stretch phase yields the extensional viscosity of the test fluid as a function of nominal strain rate.

Results



Representative results of the data analysis of the ISS onboard experiments.

- In all experiments strain hardening was observed during the stretch phase as well as the capillary thinning phase; this strain hardening arises from the extension of the polymer chains under the action of the extensional flow field.
- For a strain rate of $\dot{\varepsilon}$ = 3 s-1, it is observed that strain hardening in the stretch phase is decreased with increasing preshear rates (Figure a). This is in accordance with the literature (Anna and McKinley, 2008) and arises from the orthogonal alignment of polymer chains during preshear.
- This effect is not significant enough to manifest itself under the stronger extensional field of $\dot{\varepsilon}$ = 5 s-1, and the extensional viscosity is not a function of preshear (Figure b).
- The Trouton ratio in the capillary thinning regime is independent of the preshear rate (Figure c), indicating that the alignment effect of the chains vanish upon completion of the stretch. The Trouton ratio averaged over preshear rates increases with increasing extensional strain rate (Figure d).



Exponential fit to the elasto-capillary regime of the thinning phase of the experiment. $\dot{\varepsilon}$ = 3 s-1, $\dot{\gamma}$ = 0 s-1.

- The elasto-capillary regime of the thinning phase (where fluid elasticity balances forces due to surface tension) gives us an accurate measurement of the fluid relaxation time.

Conclusions

- Measurements of the extensional viscosity of dilute suspensions of rigid microparticles in dilute polymer solutions have been performed in microgravity. Extensional viscosity decreases with increasing preshear at moderate extensional strain rates.
- Capillary thinning measurements yield estimates of the relaxation time of the polymer-particle suspension.

References

- R. Scirocco, J. Vermant, and J. Mewis, J. Rheol, (2005), 49:551-568.
- S.L. Anna, G.H. McKinley, Rheol. Acta, (2008), 47:841-859.

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Contact: adityaj@mit.edu