CE 319 F

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Elementary Mechanics of Fluids

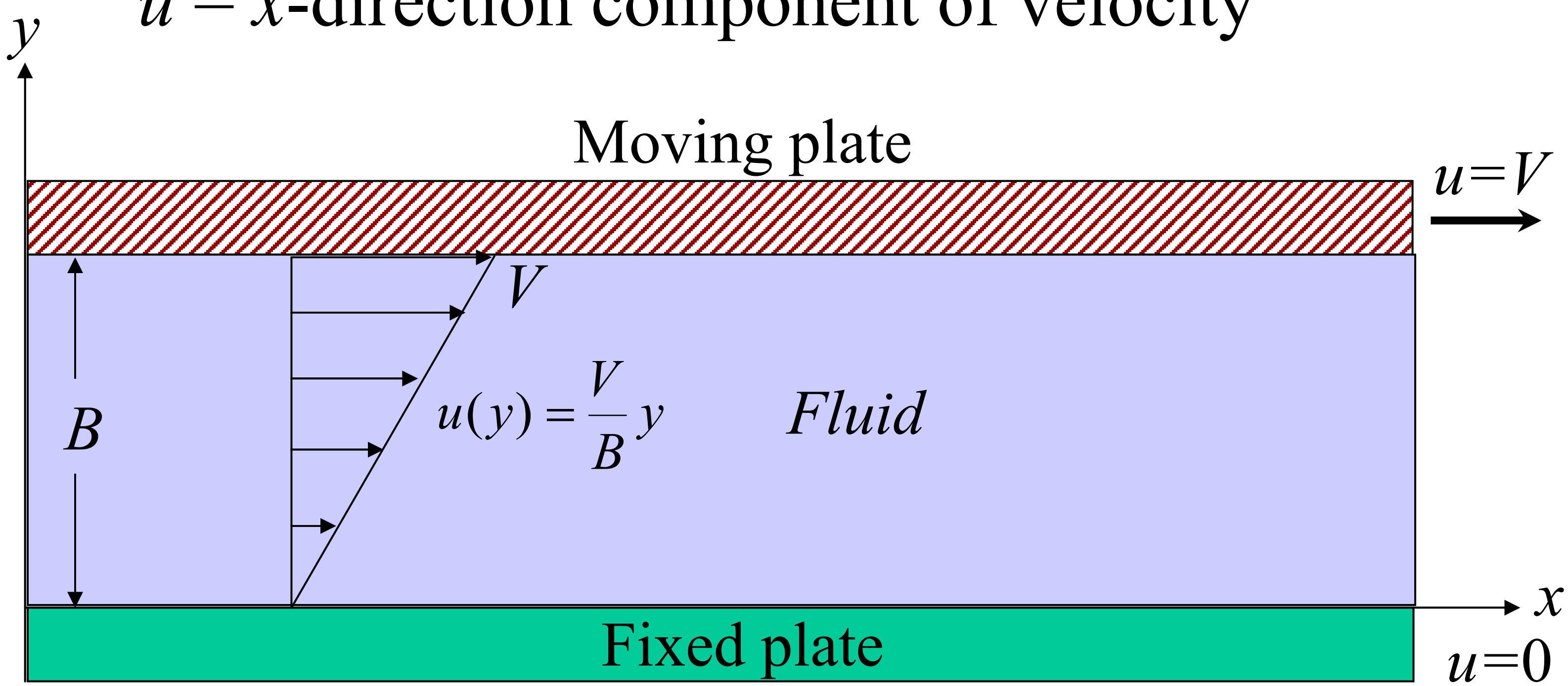
Viscosity

Some Simple Flows

- Flow between a fixed and a moving plate

    Fluid in contact with the plate has the same velocity as the plate

