Problem (1)

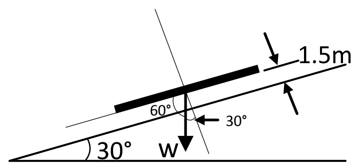
A plate of size 60 cm x 60 cm slides over a plane inclined to the horizontal at an angle of 30°. It is separated from the plane with a film of oil of thickness 1.5 mm. The plate weighs 25kg and slides down with a velocity of 0.25 m/s. Calculate the dynamic viscosity of oil used as lubricant. What would be its kinematic viscosity if the specific gravity of oil is 0.95.

Solution

Component of W along the plane =W cos(60) =W sin(30)
= 25 (0.5) = 12.5 kg

$F = 12.5 \text{ kg } (9.81 \text{ m/s}^2) = 122.625 \text{ N}$

$\tau = F/A = 122.625 \text{ N}/(0.6 \times 0.6) \text{ m}^2 = 340.625 \text{ Pa}$



$$\mu = \frac{\tau}{(du/dy)} = \frac{340.625\ Pa}{(0.25/0.0015)s^{-1}} = 2.044 Pa.s = 20.44\ poise$$

$$\nu = \frac{\mu}{\rho} = \frac{2.044\ Pa.s}{950\ kg/m^3} = 0.00215\ m^2/s = 21.5\ stoke$$

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Problem (2)

By dimensional analysis, obtain an expression for the drag force (F) on a partially submerged body moving with a relative velocity (u) in a fluid; the other variables being the linear dimension (L), surface roughness (e), fluid density (ρ), and gravitational acceleration (g).

Solution

Drag force (F) N	$\equiv [MLT^{-2}]$
Relative velocity (u) m/s	$\equiv [LT^{-1}]$
Linear dimension (L) m	$\equiv [L]$
Surface roughness (e) m	$\equiv [L]$
Density (ρ) kg/m^3	$\equiv [ML^{-3}]$
Acceleration of gravity (g) m/s^2	$\equiv [L\ T^{-2}]$

$$F = k\ (u, L, e, \rho, g)$$

$$f\ (F, u, L, e, \rho, g) = 0$$

$$n = 6,\ m = 3,\ \Rightarrow \Pi = n - m = 6 - 3 = 3$$

No. of repeating variables = m = 3
The selected repeating variables is (u, L, ρ)

$$\Pi_1 = u^{a1}\ L^{b1}\ \rho^{c1}\ F \qquad \text{--------------(1)}$$

$\Pi_2 = u^{a2}\, L^{b2}\, \rho^{c2}\, e$ --------------(2)

$\Pi_3 = u^{a3}\, L^{b3}\, \rho^{c3}\, g$ --------------(3)

For Π_1 equation (1)

$[M^0\, L^0\, T^0] = [L\, T^{-1}]^{a1}\, [L]^{b1}[ML^{-3}]^{c1}[MLT^{-2}]$

Now applied dimensional homogeneity

For M $\quad 0 = c1 + 1 \quad \Rightarrow \quad c1 = -1$

For T $\quad 0 = -a1 - 2 \quad \Rightarrow \quad a1 = -2$

For L $\quad 0 = a1 + b1 - 3c1 + 1 \quad \Rightarrow \quad b1 = -2$

$\Pi_1 = u^{-2}\, L^{-2}\, \rho^{-1}\, F \quad \Rightarrow \quad \Pi_1 = \dfrac{F}{u^2\; L^2\;\; \rho}$

For Π_2 equation (2)

$[M^0\, L^0\, T^0] = [L\, T^{-1}]^{a2}\, [L]^{b2}[ML^{-3}]^{c2}[L]$

For M $\quad 0 = c2 \quad \Rightarrow \quad c2 = 0$

For T $\quad 0 = -a2 \quad \Rightarrow \quad a2 = 0$

For L $\quad 0 = a2 + b2 - 3c2 + 1 \quad \Rightarrow \quad b2 = -1$

$\Pi_2 = L^{-1}\, e \quad \Rightarrow \quad \Pi_2 = \dfrac{e}{L}$

For Π_3 equation (3)

