Polymer Processing, Quiz 4, 2000
2/16/00

Two identical tubes are placed vertically on a rubber mat such that a seal is made at the bottom. They are filled with two different fluids, one Newtonian and the other non-Newtonian. Explain the following behavior ("a" to "e" below) in terms of

-i) A constitutive equation which might be applicable to describe the non-Newtonian Fluid behavior.

-ii) A common example of such a fluid from your experience at home, at work or in class.

-iii) A physical model for the behavior (can be of the hand-waving type, i.e. why does this behavior occur).

-iv) The importance of the behavior to processing. (For this you might want to refer to an extruder as was done in class and note the section of the extruder where this behavior might be observed.) Some of the behaviors may not be common to polymer processing.

a) An identical small bead (low mass) is placed in each fluid and it slowly falls at the same rate in both vessels. For the same two fluids the fluid is allowed to drain from each tube by lifting the tubes from the mat and the fluid flows 4 times **faster** out of the non-Newtonian tube!

b) The fluid stream from the non-Newtonian tube seems to swell in diameter as it flows out.

c) For a different non-Newtonian Fluid, the fluid is allowed to drain in the same way but **won't drain** from the non-Newtonian tube **without an added pressure** being applied by blowing in the top of the non-Newtonian tube. (The bead won't fall in this Non-Newtonian Fluid).

d) A thin stream from the non-Newtonian tube recoils from the puddle which forms on the rubber mat after flowing out of the tube.

e) Flow from a tube under a pressure difference, ΔP, such as describe in problems a to d, is described by The Rabinowitch equation as discussed in class,

$$(d\gamma/dt)_{wall} = (1/\pi R^3)\ [3Q + \Delta P\ (dQ/d(\Delta P))]$$

$$\tau_{wall} = \Delta PR/(2L)$$

The Rabinowitch equation can be used to obtain Poisseuille's Law.

-What is assumed to obtain Poisseuille's Law?

-What is Poisseuille's Law for viscosity?

-Can Poisseuille's Law be applied to both the Newtonian and the Non-Newtonian Fluids of problems a-d?

Quiz 4, **ANSWERS** Polymer Processing 2000

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a.) i) This is shear thinning behavior which could be described with a power-law model:

$$\eta(d\gamma/dt) = m\,(d\gamma/dt)^{n-1}$$

n is generally near 0.5, i.e. less than 1.
ii) Shampoo flows this way.
iii) Structuring of the fluid by orientation in the direction of flow reduces viscosity with higher shear rate.
iii) High-shear rate processing conditions such as in the die of an extruder.

b.) i) The CEF equation would be used to empirically model this system.

$$\psi_1 = \Psi_1 \dot{\gamma}^2$$

$$\psi_2 = \Psi_2 \dot{\gamma}^2$$

ii) Shampoo displays this behavior as to most polymer melts under high shear rate.
iii) Structuring of the fluid by orientation under high shear leads to an entropic normal force response.
iv) Die swell from the die of an extruder. Also pressure build up in the extruder barrel.

c.) i) Bingham Fluid behavior, a yield stress is observed.

$$\eta(\dot{\gamma}) = \eta_0 + \frac{\tau_y}{\dot{\gamma}}$$

ii) Ketchup and electrorheological fluids. Clay gels display this behavior as do gel toothpastes and gel shampoo.
iii) Structuring of the fluid in the static state leads to the presence of a yield stress. The structuring is usually due to ionic interactions of colloidal particles but can also be due to applied fields such as in electro-rheological fluids.
iv) Not common to polymer processing. This is important to gelled systems or systems undergoing crosslinking.

d.) i) The Maxwell LVE model would be used to empirically model this system.

$$\tau + \lambda_0\, d\tau/dt = \eta_0\, d\gamma/dt$$

ii) Most polymer melts display this behavior to some extent. Shampoo, molasses and pancake syrup show this behavior.
iii) The fluid is showing some elastic response which is related to an entangled network being formed. Temporary crosslinks (entanglements) are the cause of this behavior.
iv) This behavior is observed in fiber drawing, film blowing and in many other features of polymer melts.

e.) The assumption is that the fluid is Newtonian so that $\Delta P\,(dQ/d(\Delta P)) = Q$ and

$(d\gamma/dt)_{wall} = (1/\pi R^3)\ [4Q]$
and
$\eta = \pi \Delta P R^4/(8QL)$
Poisseuille's Law will only work for the Newtonian Fluid case.