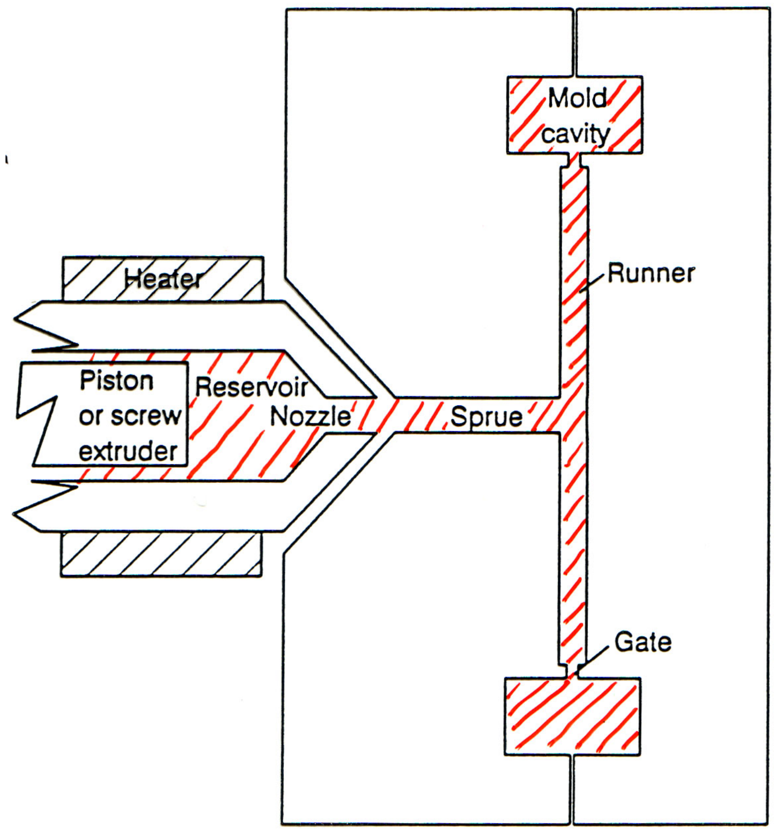
Polymer Processing

Example 1 Dissolve a polymer and apply it as a thin film on a substrate (coating)

Example 2 Melt a polymer and force it into a desired shape (molding)
Injection Molding



Both examples require three ingredients:

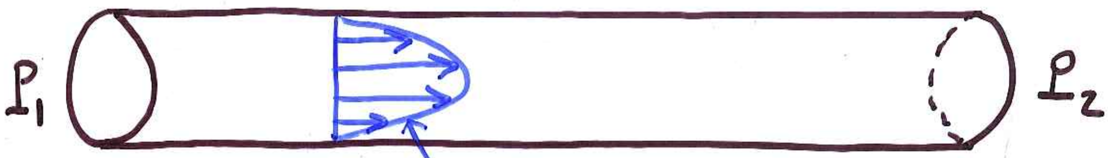
1. Fluid Mechanics - What rules govern fluid motion?

