Polymer Processing
Quiz 2, 1/23/2000

In house paint it is desirable to have a fluid that spreads easily under shear, during painting, while having a high viscosity under low shear, such as after being applied to a wall under creeping flow due to gravity. The rheological properties desired in a house paint are close to the typical viscosity dependence of a high molecular weight polymer.

a) Sketch the viscosity of a typical polymeric fluid (high molecular weight and an oligomeric fluid (low molecular weight) as a function of shear rate.
   Define the "Newtonian plateau viscosity" in this sketch.
   Give a constitutive equation that describes the flow behavior of a polymer at high rates of strain.
   What is responsible for the polymeric behavior in shear rate?

b) The Deborah number, De, for a given polymer in a given process is the ratio between the polymers relaxation time and the experimental time. The relaxation time is the time required for a polymer to relax to a random conformation from an elongated conformation, and the experimental time is often taken as the inverse of the rate of strain.
   Show in the sketch of "question a", where De << 1, De = 1, and De >> 1.
   For house paint show where creeping flow and painting (application) flow should fall (i.e. what is the desired De for each of these )?

c) You might consider the application of paint to a wall as crudely similar to parallel plate flow.
   Sketch parallel plate, laminar flow as shown in class (define a coordinate system).
   Show in this sketch the direction of motion of one plate and it's velocity, V_0.
   Show the velocity distribution across the gap between plates.
   Show the direction of force and the normal to the area that define shear stress.
   Show what part of this sketch defines the rate of strain.

d) The zero shear rate viscosity of linear chain molecules shows a transition in molecular weight at about 10,000 g/mole.
   Sketch the zero shear rate viscosity versus molecular weight showing this behavior.
   Write equations for the viscosity below and above this transition.
   What is responsible for this transition in behavior?
   Show on this plot where a good material for house paint would lie?

e) The temperature dependence of viscosity for a fluid such as water is described by the Arrhenius equation, \( \log \left( \frac{\eta(T)}{\eta_\infty} \right) = \frac{T_a}{T} \), where \( T_a \) is called an activation temperature for flow. For a polymeric fluid \( \log(a_T) = \log(\frac{\eta(T)}{\eta_a}) = \frac{T_a}{(T-T_v)} - C \), where \( T_v \) is called the Vogel temperature, C is a constant and \( a_T \) is the time/temperature shift factor.
   How do the two temperature dependencies differ? (Consider the limits in temperature of the two equations.)
   Is there any importance of this to paints?
\[ \eta = m \left( \frac{dv}{dy} \right)^{P-1} \] at high rates of strain.

b) See figure above.

c)
Area is Plate Area, $A_y$

Force applied to Top Plate $F_x$

Fluid Velocity Profile of Fluid

Bottom Plate Fixed

\[ \tau_{xy} = \frac{F_x}{A_y} \]

\[ \gamma_{xy} = \frac{dx}{dy} \]

\[ \tau_{xy} = \eta \dot{\gamma}_{xy} \]

\[ \dot{\gamma}_{xy} = \frac{dv_x}{dy} \]
d) See Notes:
Arrhenius for water:
\[ \frac{\eta}{\eta_s} = \exp(C/T) \]
WLF
\[ \log(a_t) = C_1(\Delta T)/(C_2 + \Delta T) \quad \text{or} \quad \frac{\eta}{\eta_s} = \exp(C_1(\Delta T)/(C_2 + \Delta T)) \]
\[ a_t = \frac{\eta}{\eta_s} \]
- The two functions show similar behavior away from \( T_0 \).

e) \[
\nabla v = \begin{pmatrix}
\frac{\partial v_1}{\partial x_1} & \frac{\partial v_2}{\partial x_1} & \frac{\partial v_3}{\partial x_1} \\
\frac{\partial v_1}{\partial x_2} & \frac{\partial v_2}{\partial x_2} & \frac{\partial v_3}{\partial x_2} \\
\frac{\partial v_1}{\partial x_3} & \frac{\partial v_2}{\partial x_3} & \frac{\partial v_3}{\partial x_3}
\end{pmatrix}
\]
\[ \text{Del } v = 1/2(d\gamma/dt + \text{del } \omega) \]
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\[ \text{del } \omega \text{ is the difference between del } v \text{ and its transpose.} \]
the rate of strain is the sum of del \( v \) and its transpose.