Applied Fluid Mechanics

Chapter 2

Viscosity of Fluids

Amjad El-Qanni, PhD

Spring 2022/2023

Viscosity is a fluid property indicating the ease with which a fluid pours or flows.

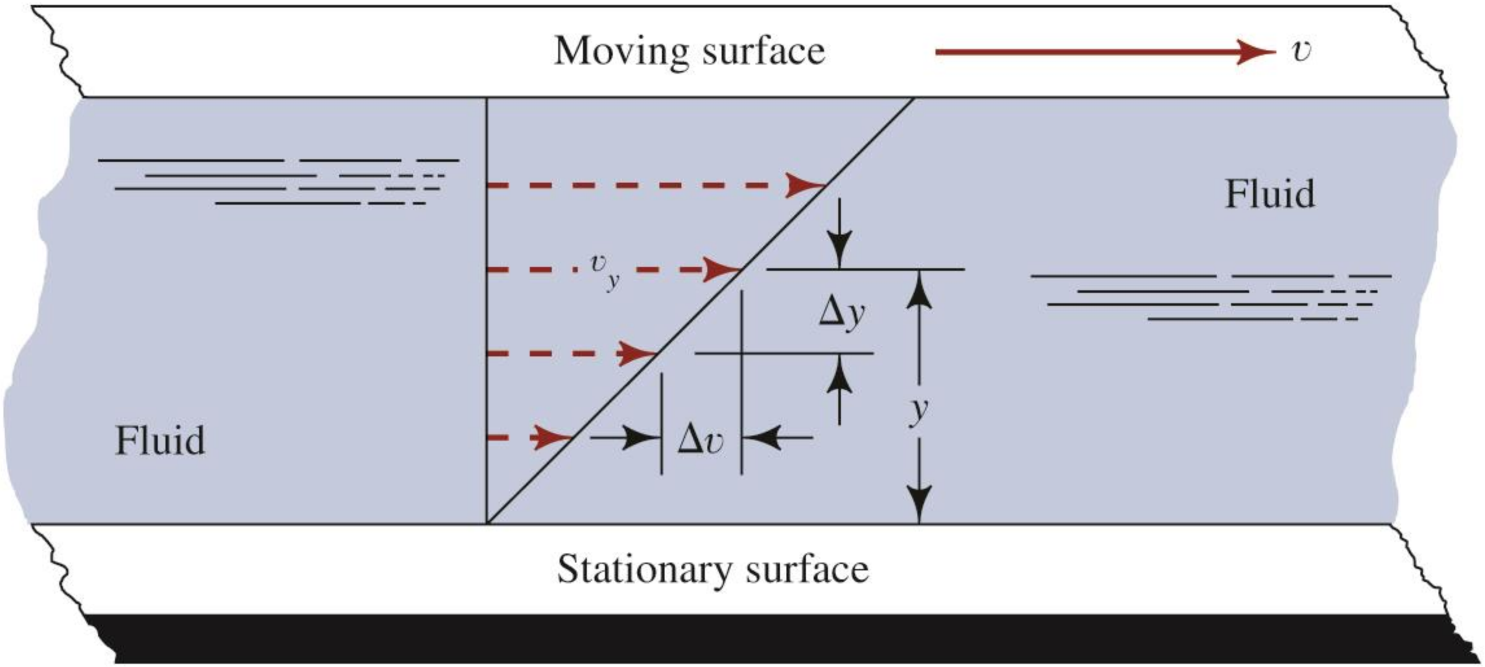
- Oil and honey are both used as examples of highly *viscous* fluids
- *All* fluids have viscosity, though, even gases.
- This property greatly affects fluid behavior in engineering systems

Fluid Viscosity

- As a fluid moves, layers of fluid must separate from the neighboring layers, and therefore a shear stress is developed in the fluid.
- This shear stress, represented with a Greek tau (τ), is a force divided by an area.
- In most fluids, the magnitude of the shearing stress is proportional to the change in velocity between different positions in the fluid.

Velocity gradient in a moving fluid

$$\tau = \eta(\Delta v / \Delta y)$$



Viscosity is expressed in two different formats *Dynamic* and *Kinematic* Viscosity.

