Final Polymer Processing Monday March 13, 2000

1) In the viscometer lab we measured torque, Tor, versus angular velocity, ω, at various temperatures.

a) **-Sketch** a simple flow analogy for this viscometer by expanding the gap region. Show in this sketch **i) the direction** of force, **ii) the area** force is applied to, **iii) the direction** of velocity and **iv) the direction** of change in velocity.
-How are torque and angular velocity related to viscosity in this viscometer? (This can either be full equations or proportionality)
-For 12 rpm we used a conversion factor of 25 to obtain viscosity. What conversion factor would be needed for 60 rpm?

b) -**Give** an example of a polymer processing situation (i.e. a piece of equipment and the position in this equipment) where a flow situation is encountered that is similar to the flow in the viscometer used in the lab.
-Your answer should include a sketch of the processing equipment and a comparative sketch of the viscometer used in the lab showing equivalent flow positions.
-What are the differences (at these flow positions) between the processing equipment and the viscometer?

c) A similar viscometer is used to determine the "melt stability" of a polymer melt as a function of time at the processing temperature. (Melt stability is a measure of degradation.)
-How do you expect angular velocity to change as a function of time in this instrument?
-How do you expect torque to vary as a function of time?
-At very long times it is observed that the rate of change of viscosity dramatically decreases with time. What might be the reason for this dramatic change in rate of change in velocity at very long times?

d) We measured the dependence of torque in angular velocity.
-What function describes the dependence of torque on angular velocity?
-List the assumptions involved in this function.
-Give one alternative function that could describe this relationship in other viscometers.

e) We also measured the temperature dependence of viscosity in this lab.
-What general function describes the change in viscosity with temperature? (give equation)
-What function describes the change in viscosity for a Polymeric fluid with temperature? (eqn.)
-What is the difference between these functions at a temperature far above the glass transition temperature (say 150C° above T_g)?

2) 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?

3) We ran several processes in lab including **1) injection molding**, **2) film blowing**, and **3) fiber spinning**.

a) In all three of these processes the process limiting step involved thermal transport.
-Explain for each of these three why thermal transport is the process limiting step.
-In your answer give specific examples of where **you observed** process limitations involving thermal transport.

b) **-Give two equations**, one from thermodynamics and one from kinetics that relate to thermal transport in a semi-crystalline polymer such as HDPE.
-How do these two equations limit each of the three processes?

c) For each of the three operations:
-draw a simple (2 axis) processing window showing where thermal transport limits the operation. One axis should be temperature and the other should be related to time since thermal transport is kinetic (involves rate).

d) Polymers require unique processing equipment because of their unique physical features, some of which involve thermal transport. Compare (make a table with comments) a ceramic such as silica glass, a metal such as silicon, and a polymer such as HDPE in terms of:
-Thermal transport
-Temperature dependence of Flow.
-Shear dependence of Flow.
-Rate of crystallization/ability to form a glass.
-Compressibility (pressure dependence of flow).
-Orientation of molecules/atoms/crystals in processing operations.

e) **Give** examples of how the special features of question "d" lead to special processing equipment for polymers.
-Compare for example, formation of a silicon boule, a silica glass window by the float glass process and blow molding of a milk jug.
(**-you can** use other examples if you are not familiar with boule formation or the float glass process.)

Answers: Final 3/13/00

2) **Quiz 5, Polymer Processing 3/1/00**

a) Die Swell. The polymer coils are oriented in the shear direction in the die. When shear stops the coils return to a random (close to spherical) shape, expanding laterally driven by entropy. This entropic restoring force makes the polymer stream expand laterally. The behavior is similar to how an elastic band expands laterally after a strained state is released. The CEF equation describes this behavior and the generalized constitutive equation is $\psi_1 = \Psi_1(d\gamma/dt)^2$, where ψ_1 is the first normal stress difference, $\psi_1 = \tau_{22}-\tau_{11}$.

b) The cone-and-plate viscometer is the best to obtain Ψ_1 since it is the only viscometer where a simple measurement can result in the normal stress difference. $\psi_1 = 2F_0/(\pi R_0^2)$, where F_0 is the force pushing upwardon the shaft of the cone and R_0 is the radius of contact of the polymer melt with the cone and plate. The shear rate is given by Ω/β where Ω is the angular velocity and β is the cone angle. The shear stress is calculated by the torque T on the shaft and R_0, $\tau = 3T/(2\pi R_0^2)$.

The Couette viscometer could measure the normal stress if pressure taps were inserted in the wall of the cup. This is a less reliable measurement since the pressure taps interfere with the flow. Normal stress can not be measured in a capillary rheometer.

$\eta = \tau/(d\gamma/dt) = 3T\beta/(2\pi\Omega R_0^2)$ and $\Psi_1 = \psi_1/(d\gamma/dt)^2 = 2F_0\beta^2/(\pi\Omega^2 R_0^2)$

c) Fiber spinning is like simple extensional flow. For simple elongational flow $\gamma'_{11} = 2\ d\varepsilon/dt$, $\gamma'_{22} = -\ d\varepsilon/dt$, and $\gamma'_{33} = -\ d\varepsilon/dt$.

d) A constant strain rate could be achieved in a tubing arrangment where 6 tubes meet at a point of simple elongational flow. Two sets of opposing tubes flow in with half the flow rate each of two opposing tubes that flow out.

The mechanical arrangement is basically a tensile strain sample. A constant strain rate can only be achieved if the crossheads in the tensile strain measurement move at an exponentially increasing function of time. The latter can not be easily achieved.

e) The Trouton viscosity is a measure of the melt strength. It is 3 times the Newtonian viscosity and is not a function of strain rate. The ratio of the non-strain rate dependent Trouton viscosity and the strain rate dependent viscosity for a polymer melt as a function of the rate of strain is an indication of the "spinnability" or "blowability" of a polymer melt. The ability to form fibers from polymer melts is related to a large value for this ratio in power-law fluids at high rates of strain.0