CHAPTER (2)

FLUID PROPERTIES

SOLVED PROBLEMS

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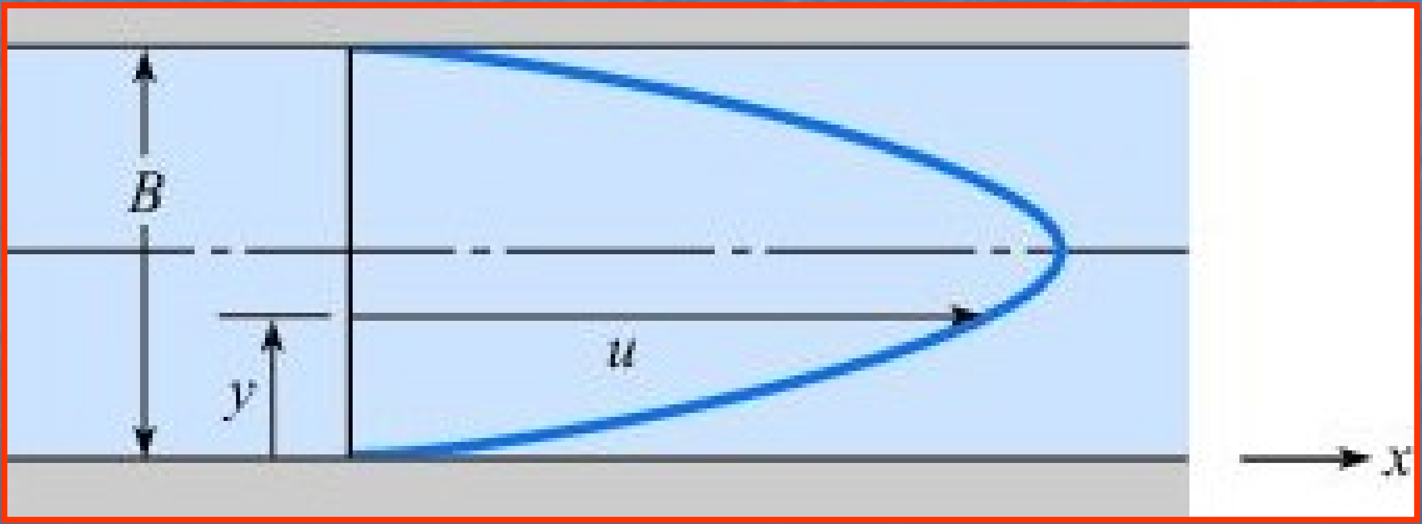
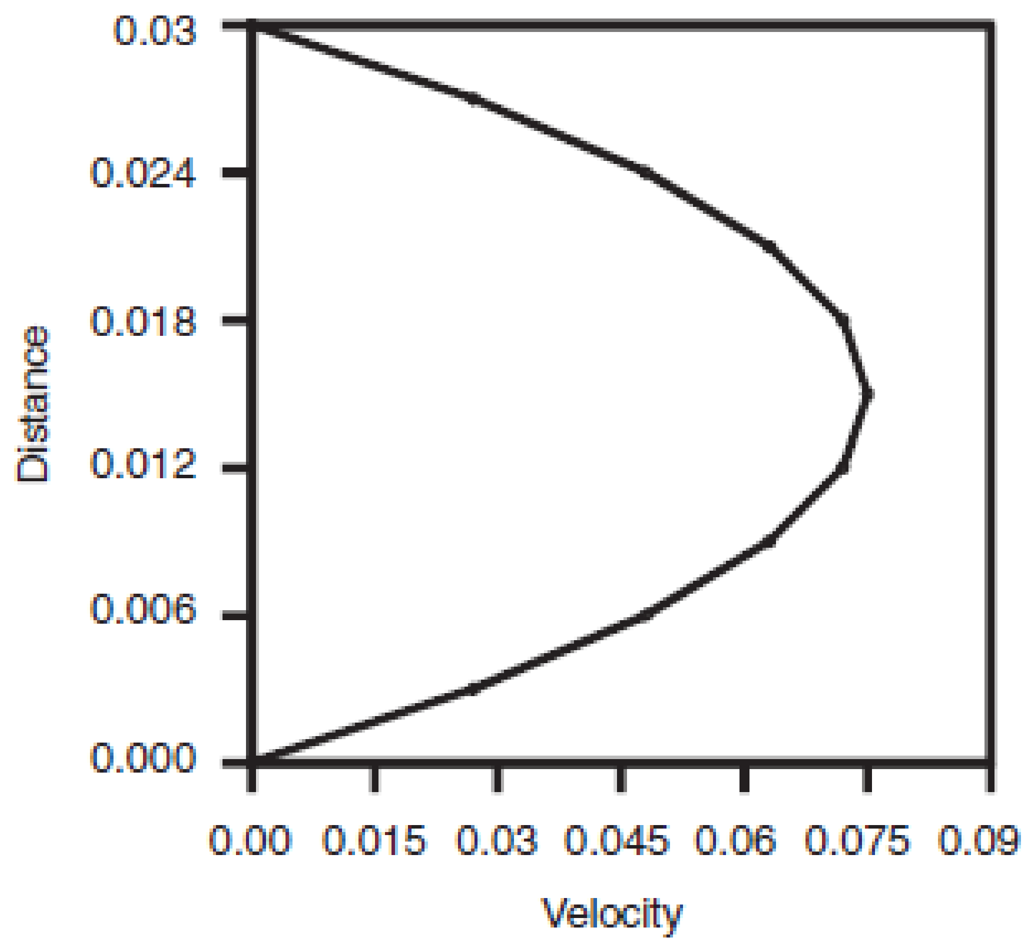
Problem (2.31)