    $u = x$-direction component of velocity

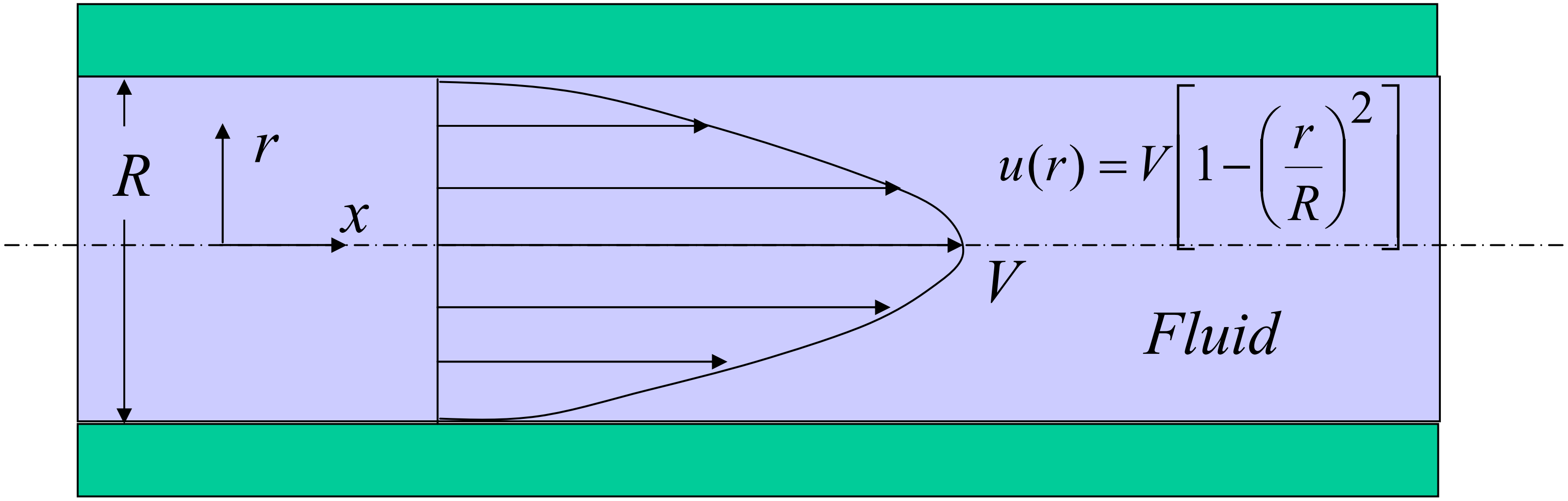


Some Simple Flows

- Flow through a long, straight pipe

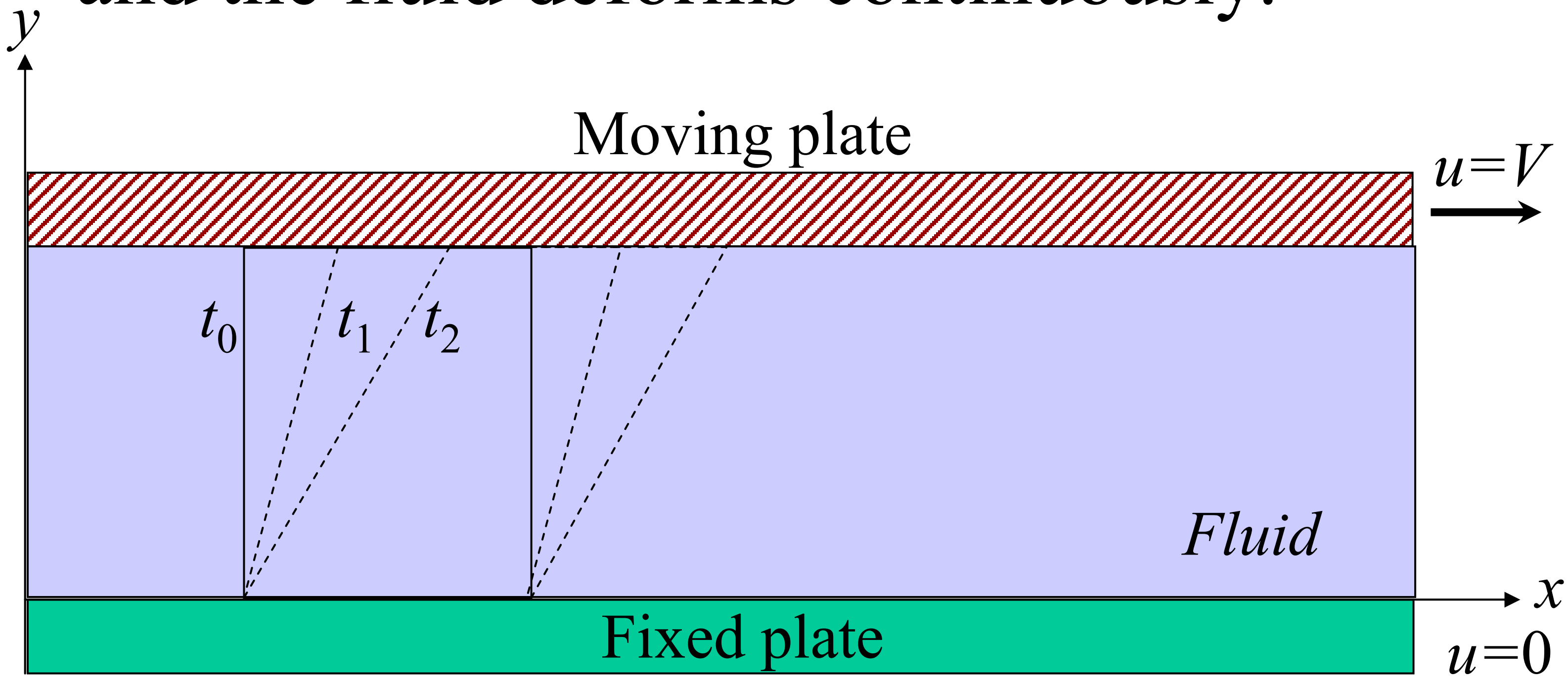
  Fluid in contact with the pipe wall has the same velocity as the wall

