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Département de
Génie Chimique

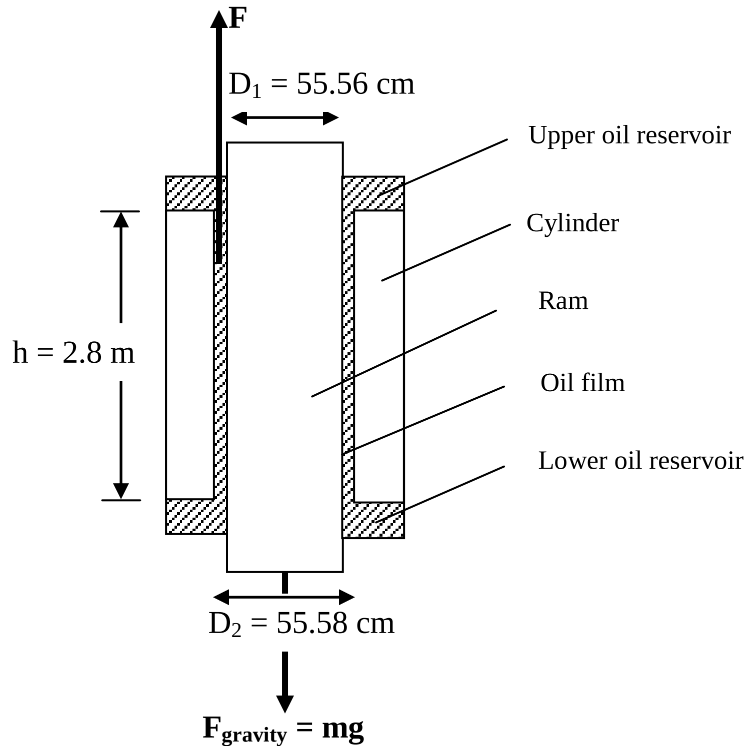
University of Ottawa
Faculty of Engineering

Department of
Chemical & Biological Engineering

CHG 2312 – Fluid Flow

Solution-Assignment #1

Question 1:



Given:
$D_1 = 55.56$ cm
$D_2 = 55.58$ cm
h = 2.8 m
m = 1750 kg
V = 0.25 m/s

Find:
μ = ? Pa.s.

Assomption:
Newtonien fluid
Ram moving at constant velocity

Solution:

$$\sum F = 0$$

$$F = F_{gravity}$$

$$\tau . A = m . g$$

$$\mu \frac{V}{d} . A = m . g$$

$$\mu \frac{V}{\left(\frac{D_2 - D_1}{2}\right)} . \left(2\pi \frac{D_1}{2} h\right) = m . g$$

$$\mu = \frac{mg\left(D_2 - D_1\right)/2}{V\left(\pi D_1 h\right)} = \frac{(1750 \ kg)(9.81\, m/s^2)(0.5558 - 0.5556)m/2}{(0.25 \ m/s)(\pi \ x\ 0.5556 \ m \ x \ 2.8 m)} = 1.41 \ kg/m.s = 1.41 \ Pa.s$$

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Question #2:

Given:

Material thickness = Y = 1 mm = 0.001

Find:

Type of the material of the first material

If minimum stress of 250 Pa needed for a second material, at shear stress of 450 Pa, what is μ?

Solution:

The velocity gradient for each shear stress can be calculated as:

du/dy = U/Y

τ (Pa)	U (m/s)	du/dy (1/s)
50	0	0
100	0	0
150	0	0
163	0.005	5
171	0.01	10
170	0.025	25
202	0.05	50
246	0.1	100
349	0.2	200
444	0.3	300

Plot shear stress vs. velocity gradient from table above in Excel.