Units for dynamic viscosity, η (Greek letter eta)

Unit System	Dynamic Viscosity (η) Units
International System (SI)	$N \cdot s/m^2$, $Pa \cdot s$, or $kg/(m \cdot s)$
U.S. Customary System	$lb \cdot s/ft^2$ or $slug/(ft \cdot s)$
cgs system (obsolete)	$\text{poise} = dyne \cdot s/cm^2 = g/(cm \cdot s) = 0.1\ Pa \cdot s$ $\text{centipoise} = \text{poise}/100 = 0.001\ Pa \cdot s = 1.0\ mPa \cdot s$

Kinematic Viscosity, *v* (Greek letter nu)

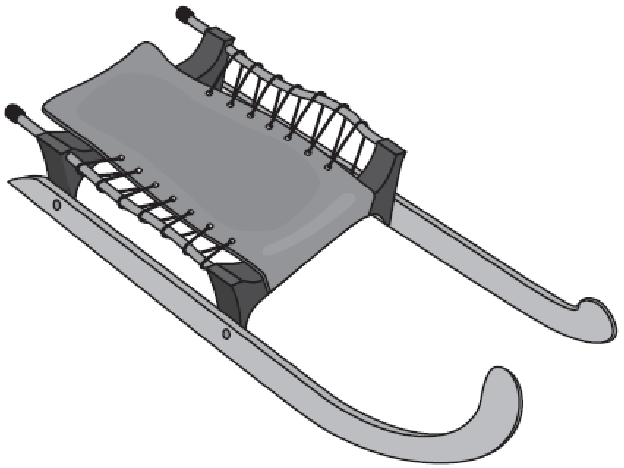
Since many fluid calculations involve the ratio of the dynamic viscosity to the density of the fluid, this ratio is often used and is referred to as kinematic viscosity.

$$v = \eta / \rho$$

Unit System	Kinematic Viscosity (ν) Units
International System (SI)	m^2/s
U.S. Customary System	ft^2/s
cgs system (obsolete)	stoke = $cm^2/s = 1 \times 10^{-4}\ m^2/s$ centistoke = stoke/100 = $1 \times 10^{-6}\ m^2/s = 1\ mm^2/s$

Example 1 – Viscosity

The sled shown in the figure slide along on a thin horizontal layer of water between the ice and the runners. The horizontal force that the water puts on the runners is equal to 1.2 lb when the sled's speed is 50 ft/s. The total area of both runners in contact with the water is 0.08 ft^2, and the viscosity of the water is 3.5×10^{-5} $lb.s/ft^2$. Determine the thickness of the water layer under the runners. Assume a linear velocity distribution in the water layer.



Pearson

Example 2 – Viscosity

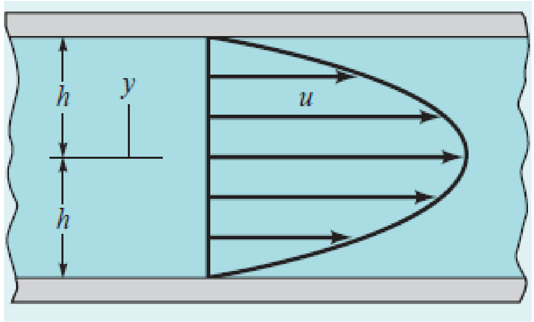
The velocity distribution for the flow of a Newtonian fluid between two wide parallel plates is given by the equation:

$$u = \frac{3v}{2}\left[1 - \left(\frac{y}{h}\right)^2\right]$$

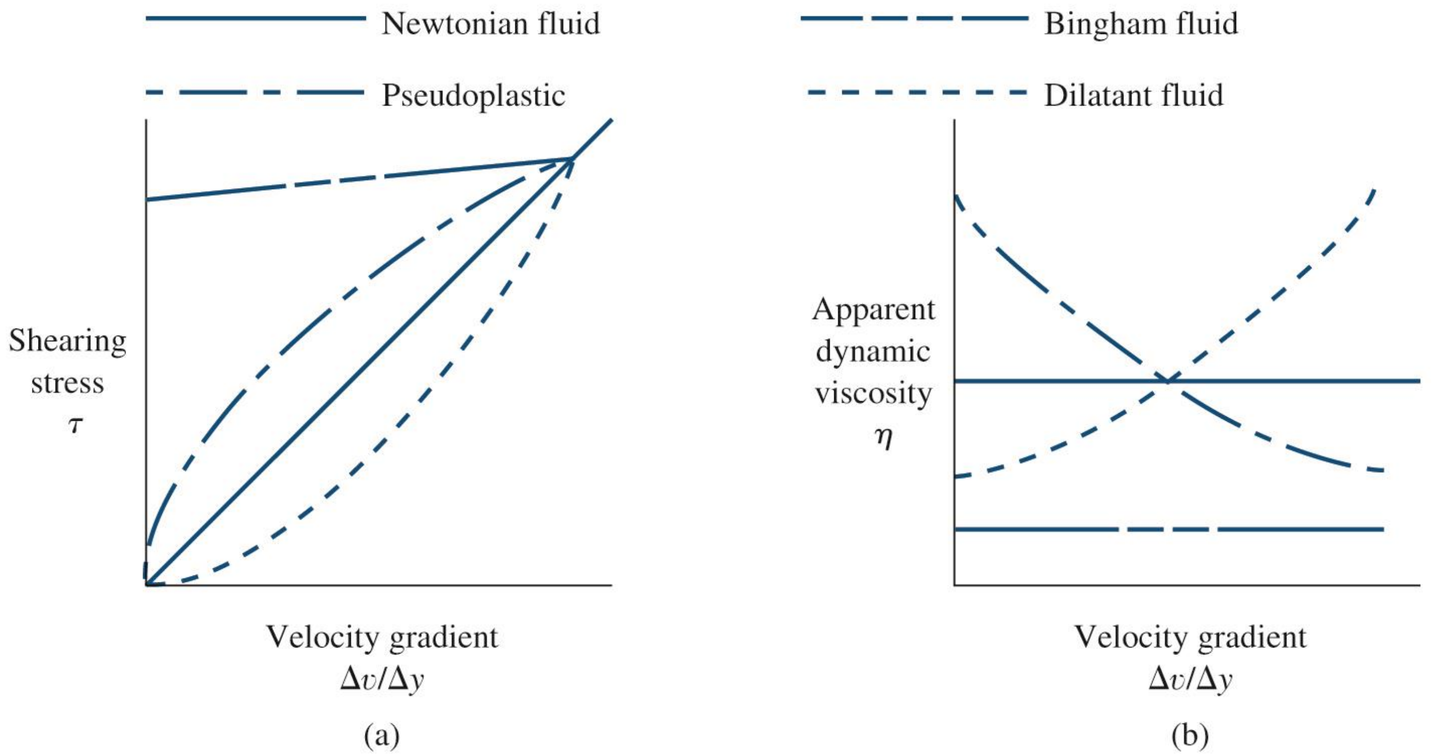
where V is the mean velocity. The fluid has a viscosity of 0.04 lb.s/ft^2. Also, V = 2 ft/s and h = 0.2 in. Determine:

(a) the shearing stress acting on the bottom wall.

(b) the shearing stress acting on a plane parallel to the walls and passing through the centerline (midplane).