  u = x-direction component of velocity



Fluid Deformation

- Flow between a fixed and a moving plate
- Force causes plate to move with velocity V and the fluid deforms continuously.

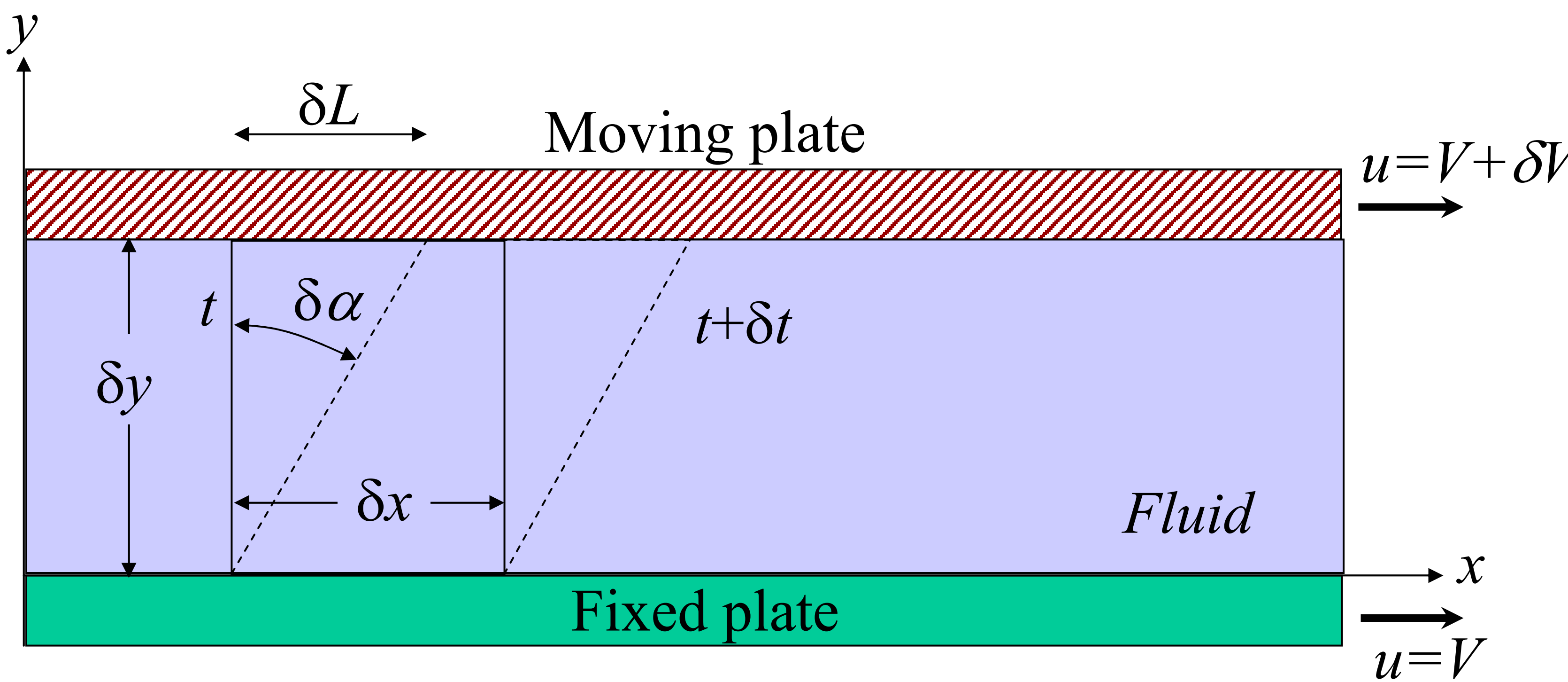


Fluid Deformation

Shear stress on the plate is proportional to deformation rate of the fluid

$$\tau \propto \frac{\delta\alpha}{\delta t}$$

$$\delta\alpha = \frac{\delta L}{\delta y} \qquad \delta t = \frac{\delta L}{\delta V} \qquad \frac{\delta\alpha}{\delta t} = \frac{\delta V}{\delta y} \qquad \tau \propto \frac{\delta V}{\delta y}$$

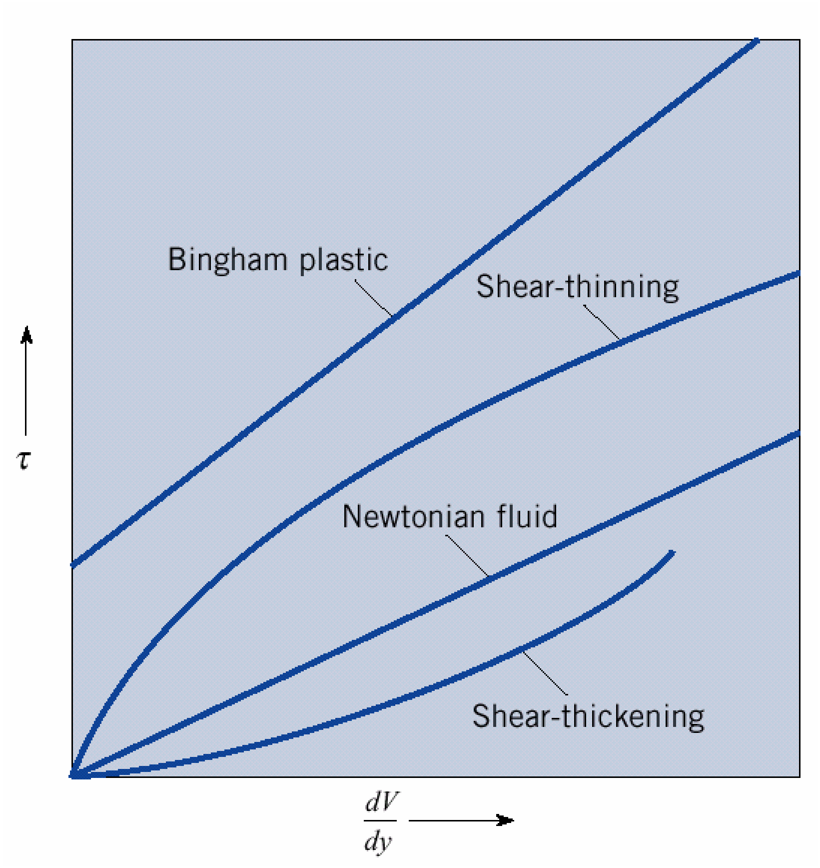


Shear in Different Fluids

- Shear-stress relations for different types of fluids
- Newtonian fluids: linear relationship
- Slope of line (coefficient of proportionality) is "viscosity"