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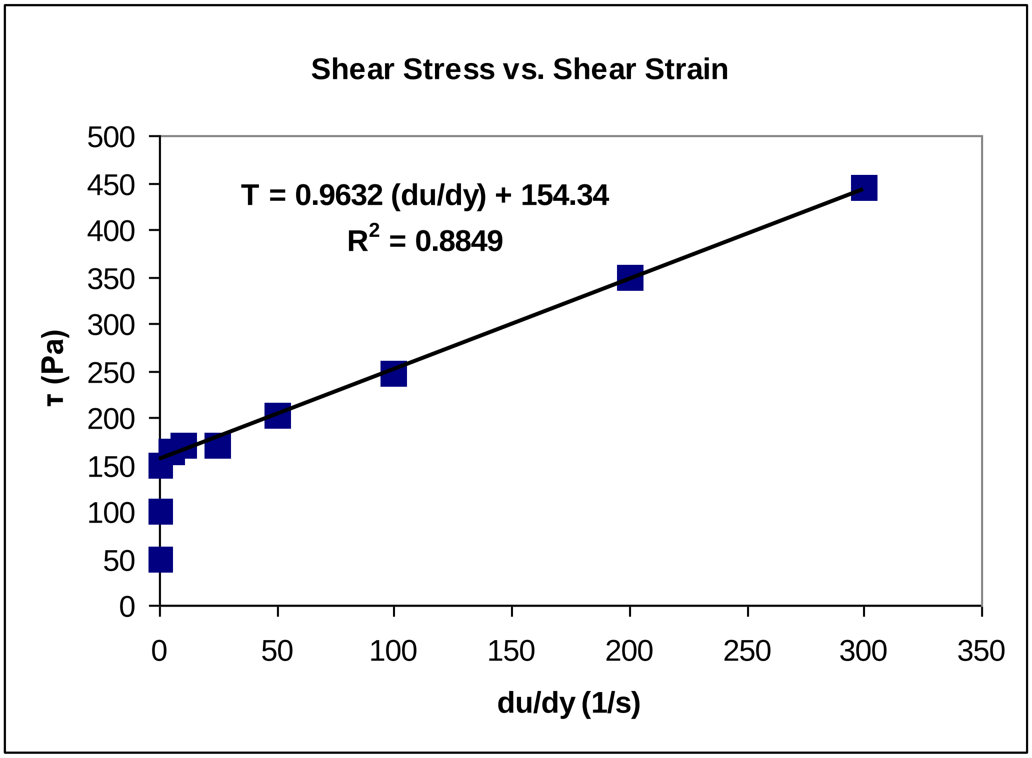
Solution-Assignment #1



Results show that the material is behaving as a Bingham fluid.

Now if at shear stress of 450 Pa, if another material behaving the same as the current material, we can take the linear equation found from the plot above and then,

At $\tau = 450$ Pa, du/dy = 307 1/s

Now for a fluid that requires a minimum stress of 250 Pa to move, then we can use the same equation and back calculate the viscosity:

$$(450 \text{ Pa}) = \mu\, (307 \text{ 1/s}) + (250 \text{ Pa})$$

$$\mu = 0.6515 \text{ Pa.s}$$

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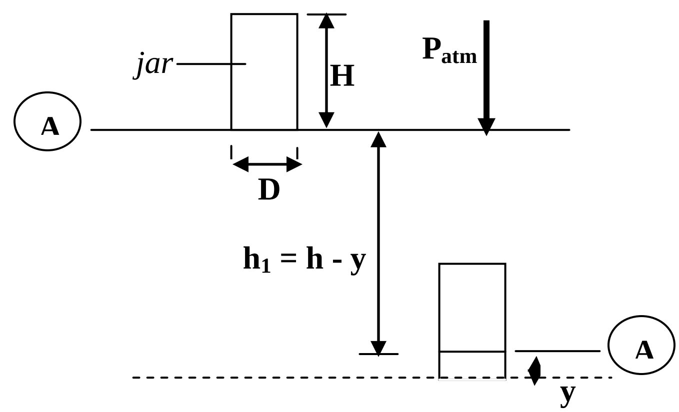
Solution-Assignment #1

Question 3:

Given:

D = 10 cm = 0.1 m
H = 20 cm =0.2 m
$\rho_{water} = 998$ kg/m^3
h = 4 m



Find:

Height y = ?