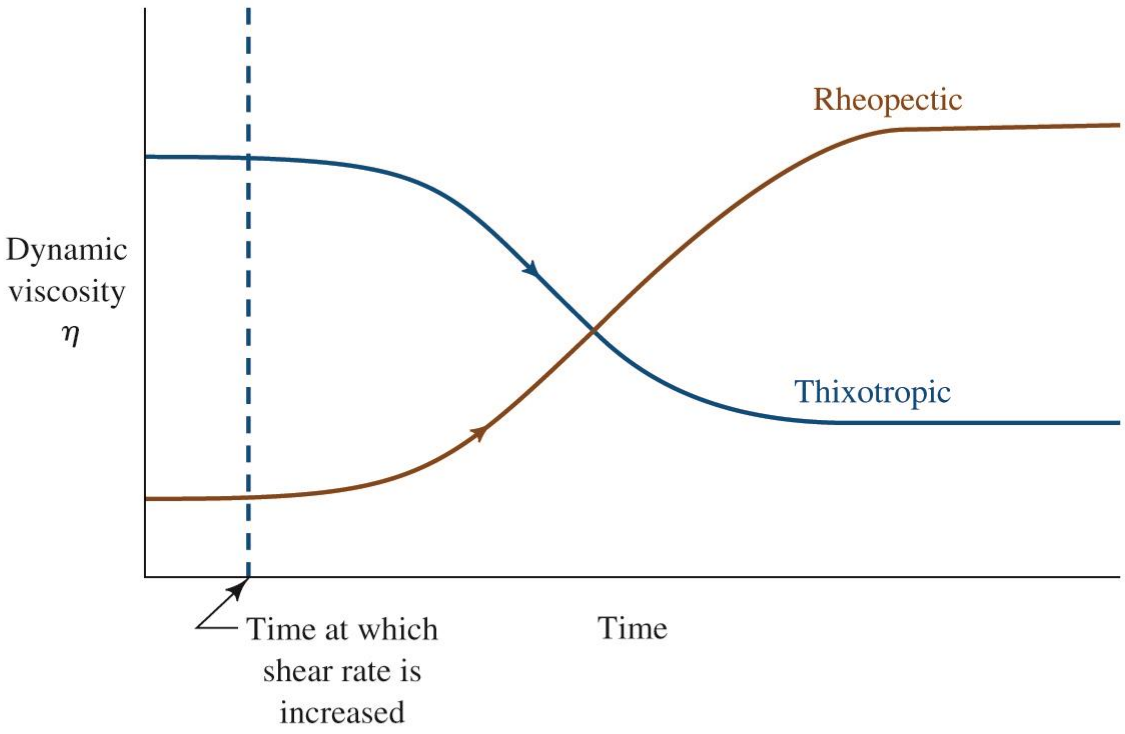


Newtonian and non-Newtonian fluids (time-independent)



Check page 23 in the textbook.

Behavior of non-Newtonian time-dependent fluids

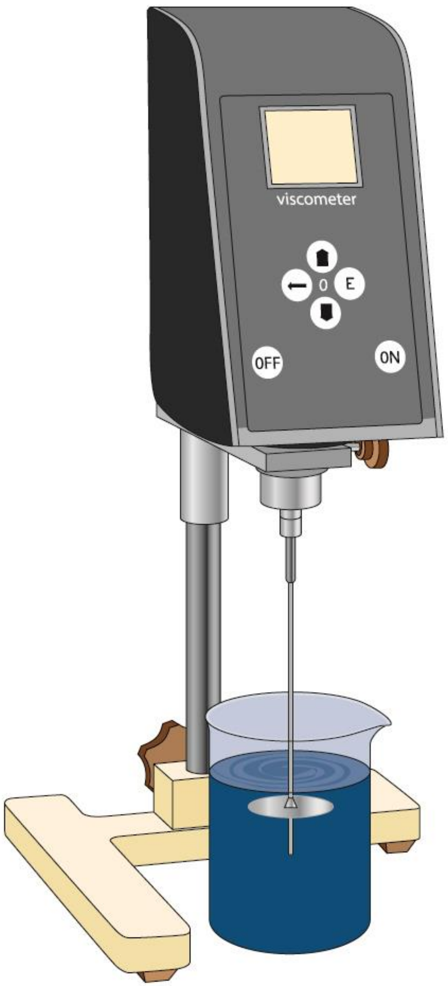


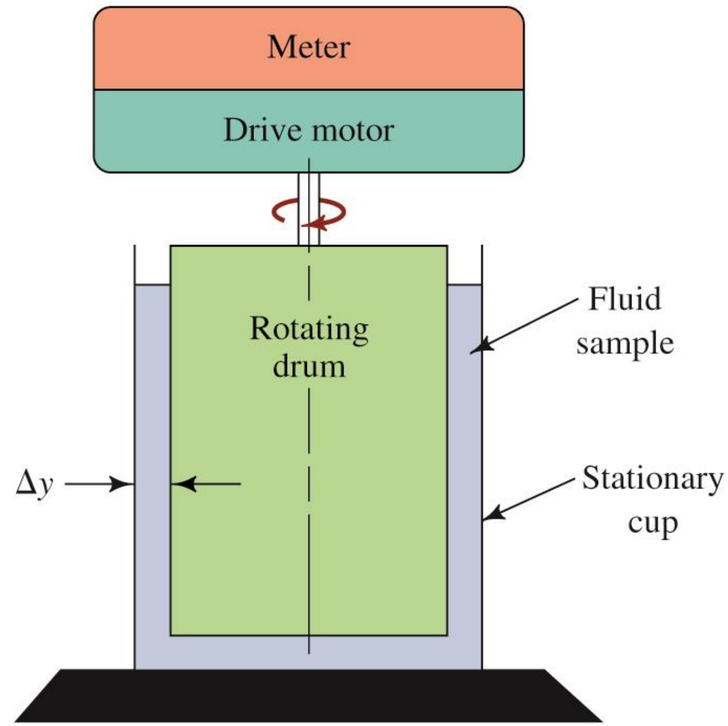
Check pages 24 in the textbook.

Viscosity is very dependent on fluid temperature

- Fluid viscosity typically increases as the fluid is cooled. Viscosity drops at higher temperature.
- *Viscosity Index* is a measure of how sensitive a fluid's viscosity is to changes in temperature.
- A high *VI* indicates that a fluid exhibits a small change in viscosity with changes in temperature.