$$\tau \propto \frac{dV}{dy}$$

$$\tau = \mu \frac{dV}{dy}$$



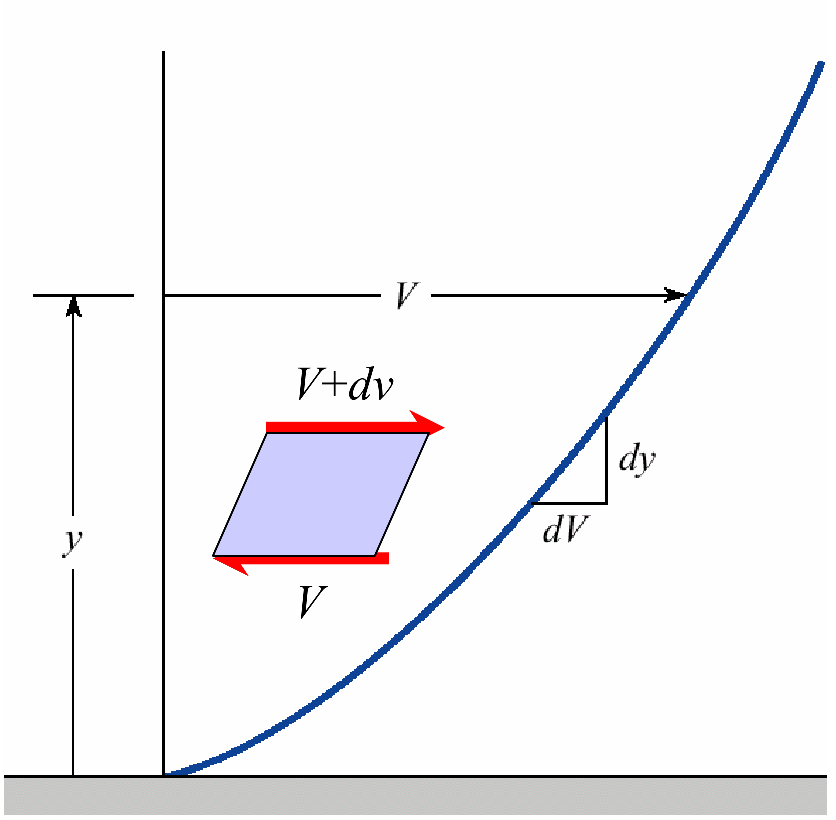
Viscosity

- Newton's Law of Viscosity $\tau = \mu \dfrac{dV}{dy}$

- Viscosity $\mu = \dfrac{\tau}{dV/dy}$

- Units $\dfrac{N/m^2}{m/s/m} = \dfrac{N \cdot s}{m^2}$

- Water (@ 20°C)
  - $\mu = 1x10^{-3}$ *N-s/m²*
- Air (@ 20°C)
  - $\mu = 1.8x10^{-5}$ *N-s/m²*
- Kinematic viscosity $\nu = \dfrac{\mu}{\rho}$