Assumptions:

Air inside the jar compressed isothermally
Newtonian fluid

Solution:

Volume of jar at water surface = $V_{jar, A} = \pi r^2 H = \pi (0.05m)^2 (0.2m) = 1.57x10^{-3}\ m^3$

For the air inside the jar, we can apply the ideal gas low: PV = n R T = constant
So when jar is 4 m below the water surface (i.e. at point B), PV stays the same. Therefore, from point A to point B, we can write

$(P_A V_{jar, A}) = (P_B V_{jar, B})$
$(P_{atm}) (V_{jar,A}) = [P_{atm} + \rho\ g\ (h – y)] (V_{jar,B})$
$(101.3x10^3$ Pa$) (1.57x10^{-3}\ m^3) = [101.3x10^3$ Pa $+ (998$ kg/m$^3) (9.8$ m/s$^2) (4-y)m] (1.57x10^{-3} – \pi(0.05m)^2 y)m^3$

y = 0.0549 m = 5.49 cm

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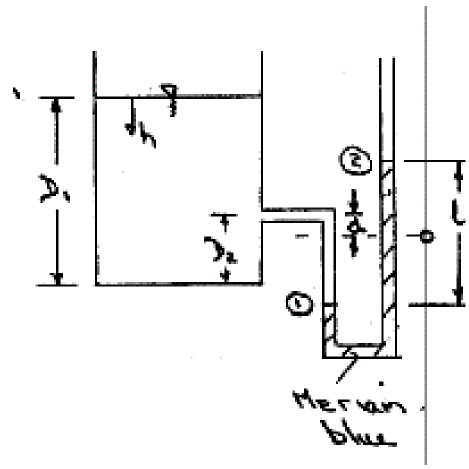
Solution-Assignment #1

Question 4:



Given:

Tank open to atmosphere

$D_1 = 2.5$ m

$D_2 = 0.7$ m

$d = 0.2$ m

Find:

$l = ?$

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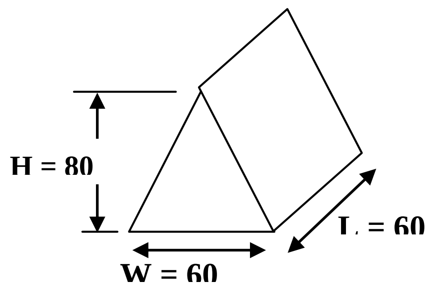
Solution-Assignment #1

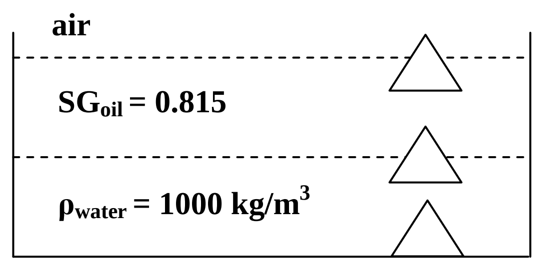
Question 5:

<u>Given,</u>
m_{block} = 135 kg
H = 1.5 m
ρ_w = 1000 kg/m^3
SG_{oil} = 0.815



<u>Find:</u>
h = ?

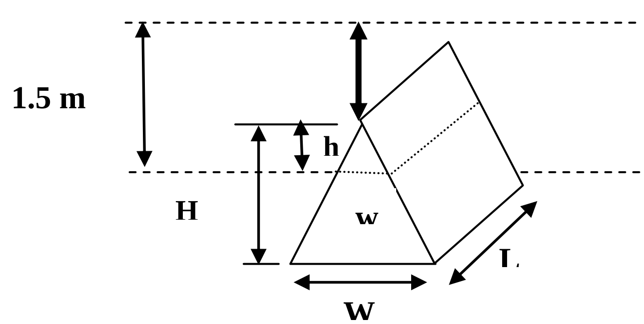
<u>Solution:</u>



In order to determine how far the block moves down into the tank, we can first compare the densities of the block with that of the oil and water.

$$\rho_{block} = \frac{m_{block}}{V_{block}} = \frac{135\ kg}{(\frac{1}{2}\,0.8x0.6x0.6)m^3} = 937.5 kg/m^3$$