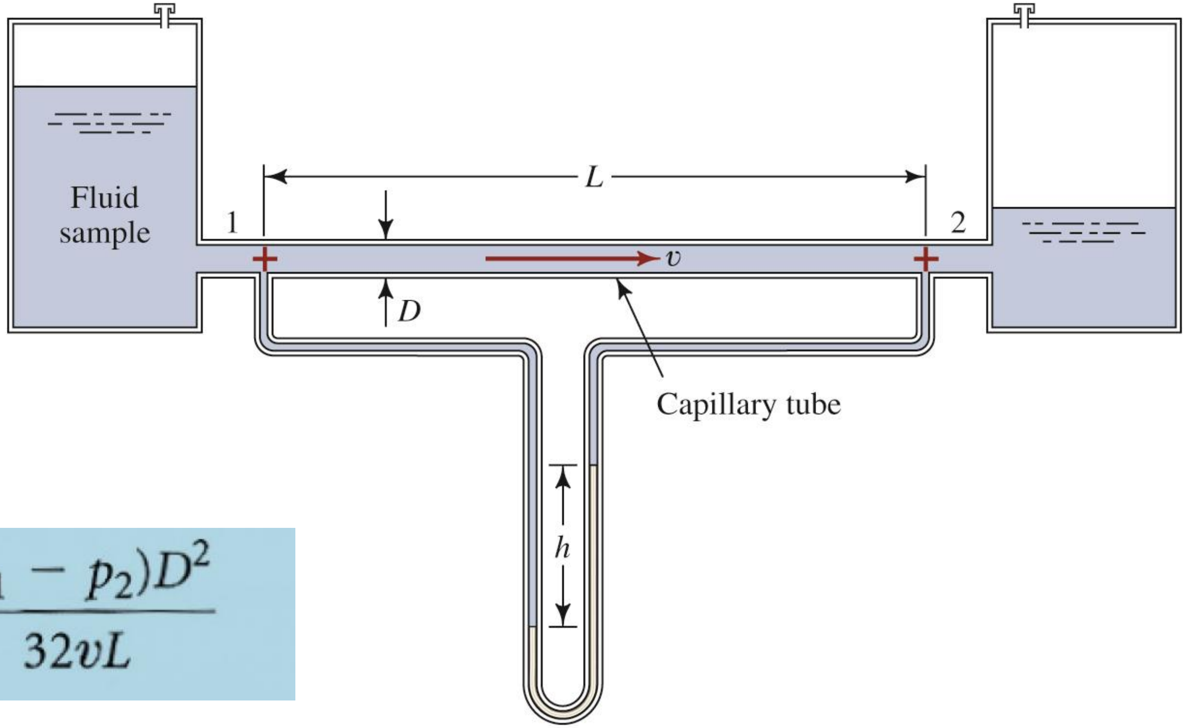
A rotating-drum viscometer measures torque to indicate viscosity





$$\eta = \tau/(\Delta v/\Delta y)$$

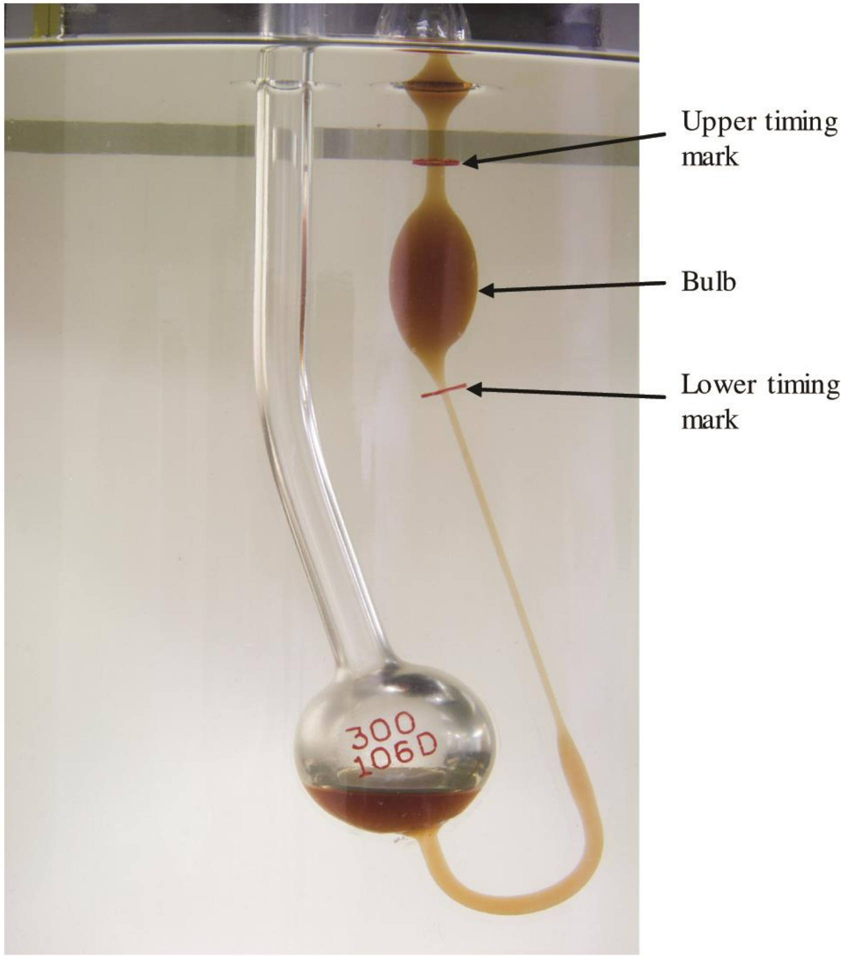
A Capillary-tube viscometer measures pressure difference to indicate viscosity