$[M^0\, L^0\, T^0] = [L\, T^{-1}]^{a3}\, [L]^{b3}[ML^{-3}]^{c3}[L\, T^{-2}]$

For M $\quad 0 = c3 \quad \Rightarrow \quad c3 = 0$

For T $\quad 0 = -a3 - 2 \quad \Rightarrow \quad a3 = -2$

For L $\quad 0 = a3 + b3 - 3c3 + 1 \quad \Rightarrow \quad b3 = 1$

$\Pi_3 = u^{-2}\, L\, g \quad \Rightarrow \quad \Pi_3 = \dfrac{L\, g}{u^2}$

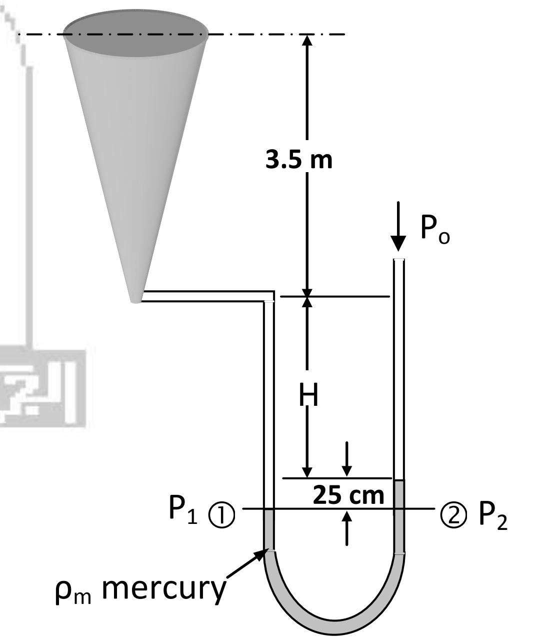
$f_1\, (\Pi_1, \Pi_2, \Pi_3) = 0 \quad \Rightarrow \quad f_1(\dfrac{F}{u^2\; L^2\;\; \rho}, \dfrac{e}{L}, \dfrac{L\, g}{u^2}) = 0$

$\therefore\;\; F = u^2 L^2\;\; \rho\;\, f(\dfrac{e}{L}, \dfrac{L\, g}{u^2})$

Problem (3)

A conical vessel is connected to a U-tube having mercury and water as shown in the Figure. When the vessel is empty the manometer reads 0.25 m. find the reading in manometer, when the vessel is full of water.

Solution



$P_1 = P_2$

$P_1 = (0.25 + H)\,\rho_w\, g + P_o$

$P_2 = 0.25\,\rho_m\, g + P_o$

$\Rightarrow (0.25 + H)\,\rho_w\, g + P_o = 0.25\,\rho_m\, g + P_o$

$\Rightarrow H = 0.25\,(\rho_m - \rho_w)/\,\rho_w$

$= 0.25\,(12600\,/1000) = 3.15$ m

When the vessel is full of water, let the mercury level in the left limp go down by (x) meter and the mercury level in the right limp go to up by the same amount (x) meter.
i.e. the reading manometer = (0.25 + 2x)

$P_1 = P_2$

$P_1 = (0.25 + x + H + 3.5)\,\rho_w\, g + P_o$

$P_2 = (0.25 + 2x)\,\rho_m\, g + P_o$

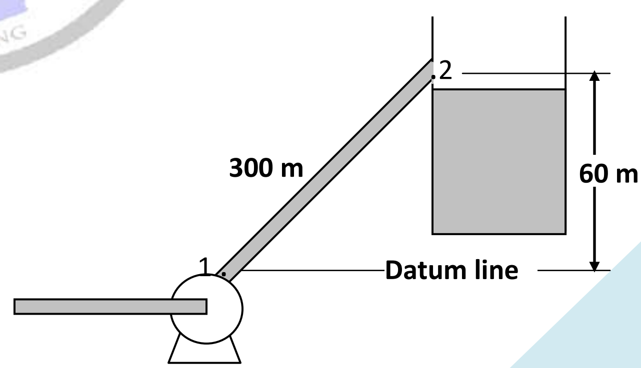
$\Rightarrow (0.25 + x + H + 3.5)\,\rho_w\, g + P_o = (0.25 + 2x)\,\rho_m\, g + P_o$