Since $\rho_{oil} < \rho_{block} < \rho_{water}$, block floats at the interface between the oil and water. Now we can calculate the depth by,



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Solution-Assignment #1

$$\Sigma F = 0$$

$$F_{gravity,block} = F_{buoyancy,oil} + F_{buoyancy,water}$$

$$V_{block}\,\rho_{block}\,g = \rho_{oil} V_1 g + \rho_{water}(V_{block} - V_1) g$$

$$\frac{V_1}{V_{block}} = \frac{\rho_{water} - \rho_{block}}{\rho_{water} - \rho_{oil}}$$

Using the similar triangle rules we can write :

$$\frac{H}{h} = \frac{W}{w}$$

$$\frac{V_1}{V_{block}} = \frac{\frac{1}{2} h (\frac{h}{H} W) L}{\frac{1}{2} HWL}$$

$$h = H\sqrt{\frac{\rho_{water} - \rho_{block}}{\rho_{water} - \rho_{oil}}} = (0.8m)\frac{(1000 - 937.5) kg/m^3}{(1000 - 815) kg/m^3} = 0.465\ m$$

Thus, the distance of the top of block from air-oil interface = 1.5 m – 0.465 m = 1.035 m

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Solution-Assignment #1

Question 6:

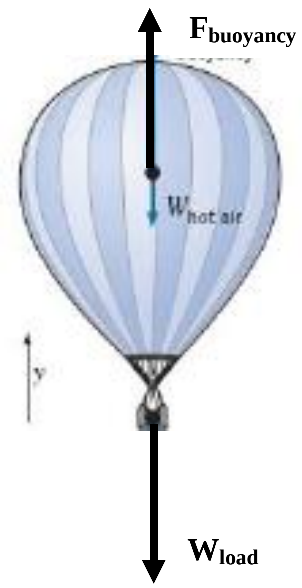
Given:

m_{load} = 450 kg
T_{air} = 9 ˚C
$T_{warm\ ari}$ = 70˚C
$P_{inside} = P_{ouside}$ = 101 kPa

Find:

V_{air} = ?

If a = 0.8 m/s^2, then find the new volume of air. In this case assume the total mass accelerated is the mass of the total load and mass of twice the air inside the balloon.



Solution:

$$\Sigma F_y = o$$

$$W_{load} + W_{hot\ air} = F_{buoyancy}$$

$$m_{load}\, g - \rho_{hot\ air} V g = \rho_{atm} V g$$

$$V = \frac{m_{load}}{\rho_{atm} - \rho_{hot\ air}} = \frac{m_{load}}{\left(\frac{PM_{air}}{RT_{atm}}\right) - \left(\frac{PM_{hot\ air}}{RT_{hot\ air}}\right)} = \frac{m_{load} R}{PM_{air}} \left(\frac{1}{\frac{1}{T_{atm}} - \frac{1}{T_{hot\ air}}} \right)$$

$$= \frac{(450\ kg)(8.314\ \frac{J}{mol.K})}{(101\ x10^3\ Pa)(29\ x10^{-3}\ kg\ /\ mol)} \left(\frac{1}{\frac{1}{(9+273)K} - \frac{1}{(70+273)K}} \right)$$

$$V = 2025\ m^3$$

Now calculate the additional volume of air requird to create a vertical take off with an acccelerat ion of 0.8 m/s ^{2}

$$\Sigma F_y = ma$$

$$F_{buoyancy} - W_{load} - W_{hot\ air} = m_{accelerated}\, a$$

$$\rho_{atm} V_{new}\, g - m_{load}\, g - \rho_{hot\ air} V_{new}\, g = (m_{load} + m_{hot\ air})a = (m_{load} + 2\rho_{hot\ air} V_{new})a$$

$$V_{new} = \frac{m_{load}(g+a)}{(\rho_{atm} - \rho_{hot\ air})g - 2\rho_{hot\ air}\, a} = \frac{m_{load}(g+a)R}{PM_{air}}\left(\frac{1}{\left[\frac{1}{T_{atm}} - \frac{1}{T_{hot\ air}}\right]g - 2a\frac{1}{T_{hot\ air}}}\right)$$