$$\eta = \frac{(p_1 - p_2)D^2}{32vL}$$

Pearson

A Cannon–Fenske viscometer measures flow time to indicate viscosity



Source: Alexey Stiop/Shutterstock

Falling-ball viscometer measures the speed of the ball to indicate viscosity

$$w - F_b - F_d = 0$$

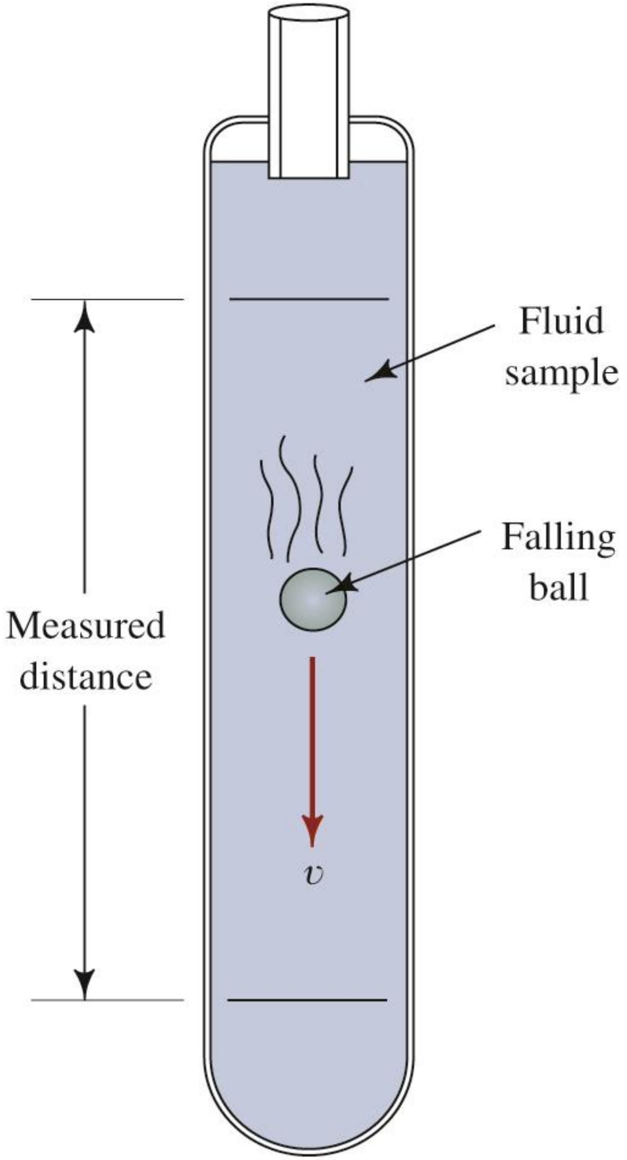
$$w = \gamma_s V = \gamma_s \pi D^3/6$$

$$F_b = \gamma_f V = \gamma_f \pi D^3/6$$

$$F_d = 3\pi\eta v D$$

Solve for viscosity:

$$\eta = \frac{(\gamma_s - \gamma_f)D^2}{18v}$$



A Saybolt viscometer measures the time required to drain a fluid in a standardized arrangement