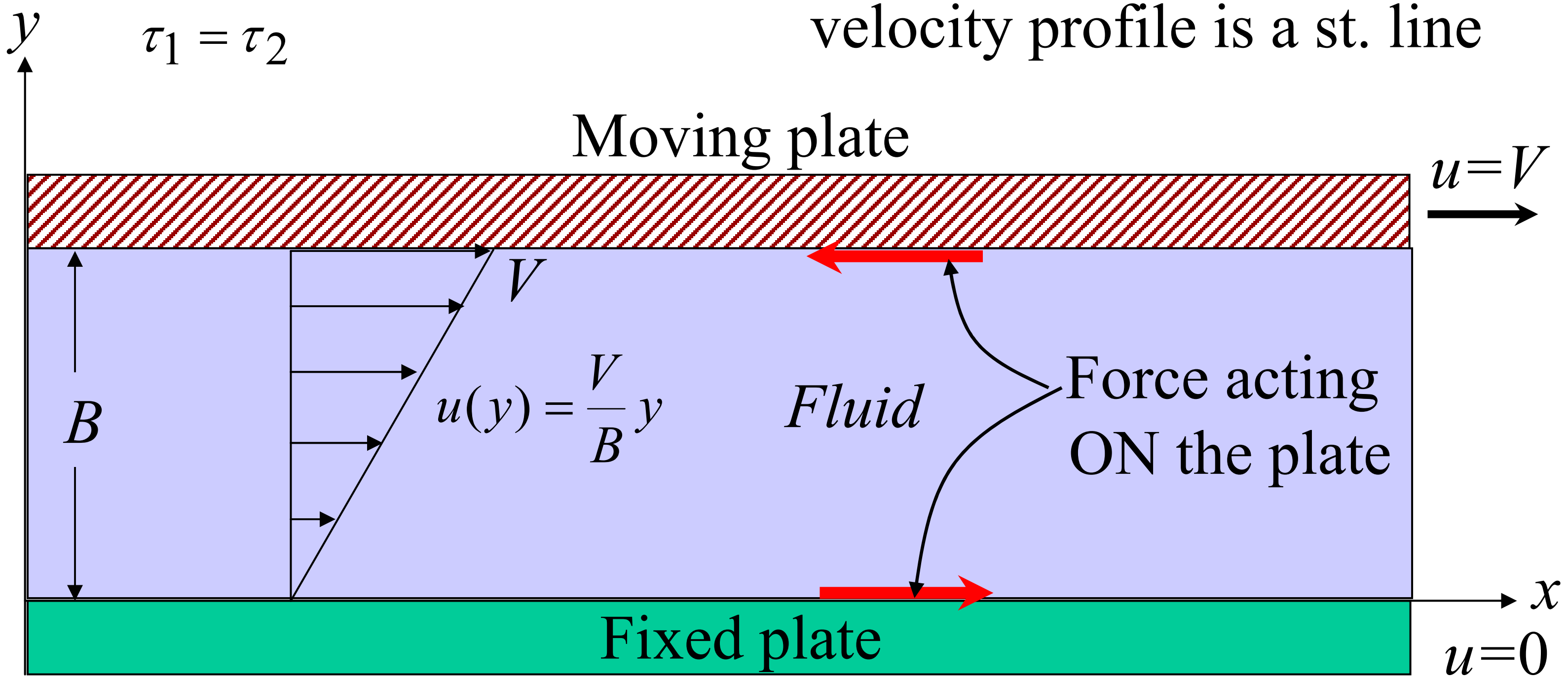
Flow between 2 plates

Force is same on top and bottom

$$\tau_1 = \mu \left.\frac{du}{dy}\right|_1 = \mu \left.\frac{du}{dy}\right|_2 = \tau_2$$

