Tubeless Siphon and Die Swell Demonstration

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September 26, 2004
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These notes accompany the two Quicktime movies available for download at http://web.mit.edu/nnf. Please feel free to download them for use in the classroom (non-commercial) environment. We request that you provide appropriate citation credit if you do use this material.

The Tubeless Siphon

A commonly quoted demonstration of non-Newtonian fluid phenomena is the ability of a fluid to form a *tubeless siphon* or *open siphon*. To create a tubeless siphon, a siphon is first started by inserting a nozzle (connected to a tube and vacuum source) into a dish of non-Newtonian fluid. The siphon nozzle is then raised above the free surface of the fluid, but the siphoning action continues (in marked contrast to the entrainment of air and disruption of the siphon that is seen in a Newtonian fluid such as water or corn syrup). This phenomenon is caused by non-Newtonian viscoelastic stresses (resulting from stretching of the polymer molecules in solution), which support the weight of the jet against the gravitational body force as shown in the diagram below.

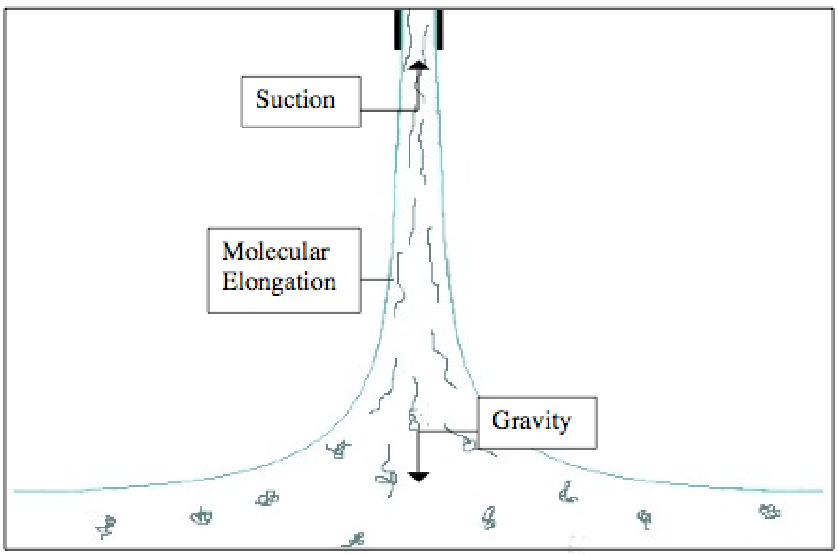


Figure 1. The molecular basis of rod climbing: viscoelastic stresses resulting from the extensional flow (generated from suction into the nozzle) balance the weight of the fluid column.

Excellent photographs of the tubeless siphon effect abound in the literature (e.g. see the work of Hoyt & Taylor and Peng & Landel in such textbooks as Bird et al. 1997, pg. 75, and Boger & Walters, 1997, pg. 29). Unfortunately, it is not trivial to set up a good unambiguous demonstration of the tubeless siphon phenomenon. The apparatus described below is simple enough that it can be set up for a grade school or high-school demonstration.

The fluid used is so-called "Moon Blob" gel, available for purchase from Edmund Scientific (http://scientificsonline.com/product.asp_Q_pn_E_3038440). The purchase price is $7.95. To quote from their website:

Moon Blob acts alive and looks like a living protoplasm as it defies gravity by crawling up and out of its container. It's dehydrated plastic – just add water to activate. Completely harmless. Great fun!

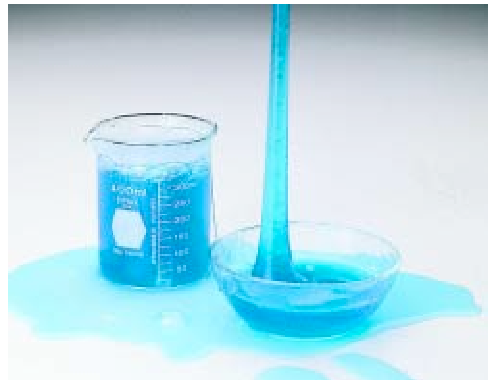
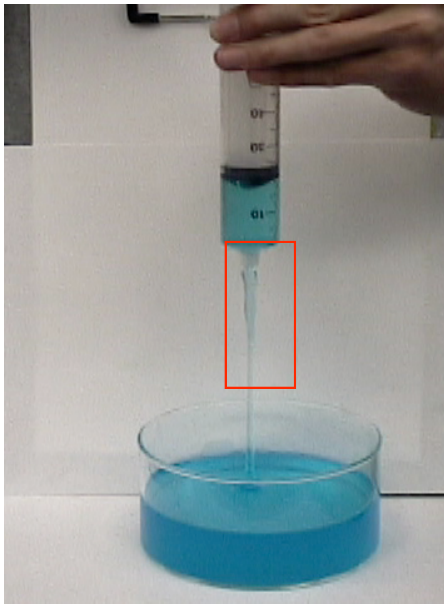