2.31 The velocity distribution for the flow of crude oil at 100°F ($\mu = 8 \times 10^{-5}$ lbf · s/ft^2) between two walls is shown and is given by $u = 100y(0.1 - y)$ ft/s, where y is measured in feet and the space between the walls is 0.1 ft. Plot the velocity distribution and determine the shear stress at the walls.



Problem (2.35)

Plot, where distance is in meters, and velocity is in m/s.



Problem (2.31)

Situation:

Velocity distribution of crude oil between two walls.

$\mu = 3.83 \times 10^{-3}\,\mathrm{N.s/m^2}$, $B = 0.03\,\mathrm{m}$.

$u = 100y(0.1 - y)\,\mathrm{m/s}$, $T = 37.8\,°\mathrm{C}$.

Find:

Shear stress at walls.

SOLUTION

Velocity distribution

$$u = 100y(0.1 - y) = 10y - 100y^2$$

Rate of strain

$$du/dy = 10 - 200y$$

$$(du/dy)_{y=0} = 10\ \mathrm{s^{-1}} \text{ and } (du/dy)_{y=0.1} = -10\ \mathrm{s^{-1}}$$

Shear stress

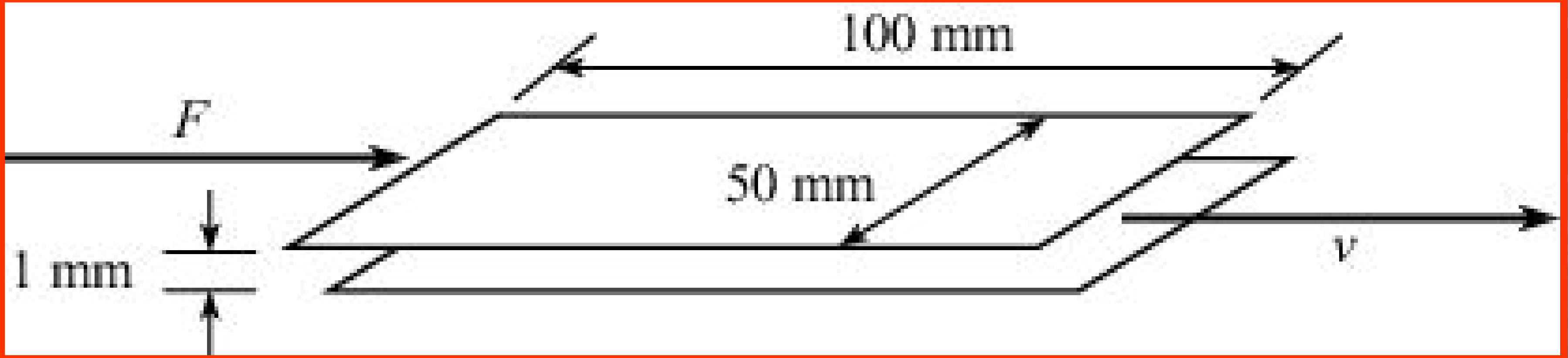
$$\tau_0 = \mu\frac{du}{dy} = (3.83 \times 10^{-3}) \times 10$$

$$\boxed{\tau_0 = 3.83 \times 10^{-2}\ \mathrm{N/m^2}}$$

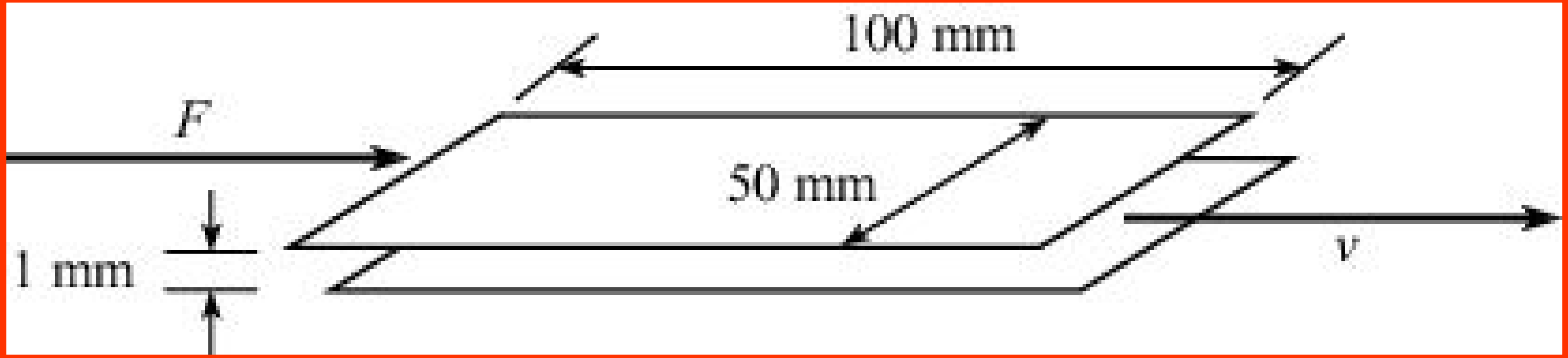
$$\boxed{\tau_{0.1} = -3.83 \times 10^{-2}\ \mathrm{N/m^2}}$$

Problem (2.31)

2.35 FLUS The sliding plate viscometer shown below is used to measure the viscosity of a fluid. The top plate is moving to the right with a constant velocity of 10 m/s in response to a force of 3 N. The bottom plate is stationary. What is the viscosity of the fluid? Assume a linear velocity distribution.



Problem (2.35)



Situation:

Sliding plate viscometer is used to measure fluid viscosity.

$A = 50 \times 100\,\text{mm}$, $\Delta y = 1\,\text{mm}$.

$u = 10\,\text{m/s}$, $F = 3\,\text{N}$.

Find:

Viscosity of the fluid.

Assumptions:

Linear velocity distribution.

