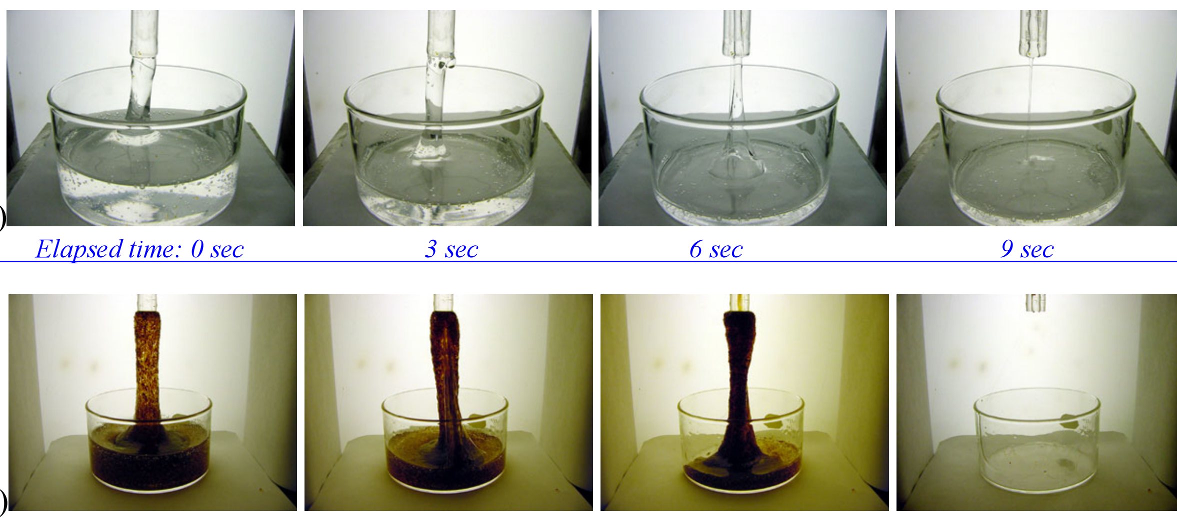
Cleanup properties of high molecular weight polymeric solutions laden with particles

Daniel D. Joseph[1]
University of Minnesota

October 2002

Part 1. White Paper

Filaments of high molecular weight polymeric solutions can support very high extensional stresses without breaking. This allows one to siphon pools of these solutions on solid or liquid substrates remotely in a tubeless siphon. The tubeless siphon is described in standard works on rheological fluid mechanics say Bird, Armstrong and Hassager 1977, Joseph 1990 and Macosko 1994. The siphon may be described as follows: a fluid is sucked through a nozzle with the nozzle elevated above the surface of the liquid. Instead of the liquid breaking as in unthickened (Newtonian) liquids like water, glycerin or oil, an unsupported fluid column is drawn from a pool below into the nozzle above without breaking as shown in figures 1 and 2.



(a) *Elapsed time: 0 sec*   *3 sec*   *6 sec*   *9 sec*

(b) *Elapsed time: 0 sec*   *3 sec*   *6 sec*   *10 sec*

Figure 1. Sequential photos of a tubeless siphon of 1% aqueous Polyox solution, (a) With no particles, the fluid is not cleaned up. (b) With a high concentration of particles, all the fluid and particles are removed. The particles are resin particles with a size in the range of 600-700 μm.
(Click on the image or blue text to view a movie or photograph.)

[1] *http://www.aem.umn.edu/people/faculty/joseph/index.shtml*

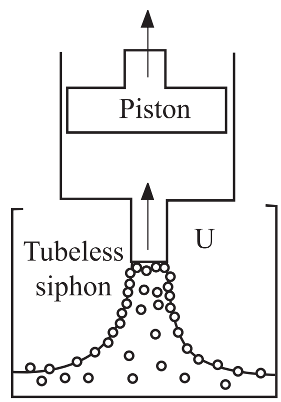


Figure 2. The schematic of the experimental set up.