$$F_1 = \tau_1 A_1 = \tau_2 A_2 = F_2$$
$$A_1 = A_2$$
$$\tau_1 = \tau_2$$

Thus, slope of velocity profile is constant and velocity profile is a st. line



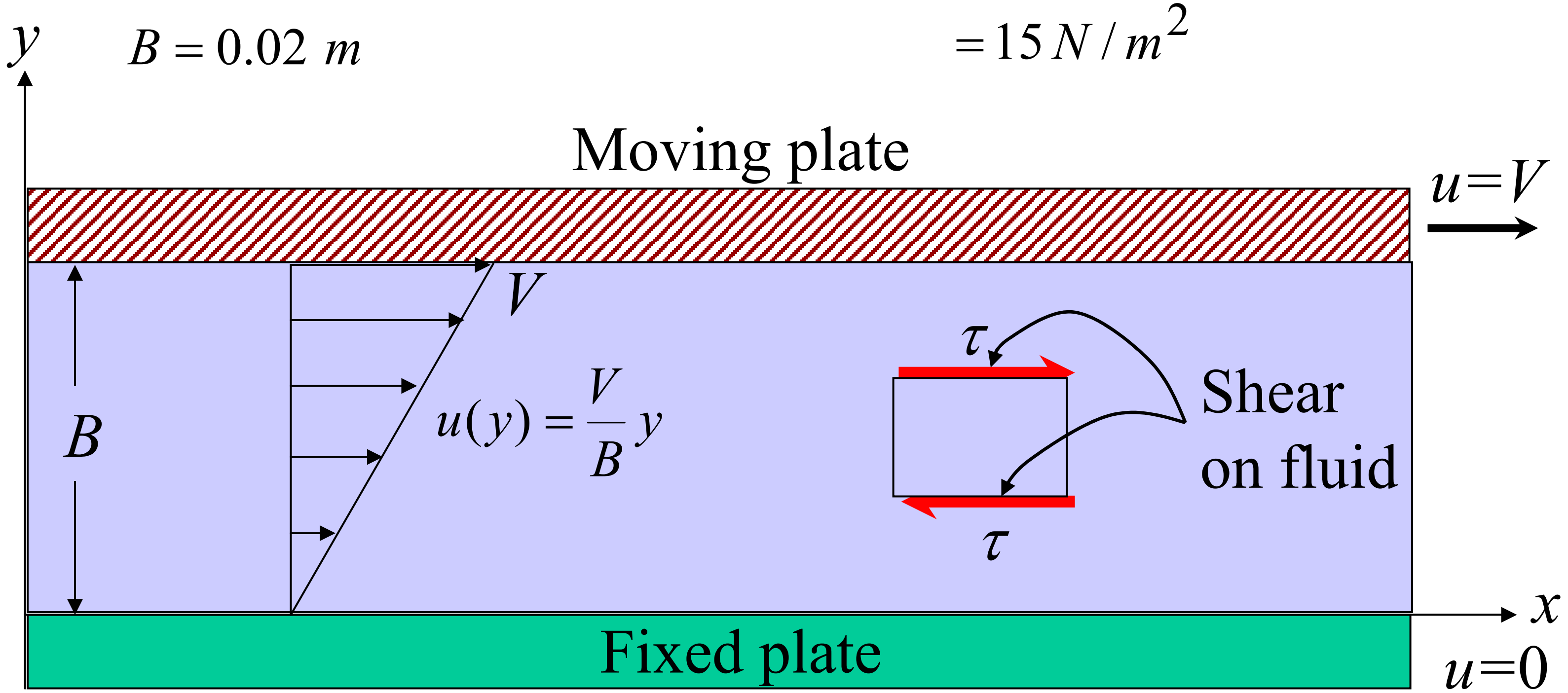
Flow between 2 plates