2. Rheology - Specific material properties.

3. Processing Equipment - Geometry, rate, pressure, etc.

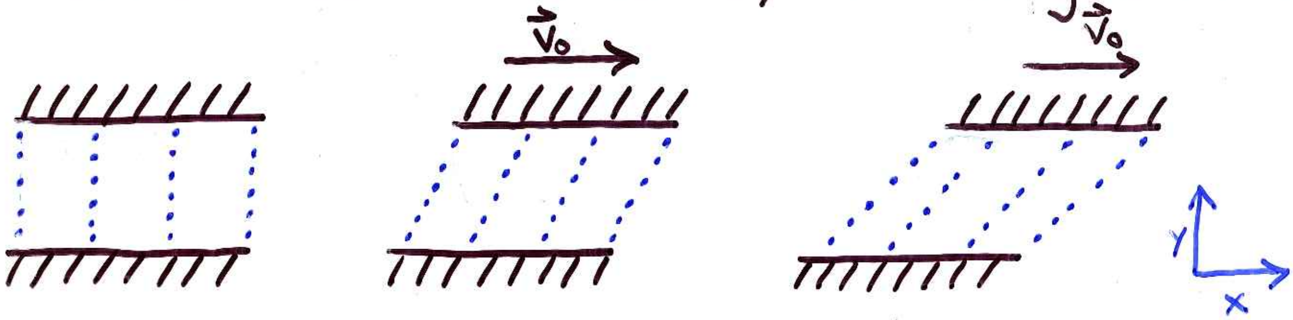
EXAMPLES OF FLOW

Poiseuille Flow : driven by a pressure



$P_1 > P_2$

Couette Flow : driven by a moving surface



$t=0$ $\quad$ $t_1>0$ $\quad$ $t_2>t_1$

All velocity in x-direction

At $y=0$ (bottom, stationary plate) $\vec{V}=0$

At $y=h$ (top, moving plate) $\vec{V}=\vec{V}_0=V_0\vec{i}$

these are "no-slip" boundary conditions

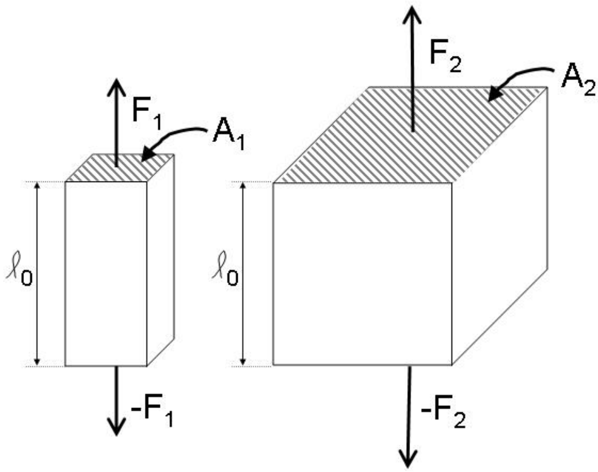
Velocity in fluid $\vec{V}=V_x\vec{i}+V_y\vec{j}+V_z\vec{k}$

$V_y=V_z=0$

$V_x=V_0\,y/h$

called SIMPLE SHEAR flow

Stress and Strain in Extension for Elastic Solids



Stretch each from initial length ℓ_0 to final length ℓ

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \qquad \therefore F \sim A \quad \text{define stress} \quad \sigma_e \equiv F/A \tag{1}$$

Stretch same bar to different final lengths.

$$F \sim \Delta\ell/\ell_0 \qquad \Delta\ell = \ell - \ell_0 \tag{2}$$

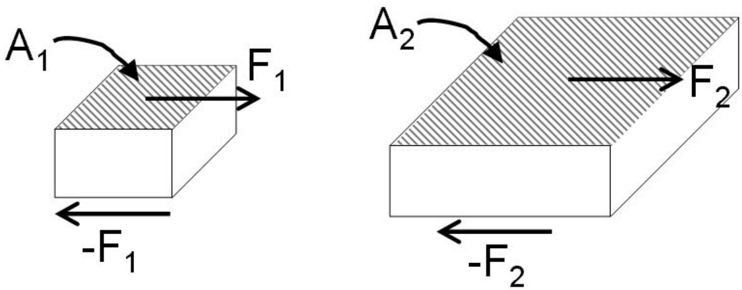
define extensional strain $\varepsilon \equiv \Delta\ell/\ell_0$

Hooke's Law for Elastic Solids:

$$\sigma_e = G_e \varepsilon \tag{3}$$

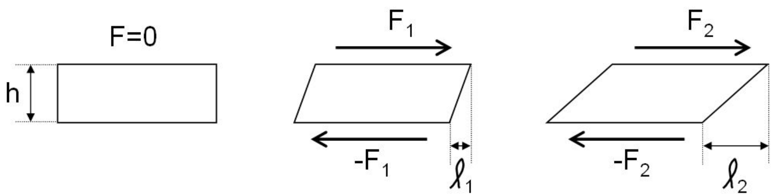
G_e is the extensional modulus

Stress and Strain in Shear for Hookean (elastic) Solids



Force F applied over area A

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \qquad \therefore F \sim A \quad \text{define shear stress} \quad \sigma_s \equiv F/A \tag{4}$$



$$F \sim \frac{\ell}{h}, \text{define shear strain} \gamma \equiv \ell/h \tag{5}$$

Hooke's Law in Shear:

$$\sigma_s = G_s \gamma \tag{6}$$

G_s is the shear modulus

$$G_e = 3G_s \tag{7}$$

Modulus is a **material property** of a solid.