We may suck the thickened (viscoelastic) liquids from a substrate remotely with a "vacuum cleaner". It appears not to have been known before our recent work (Wang and Joseph 2002) that if the rate of withdrawal, the sucking power, is high enough or if the sucking power is much lower but the liquid loaded with small particles in concentrations less than 10%, the substrate can be cleaned completely. This very remarkable cleaning property can be seen in the movies of our experiments on the CD-ROM which is included with this preproprosal.

We would like to prepare a research proposal focusing on applications for homeland defense and on scientific issues which are implied by experiments just described. The applications are to cleanup and disposal of solid and contaminated substrates. We could imagine covering a contaminated solid, a portion of an airplane or tanks, with a thickened liquid laden with particles, then sucking off the liquid, particles and contaminant remotely with a powerful vacuum cleaner newly designed for efficient removal and disposal.

We may consider the removal of particle laden thickened liquids as a competitor for foams say in Anthrax applications. If such a liquid is laid on an Anthrax contaminated surface, there is no way that the spores could be aerosolized. Moreover, it is likely that the spores would be trapped in the thickened liquid and sucked away with the liquid for safe disposal.

A second application is to the removal of oil slicks. There is a little story that goes with this. I had the idea that if I could clean solid substrates by pulling off thickened liquids, I could do the same for oil slicks. I spread motor oil on water in a petri dish and showed that I could not suck off the oil because it would break when sucked. Then I put STP on top of the oil. STP is an oil with polymer which is miscible with motor oil so the motor oil and STP mixed. STP is certainly not the best that could be used since the polymer in it does not have a very high molecular weight and is present only at less than desirable concentration. Nevertheless, the experiment worked. We pulled out the STP-oil slick mixture easily. I called the University lawyer for a patent; they did a search and found a patent which had been developed into commercial "Elastol" for the removal of oil slicks.

The Elastol people do not yet know their product could be used for cleaning solid substrates and the possible beneficial effects of adding particles.

The scientific issues and application issues are not separated strictly. We may consider parameter studies of performance to apply both to the science and applications. The parameter studies which ought to be done are as follows:

Solution properties focusing on the molecular weight, type and concentration of the polymer and the quality of the solvent polymer interactions.

Particle properties focusing on the size, weight wetting and reactivity properties. So far we used submillimeter nearly neutrally buoyant particles which were lying around the lab. What are the optimal concentrations? Can we use reacting particles? nanoparticles?

Sucking apparatus properties Since the cleaning property of siphon demands on the rate of withdrawal and since many requirements for effective manipulation, placement, storage and disposal will inevitably arise,. the design of effective sucking devices ought to be studied and implemented. We have a very good shop in this department and a very creative shop manager. We can do instrument development.

The direct science issues of the research are theoretical understanding of the fluid dynamics of tubeless siphons under realistic conditions. The role of particles in enhancement of extensional stresses is a virgin subject without a prior art. These are complicated problems which are best studied by numerical methods. I am very well connected for these kinds of numerical studies since I work and am the PI on several multi-million dollar NSF grants on the direct numerical simulation of solid-liquid flows.

I would love to be able to do research with a direct and immediate impact on problems of homeland security.

Budget

I would like $250,000 per year for three years. The budget is for:

1. Joseph's pay: one month summer, 2 months academic year
2. Grad student and Post Doc
3. Subcontract for Pushpendra Singh who is my CFD expert
4. Shop time and equipment

References

Bird, R.B., Armstrong, R.C. & Hassager, O. 1977, 1987. Dynamics of Polymeric Liquids. *Volume 1, Fluid Mechanics.* Wiley, New York.
Joseph, D.D. 1990. *Fluid Dynamics of Viscoelastic Liquids.* Applied Math Series.
Macosko, C.W. 1994. *Rheology: principles, measurements, and applications.* Wiley-VCH.
Wang, J. and Joseph, D.D. 2002. Particle-laden tubeless siphon, submitted to *J. Fluid Mech.*

Part 2. Movies of the experiments

The movies (MPG format) which may be viewed here (and at the web site*) show that solid and liquid substrates may be cleaned by sucking off polymeric liquids of high molecular weight and that loading these liquids with small particles greatly enhances this cleaning. The movies are divided into three parts.