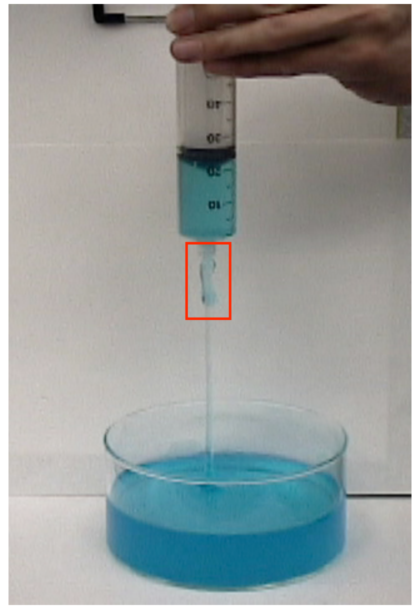
Figure 2. Moon Blob description and picture, © Edmund Scientific, 2004

All that is needed in addition to the Moon Blob polymer is a dish to hold it, a spatula to mix it, and a large plastic syringe. Syringes can be hard to find; try a local drug store or medical supply store, or a mail order company such as VWR (http://www.vwr.com, part number WLS79406-D).

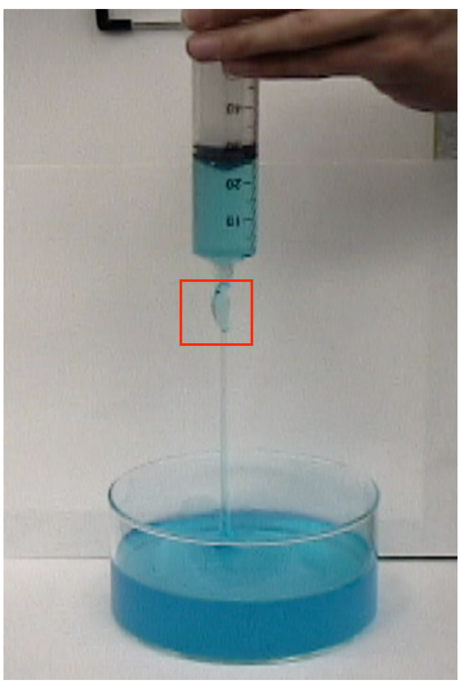
This polymer solution can be mixed up readily with tap water at the desired concentration (see package for specific directions). A hint: remember to stir vigorously as you add the powder to the water to avoid the formation of large jelly-like clumps, which dissolve extremely slowly). Such 'jellyfish' can be readily seen in the pictures overleaf – one benefit thereof is that they serve as flow tracers, which can show the upward flow, even for students at back of the classroom. Allow the solution to fully dissolve and equilibrate overnight. The resulting material can be siphoned readily. You can also (with some skill) start pouring the fluid from one glass to another; then decrease the pouring angle and see the fluid continue to siphon from one glass to another.



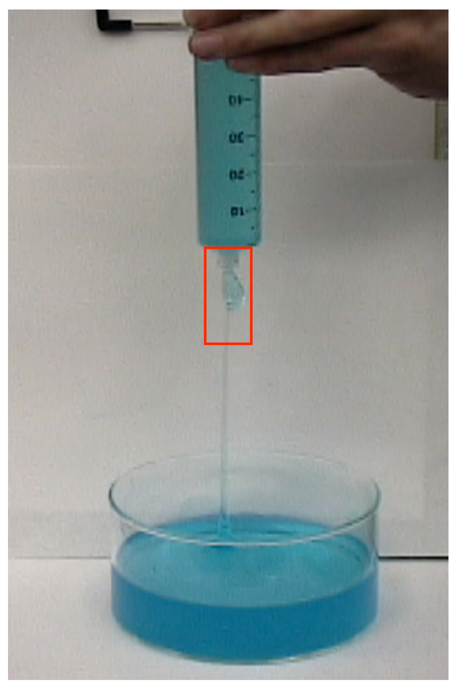
(a)



(b)



(c)



(d)

Figure 3. (a) – (d) sequence of still images showing a “jellyfish” rising along the stream tube during tubeless siphoning.