Mechanical Properties of Newtonian (viscous) Liquids

Stress and **strain** are defined in the same ways for all materials.

Hooke's Law does not hold for liquids.

Newtonian liquids have no shape memory.

$\therefore$ Stress is not determined by strain.

Stress in a Newtonian liquid is proportional to the rate of strain.

Extension rate $\dot{\varepsilon} \equiv d\varepsilon/dt$

Shear rate $\dot{\gamma} \equiv d\gamma/dt$

Newton's Law for Viscous Liquids:

$$\sigma_e = \eta_e \dot{\varepsilon} \qquad \sigma_s = \eta_s \dot{\gamma} \tag{8}$$

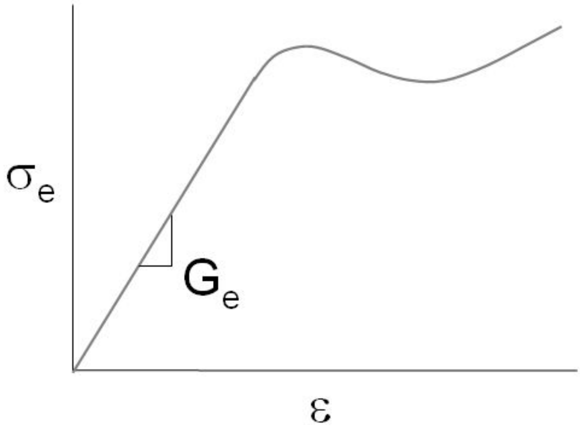
η_e = extensional viscosity

η_s = shear viscosity

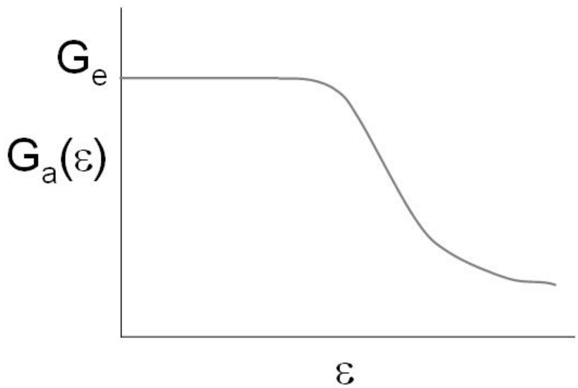
Trouton's Rule: $\eta_e = 3\eta_s$

Viscosity is a material property of a liquid.

Stress and Strain for a Polymer Solid

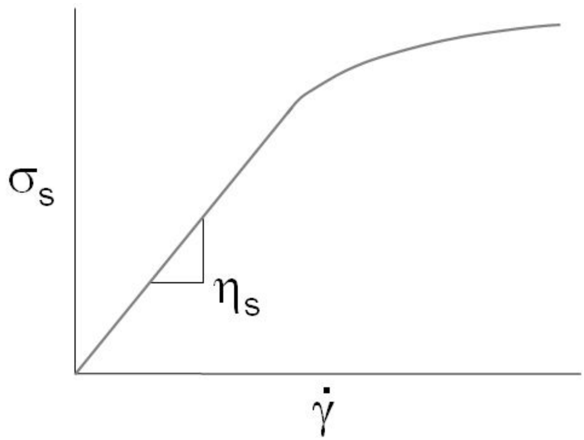


Apparent Modulus $G_a(\varepsilon) \equiv \frac{\sigma_e(\varepsilon)}{\varepsilon}$

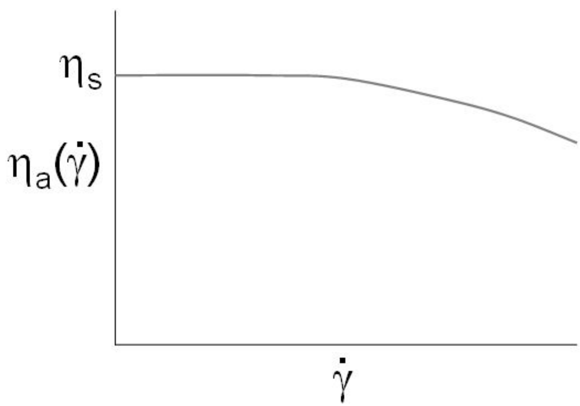


Generalization of the concept of a modulus to the regime of non-linear response.