1. Particle laden tubeless siphon. This experiment uses a piston and cylinder sucking device automated on a MTS machine. The liquid is a water-based polymer.
2. Cleaning of oil contaminated substrate with a commercial solution of polymer in oil used for oil recovery (Elastol). We demonstrate that particles enhance the cleaning property.
3. Enhancement of oil slick cleaning by adding particles to Elastol.

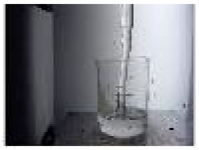
1. Particle laden tubeless siphon.

This experiment uses a piston and cylinder sucking device automated on a MTS machine. The liquid is a water-based polymer.

- 1% Poly (ethylene oxide).
- Molecular weight 8 million.
- 80 ml initial volume.
- Sucking velocity 1.22 in/min.

The first movie is without particles. The siphon breaks before all the polymer is sucked out the beaker. Every thing is the same with the second movie except that small particles were added. The cleanup with the particle-laden siphon is complete. Complete cleaning with particles.

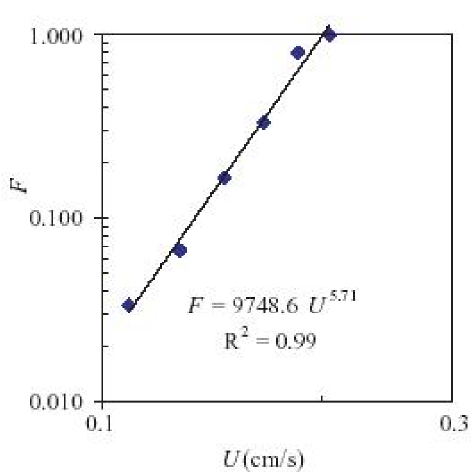
- Diameter 850 micron.
- 4% by volume.
- Neutrally buoyant.



(i) No particles)

(ii) With particles

In the case when no particles are present, one can monitor the volume of liquid left behind after the siphon breaks as a function of the rate of suction (the velocity of the piston). The suction fraction F, defined as the volume sucked out to the initial volume, increases as 5.71 power of the velocity. At a high enough velocity one gets complete cleanup, even when no particles are present.



2. Cleaning oil contaminated solid substrate with Elastol and Elastol plus particles.

We use a handheld piston in a cylinder sucking device to demonstrate the principles. There are 5 parts:

1. Oil is in the beaker. We cannot suck it out.
2. We add a small amount of Elastol to the oil.
3. We pull out the Elastol and oil but the bottom of the beaker is slightly soiled with oil.
4. We add particles to the Elastol plus oil. The particles are sub-millimeter and nearly neutrally buoyant; nothing special.
5. We pull out the Elastol, oil and particle mixture. The bottom of the beaker is cleaned.


1. Suction


2. Add Elastol


3. Suction


4. Add particles


5. Suction

3.Oil spill remediation. In the first experiment we lay down an oil slick

1. Motor oil on water in a petrie dish.
2. We cannot suck out all the oil with our sucking device, because the oil breaks.
3. We add Elastol; it mixes with the oil.
4. We can pull out the mixture, but a little slick is left.
5. We add particles to the mixture.
6. We pull out the oil-Elastol-particle mixture. It cleans up nicely, better than when there are no particles
7. Capillary attraction and self-assembly of particles in the oil-Elastol mixture. The phenomenon here is possibly fundamental to the improved performance of the particle-laden mixture.


1.Oil


2.Suction


3. Add Elastol


4. Suction


5. Add particles


6. Suction


7.Self-assembly
(photo)

[*] Part 2 is on the web: http://www.aem.umn.edu/cleanup.