PLAN

1. The shear force τ is a force/area.
2. Use equation for viscosity to relate shear force to the velocity distribution.

Problem (2.35)

SOLUTION

1. Calculate shear force

$$\tau = \frac{Force}{Area}$$

$$\tau = \frac{3\,\mathrm{N}}{50\,\mathrm{mm} \times 100\,\mathrm{mm}}$$

$$\tau = 600\,\mathrm{N/\,m^2}$$

2. Find viscosity

$$\mu = \frac{\tau}{\left(\frac{du}{dy}\right)}$$

$$\mu = \frac{600\,\mathrm{N/\,m^2}}{[10\,\mathrm{m/\,s}]\,/\,[1\,\mathrm{mm}]} \times \frac{1\,\mathrm{m}}{1000\,\mathrm{mm}}$$

$$\boxed{\mu = 6 \times 10^{-2}\,\frac{\mathrm{N \cdot s}}{\mathrm{m^2}}}$$

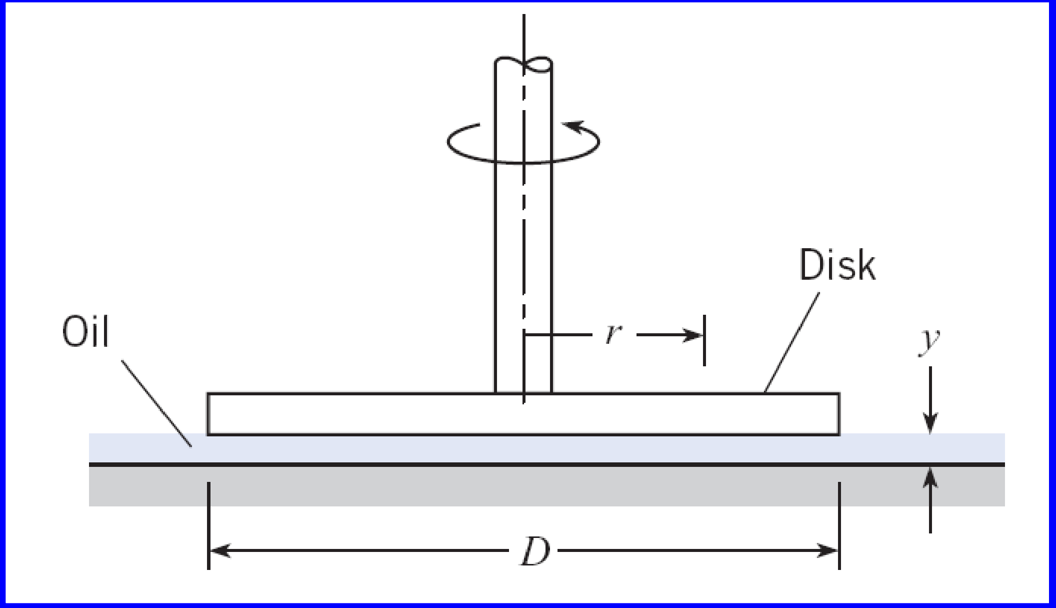
Problem (2.38)

2.41 The device shown consists of a disk that is rotated by a shaft. The disk is positioned very close to a solid boundary. Between the disk and the boundary is viscous oil.

a. If the disk is rotated at a rate of 1 rad/s, what will be the ratio of the shear stress in the oil at $r = 2$ cm to the shear stress at $r = 3$ cm?

b. If the rate of rotation is 2 rad/s, what is the speed of the oil in contact with the disk at $r = 3$ cm?

c. If the oil viscosity is 0.01 $N \cdot s/m^2$ and the spacing y is 2 mm, what is the shear stress for the conditions noted in part (b)?



CONT.

PROBLEM 2.41

Situation: A disk is rotated very close to a solid boundary—details are provided in problem statement.

Find: (a) Ratio of shear stress at $r = 2$ cm to shear stress at $r = 3$ cm. $\omega = 1 rad/s$
(b) Speed of oil at contact with disk surface. $\omega = 2 rad/s$
(c) Shear stress at disk surface.