Stress and Strain for a Polymer Liquid



Apparent Viscosity $\eta_a(\dot{\gamma}) \equiv \frac{\sigma_s(\dot{\gamma})}{\dot{\gamma}}$



Generalization of the concept of a viscosity to the regime of non-linear response.

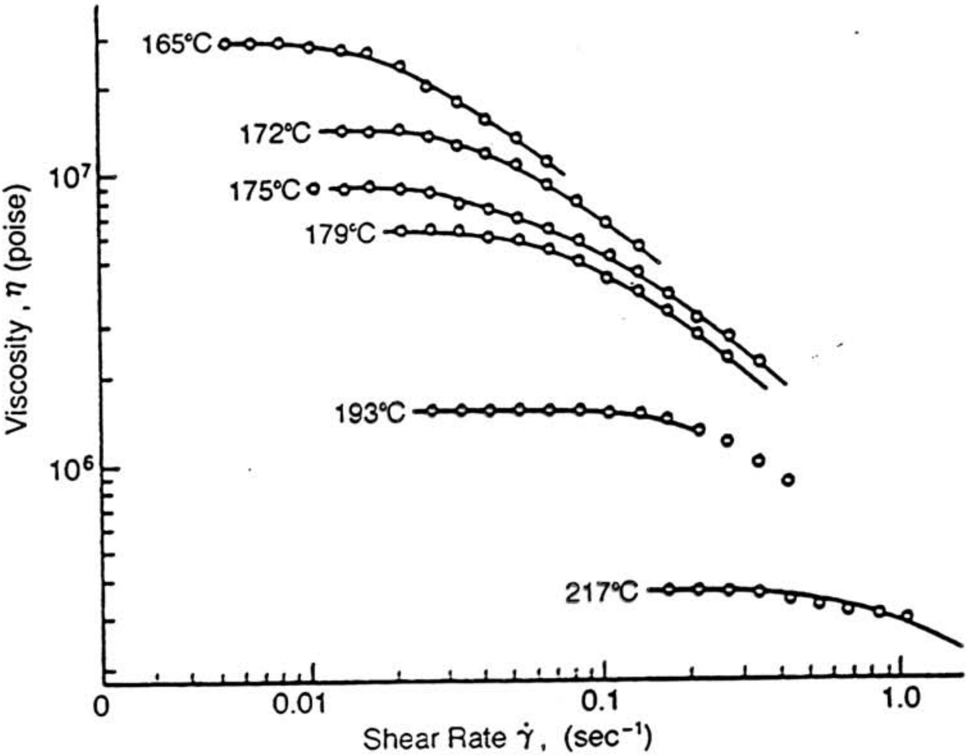


FIGURE 26. Viscosity versus shear rate for a nearly monodisperse polystyrene at several temperatures. (Reproduced with permission from reference 17. Copyright 1974 John Wiley and Sons, Inc.)

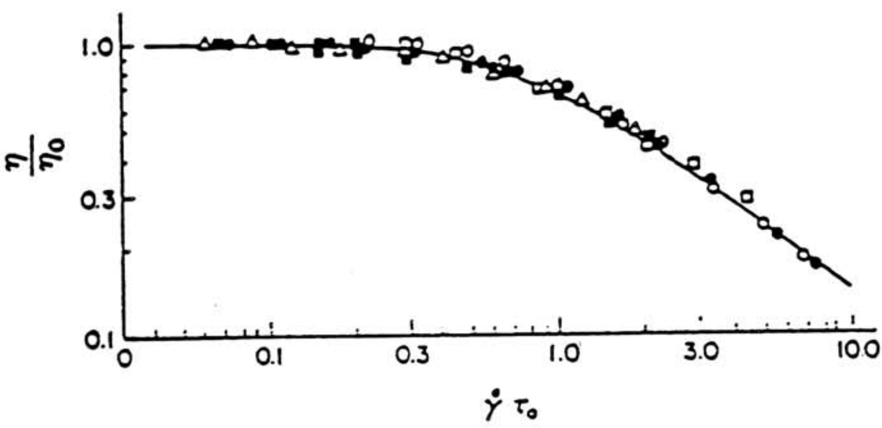


FIGURE 27. Viscosity–shear rate master curve for results shown in Figure 26. The various symbols represent data obtained at different temperatures. (Reproduced with permission from reference 17. Copyright 1974 John Wiley and Sons, Inc.)