Die Swell

A closely related non-Newtonian phenomenon is known as “die-swell,” or, more correctly, “extrudate swell”. When a polymer solution if forced out of the orifice of a syringe, the jet of extrudate swells (i.e. it expands radially to a diameter much greater than that of the orifice). This is again a result of the large viscoelastic stresses in the fluid that ‘remember’ the deformation history of the fluid as it flows through the converging region of the syringe tip, and then out into the air. For additional details see Tanner (2000) or Bird et al. (1987). Figure 4 below is a schematic outline of the polymer dynamics that lead to the die-well phenomenon.

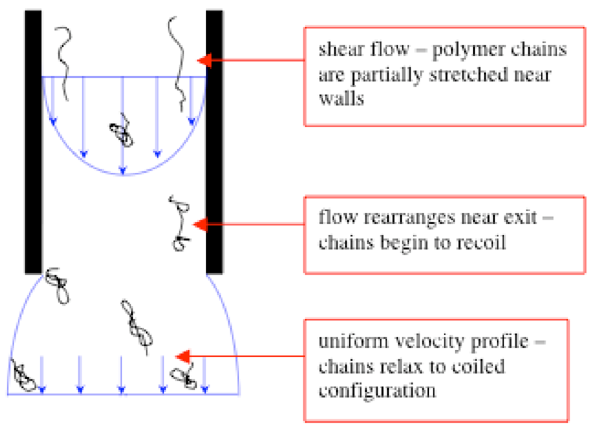
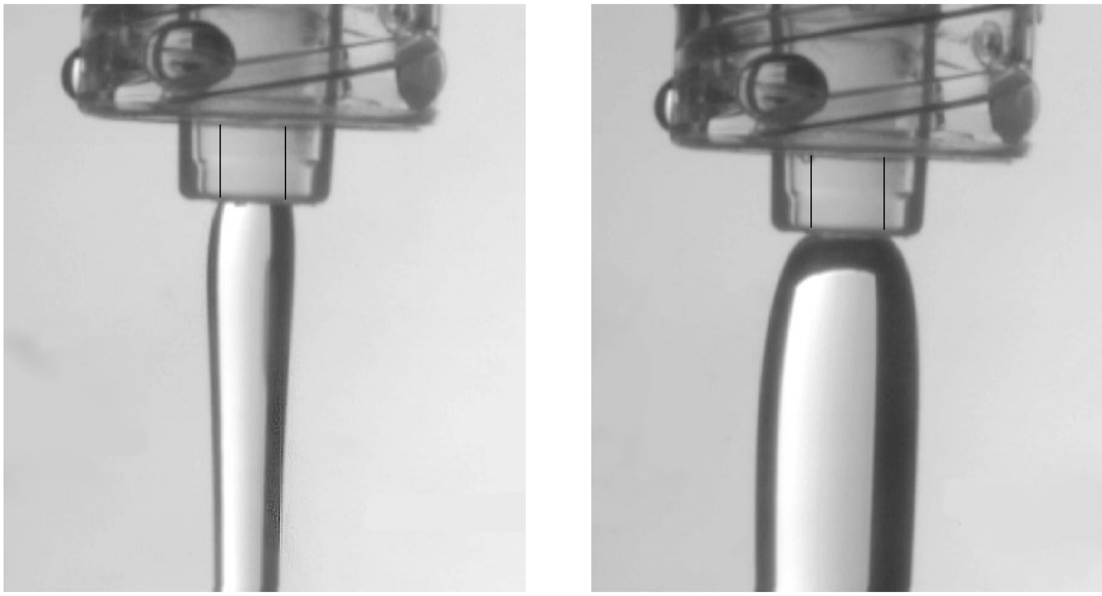


Figure 4. Schematic outline of polymer dynamics in die swell.

Below we show two images of the Moon Blob fluid being extruded through the end of the same simple plastic syringe used in the tubeless siphon demonstration. The nozzle diameter is 0.075”. The jet swells by a ratio of 1.16 when the extrusion rate is slow, as shown in Figure 5(a) below (this is close to the expected Newtonian limit of 1.13). As the extrusion rate is increased and the molecular deformation increases, so does the swell. At the faster speed shown in Figure 5(b), the swell ratio has increased to a value of 1.94.



(a) (b)

Figure 5. "Moon Blob" experiencing (a) low-speed and (b) high-speed extrudate swell during extrusion through a nozzle. Note the dramatic difference in jet diameter commonly known as "swell."

References

Bird, R.B., Armstrong, R.C. and Hassager, O., *Dynamics of Polymeric Liquids. Volume 1: Fluid Mechanics*, 2nd Edition, Wiley Interscience, New York, 1987.

Boger, D.V. and Walters, K., *Rheological Phenomena in Focus*, Rheology Series, Elsevier, Amsterdam, 1993.

Tanner, R.I., *Engineering Rheology*, Oxford Engineering Science Series, 2nd Edition, Clarendon, Oxford, 2000.