Quiz 5, Polymer Processing 3/1/00

You are working for Cooper Tire in the manufacture of polyester fibers. The operation uses a die with a circular diameter of 5 mm. The fibers are extruded and then drawn in the melt state to a diameter of 0.3 mm and rapidly quenched to the crystalline state. The operation runs at a rate of 100 ft/minute on the take-up roll.

a) It is noticed that the fiber diameter just after extrusion is 1.4 times the die diameter.
-Explain this observation.
-How would you explain the physical basis for this phenomena on a molecular level to a technician running the fiber spinning machine?
-What constitutive equations would be used to describe this phenomena?

b) **-Which viscometer** would be best to obtain the constitutive parameters necessitated by your answer to part "a"?
-Why are other viscometers not as useful?
-What parameters are measured/adjusted in this viscometer (i.e. what is the raw data).
-Give an equation that relates these raw data to the viscosity.

c) **-What type of** ideal elongational flow is important to fiber spinning?
-What components of the velocity gradient tensor are non-zero for this flow?

d) **-Could you** generate a constant strain rate in an elongational flow of this type?
-Sketch a flow tubing arrangement that can generate this flow.
-Sketch a mechanical arrangement that could generate this type deformation.
-For a constant strain rate, what is the problem with the mechanical experiment?

e) Given a series of polyesters:
-How would you determine better candidates for this fiber spinning operation? (What constitutive parameters are important and how could they be measured or estimated?)

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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