Shear stress anywhere between plates

$$\tau = \mu \frac{du}{dy} = \mu \frac{V}{B}$$

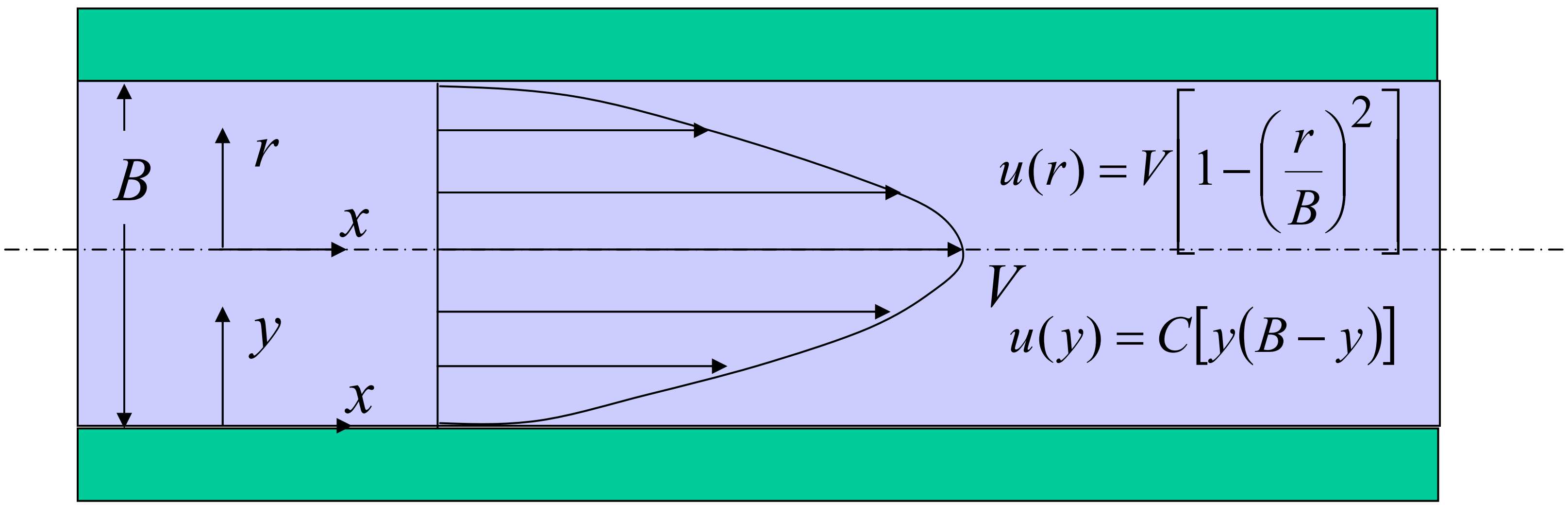
$$\mu = 0.1\ N \cdot s / m^2\ (SAE\,30 @ 38^o\,C)$$
$$V = 3\ m/s$$
$$B = 0.02\ m$$