Assumptions: Linear velocity distribution: $dV/dy = V/y = \omega r/y$.

ANALYSIS

$$\tau = \mu dV/dy = \mu\omega r/y$$

$$\tau_2/\tau_3 = (\mu \times 1 \times 2/y)/(\mu \times 1 \times 3/y) = 2/3 = \boxed{0.667}$$

$$V = \omega r = 2 \times 0.03 = \boxed{0.06 \text{ m/s}}$$ $At\ r = 3\,cm$

$$\tau = \mu dV/dy = 0.01 \times 0.06/0.002 = \boxed{0.30 \text{ N/m}^2}$$

Problem (2.47)

2.47 PLUS The dynamic viscosity of air at 15°C is 1.78×10^{-5} N · s/m². Using Sutherland's equation, find the viscosity at 100°C.

Situation:

The dynamic viscosity of air.

$\mu_o = 1.78 \times 10^{-5}\ \text{N}\cdot\text{s/m}^2$.

$T_o = 288\ \text{K},\ T = 373\ \text{K}$.

Find:

Dynamic viscosity μ.

Properties:

From Table A.2, $S = 111K$.

Problem (2.47)

SOLUTION

Sutherland's equation

$$\frac{\mu}{\mu_o} = \left(\frac{T}{T_o}\right)^{3/2} \frac{T_o + S}{T + S}$$

$$= \left(\frac{373\,\mathrm{K}}{288\,\mathrm{K}}\right)^{3/2} \frac{288\,\mathrm{K} + 111\,\mathrm{K}}{373\,\mathrm{K} + 111\,\mathrm{K}}$$

$$\frac{\mu}{\mu_o} = 1.22$$

Thus

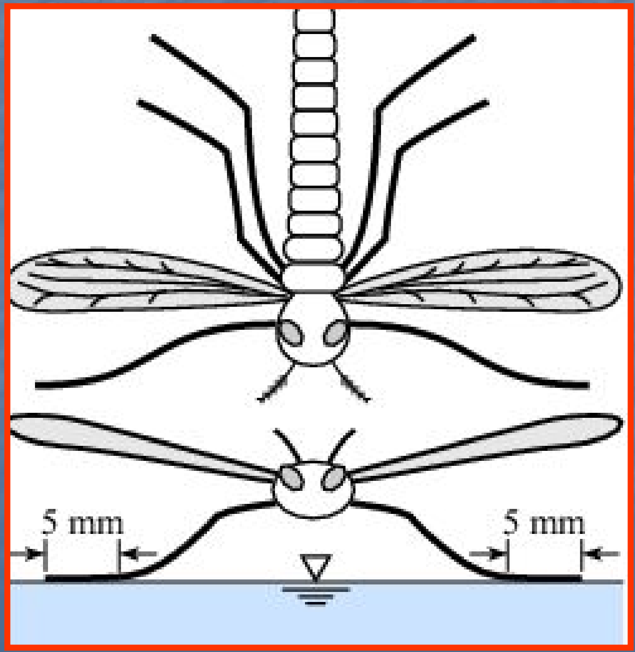
$$\mu = 1.22\mu_o$$

$$= 1.22 \times \left(1.78 \times 10^{-5}\,\mathrm{N \cdot s/\,m^2}\right)$$

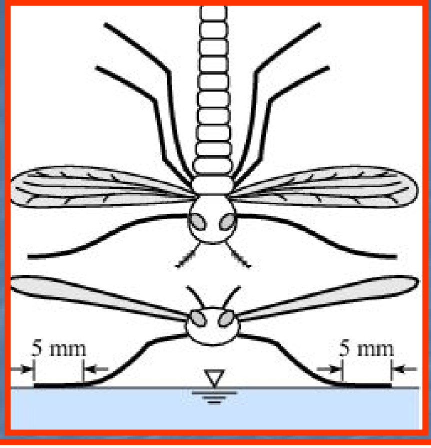
$$\boxed{\mu = 2.17 \times 10^{-5}\ \mathrm{N{\cdot}s/m^2}}$$

Problem (2.59)

2.59 PLUS A water bug is suspended on the surface of a pond by surface tension (water does not wet the legs). The bug has six legs, and each leg is in contact with the water over a length of 5 mm. What is the maximum mass (in grams) of the bug if it is to avoid sinking?