$$= \frac{(450\ kg)(8.314\ \frac{J}{mol.K})(9.8+0.8)\frac{m}{s^2}}{(101\ x10^3\ Pa)(29\ x10^{-3}\ kg\ /\ mol)}\left(\frac{1}{\left(\frac{1}{(9+273)K} - \frac{1}{(70+273)K}\right)(9.80) - 2(0.8)\frac{1}{(70+273)K}}\right)$$

$$V = 8933\ m^3$$

$$Additional\ \ required\ \ volume\ \ of\ \ air = (8933 - 2025) = 6908\ m^3$$

To make the balloon move up and down during the flight, the air needs to be heated to a higher temperature, or let cool (or let in ambient air)

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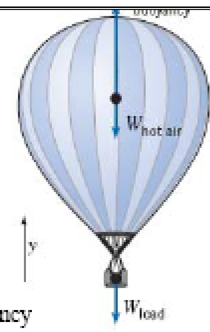

Given: Data on hot air balloon

Find: Volume of balloon for neutral buoyancy; additional volume for initial acceleration of 0.8 m/s².

Solution:

Basic equation $F_B = \rho_{atm} \cdot g \cdot V$ and $\Sigma F_y = M \cdot a_y$

Hence $\Sigma F_y = 0 = F_B - W_{hotair} - W_{load} = \rho_{atm} \cdot g \cdot V - \rho_{hotair} \cdot g \cdot V - M \cdot g$ for neutral buoyancy

$$V = \frac{M}{\rho_{atm} - \rho_{hotair}} = \frac{M}{\frac{p_{atm}}{R \cdot T_{atm}} - \frac{p_{atm}}{R \cdot T_{hotair}}} = \frac{M \cdot R}{p_{atm}} \cdot \left(\frac{1}{\frac{1}{T_{atm}} - \frac{1}{T_{hotair}}} \right)$$

$$V = 450 \cdot kg \times 286.9 \cdot \frac{N \cdot m}{kg \cdot K} \times \frac{1}{101 \times 10^3} \cdot \frac{m^2}{N} \times \left[\frac{1}{\frac{1}{(9 + 273) \cdot K} - \frac{1}{(70 + 273) \cdot K}} \right] \qquad V = 2027 \cdot m^3$$

Initial acceleration $\Sigma F_y = F_B - W_{hotair} - W_{load} = (\rho_{atm} - \rho_{hotair}) \cdot g \cdot V_{new} - M \cdot g = M_{accel} \cdot a = (M + 2 \cdot \rho_{hotair} \cdot V_{new}) \cdot a$

Solving for V_{new} $(\rho_{atm} - \rho_{hotair}) \cdot g \cdot V_{new} - M \cdot g = (M + 2 \cdot \rho_{hotair} \cdot V_{new}) \cdot a$

$$V_{new} = \frac{M \cdot g + M \cdot a}{(\rho_{atm} - \rho_{hotair}) \cdot g - 2 \cdot \rho_{hotair} \cdot a} = \frac{M \cdot \left(1 + \frac{a}{g}\right) \cdot R}{p_{atm} \cdot \left[\left(\frac{1}{T_{atm}} - \frac{1}{T_{hotair}} \right) - \frac{2}{T_{hotair}} \cdot \frac{a}{g} \right]}$$

$$V_{new} = 450 \cdot kg \times \left(1 + \frac{0.8}{9.81}\right) \times 286.9 \cdot \frac{N \cdot m}{kg \cdot K} \times \frac{1}{101 \times 10^3} \cdot \frac{m^2}{N} \times \frac{1}{\left(\frac{1}{9 + 273} - \frac{1}{70 + 273} - \frac{2}{70 + 273} \cdot \frac{0.8}{9.81} \right)} \cdot K$$

$V_{new} = 8911 \cdot m^3$ Hence $\Delta V = V_{new} - V$ $\Delta V = 6884 \cdot m^3$

To make the balloon move up or down during flight, the air needs to be heated to a higher temperature, or let cool (or let in ambient air).