$$\tau = (0.1\,N \cdot s / m^2)(\frac{3\,m/s}{0.02\,m})$$
$$= 15\,N/m^2$$



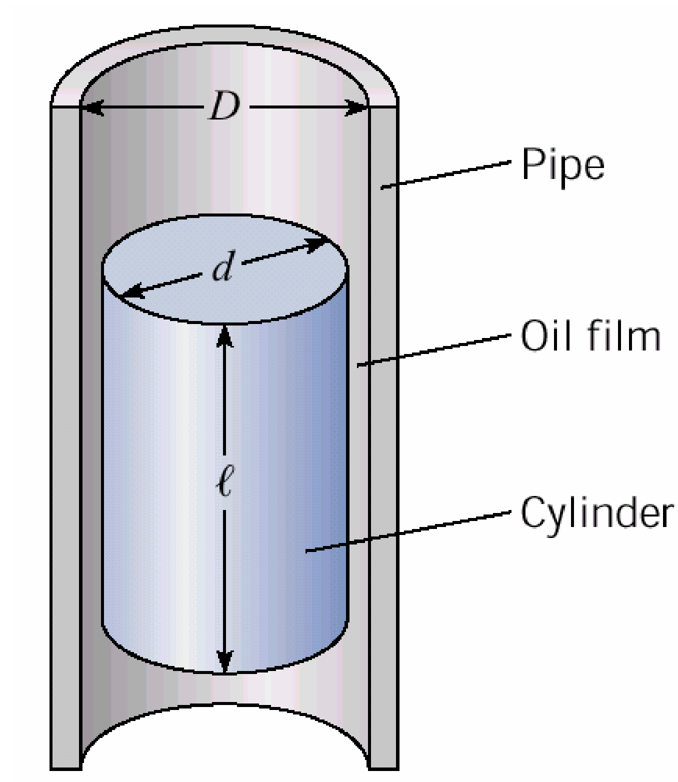
Flow between 2 plates

- 2 different coordinate systems

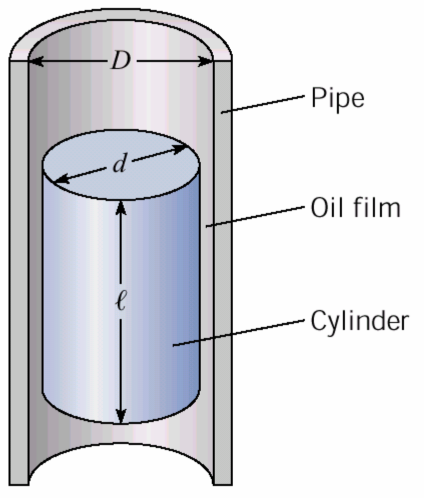


Example: Journal Bearing

- Given
  - Rotation rate, $\omega = 1500$ rpm
  - $d = 6$ cm
  - $l = 40$ cm
  - $D = 6.02$ cm
  - $SG_{oil} = 0.88$
  - $\nu_{oil} = 0.003$ m^2/s
- Find: Torque and Power required to turn the bearing at the indicated speed.



Example: cont.



- Assume: Linear velocity profile in oil film

$$\text{Shear Stress } \tau = \mu \frac{dV}{dy} = \mu \frac{\omega(d/2)}{(D-d)/2}$$

$$= (0.88 * 998 * 0.003) \frac{\left(\frac{2\pi}{60} * 1500\right)(0.06/2)}{(0.0002)/2} = 124\, kN/m^2$$

$$\text{Torque } M = (2\pi\tau \frac{d}{2} l) \frac{d}{2}$$

$$= (2\pi * 124{,}000 * \frac{0.06}{2} * 0.4) \frac{0.06}{2} = 281\, N \cdot m$$

$$\text{Power } P = M\omega = 281 * 157.1 = 44{,}100\, N \cdot m/s = 44.1\, kW$$

Example: Rotating Disk

- Assume linear velocity profile: $dV/dy=V/y=\omega r/y$
- Find shear stress