Problem (2.59)



Situation:

A water bug is balanced on the surface of a water pond.
$n = 6$ legs, $\ell = 5\,\text{mm/leg}$.

Find:

Maximum mass of bug to avoid sinking.

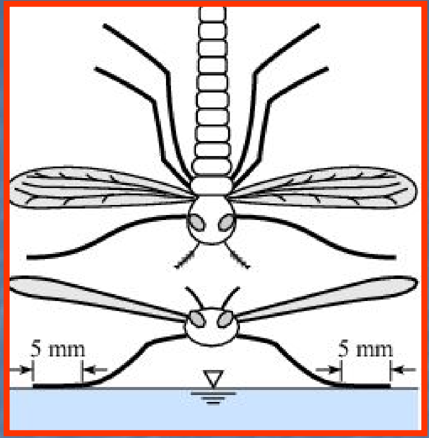
Properties:

Surface tension of water, from Table A.4, $\sigma = 0.073\ \text{N/m}$.

PLAN

Apply equilibrium, then the surface tension force equation.

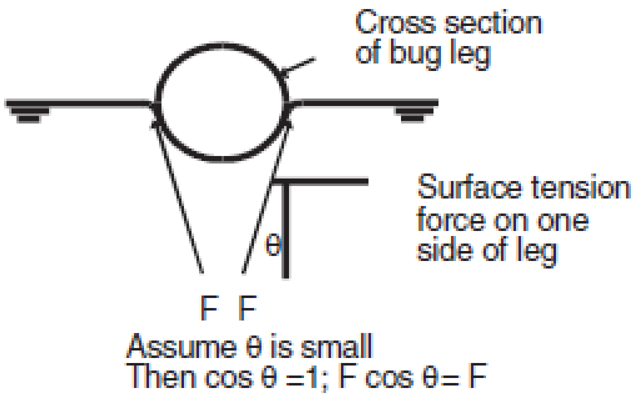
Problem (2.59)



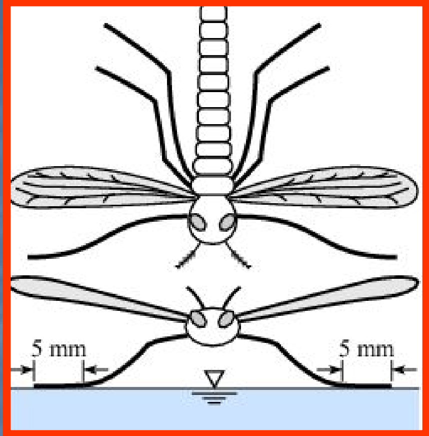
Force equilibrium

$$\text{Upward force due to surface tension} = \text{Weight of Bug}$$
$$F_T = mg$$

To find the force of surface tension (F_T), consider the cross section of one leg of the bug:



Problem (2.59)



Surface tension force

$$\begin{aligned} F_T &= (2/\text{leg})(6 \text{ legs})\sigma\ell \\ &= 12\sigma\ell \\ &= 12(0.073 \text{ N/m})(0.005 \text{ m}) \\ &= 0.00438\,\text{N} \end{aligned}$$

Apply equilibrium

$$\begin{aligned} F_T - mg &= 0 \\ m &= \frac{F_T}{g} = \frac{0.00438\,\text{N}}{9.81\,\text{m}^2/\text{s}} \\ &= 0.4465 \times 10^{-3}\,\text{kg} \end{aligned}$$

$$\boxed{m = 0.447\,\text{g}}$$

THE END