$\Rightarrow 6.9 + x = (0.25 + 2x)\,(\rho_m/\,\rho_w) \Rightarrow x = 0.1431$ m

The manometer reading = 0.25 + 2 (0.1431) = 0.536 m

Problem (4)

A pump developing a pressure of 800 kPa is used to pump water through a 150 mm pipe, 300 m long to a reservoir 60 m higher. The flow rate obtained is 0.05 m^3/s. As a result of corrosion and scalling the effective absolute roughness of the pipe surface increases by a factor of 10 by what percentage is the flow rate reduced. μ= 1 mPa.s



Solution

The total head of pump developing =($\Delta P/\rho g$) = 800,000/(1000 x 9.81)= 81.55 mH_2o

The head of potential energy = 60 m

Neglecting the kinetic energy (same diameter)

$$\boxed{\frac{\Delta P}{\rho g} + \Delta z + \cancel{\frac{\Delta u^2}{2\alpha g}} - \cancel{\frac{\eta W}{g}} s + h_F = 0}$$

$\Rightarrow \Delta P/\rho g + \Delta z + h_F = 0$

$\Rightarrow h_F = -\Delta P/\rho g - \Delta z = 81.55 - 60 = 21.55$ m
$u = Q/A = (0.05\ m^3/s)/(\pi/4\ 0.15^2) = 2.83$ m/s
$h_{Fs} = (-\Delta P_{fs}/\rho g) = 4f\,(L/d)\,(u^2/2g)$

$\Rightarrow f = h_{Fs}\, d\, 2g/(4Lu^2) = (21.55)(0.15)(9.81)/(2 \times 300 \times 2.83^2) = 0.0066$
$\Phi = 0.0033$, $Re = (1000 \times 2.83 \times 0.15)/0.001 = 4.23 \times 10^5$
From Figure (3.7) e/d = 0.003
Due to corrosion and scalling the roughness increase by factor 10
i.e. $(e/d)_{new} = 10\ (e/d)_{old} = 0.03$
The pump head that supplied is the same
$(-\Delta P_{fs}) = h_{Fs}\, \rho g = 21.55\,(1000)\,9.81 = 211.41$ kPa

$\Phi Re^2 = (-\Delta P_{fs}/L)(\rho d^3/4\mu^2) = [(211410)/(300)][(1000)(0.15)^3/(4)(0.01)^2] = 6 \times 10^8$

From Figure (3.8) $Re = 2.95 \times 10^5$ $\Rightarrow u = 1.97$ m/s

The percentage reduced in flow rate = (2.83 - 1.97)/ 2.83 x 100 % = 30.1 %.

Problem (5)

It is required to pump cooling water from storage pond to a condenser in a process plant situated 10 m above the level of the pond. 200 m of 74.2 mm i.d. pipe is available and the pump has the characteristics given below. The head loss in the condenser is equivalent to 16 velocity heads based on the flow in the 74.2 mm pipe. If the friction factor Φ = 0.003, estimate the rate of flow and the power to be supplied to the pump assuming η = 0.5

Q (m^3/s)	0.0028	0.0039	0.005	0.0056	0.0059
Δh (m)	23.2	21.3	18.9	15.2	11.0

Solution

[Usually the pump done its exact duty and return the liquid at the suction pressure i.e the pump give the minimum limit of energy required to arrive the liquid to point 2 or d]

$$\Delta h = \Delta z + \cancel{\frac{\Delta P}{\rho g}} + \cancel{\frac{\Delta u^2}{2g\,\alpha}} + \left[(h_F)_d + (h_F)_s + (h_F)_{condenser}\right]$$

$$(h_F)_{d+s} = 4f\frac{L}{d}\frac{u^2}{2g} = 4(0.006)(200/0.0742)(u^2/2g) = 3.3\,u^2$$

$$(h_F)_{condenser} = 16\frac{u^2}{2g} = 0.815\,u^2$$

u = Q/A = 321.26 Q

$\Rightarrow \Delta h = 10 + (0.815 + 3.3)(321.26\,Q)^2 = 10 + 2.2 \times 10^5\,Q^2$

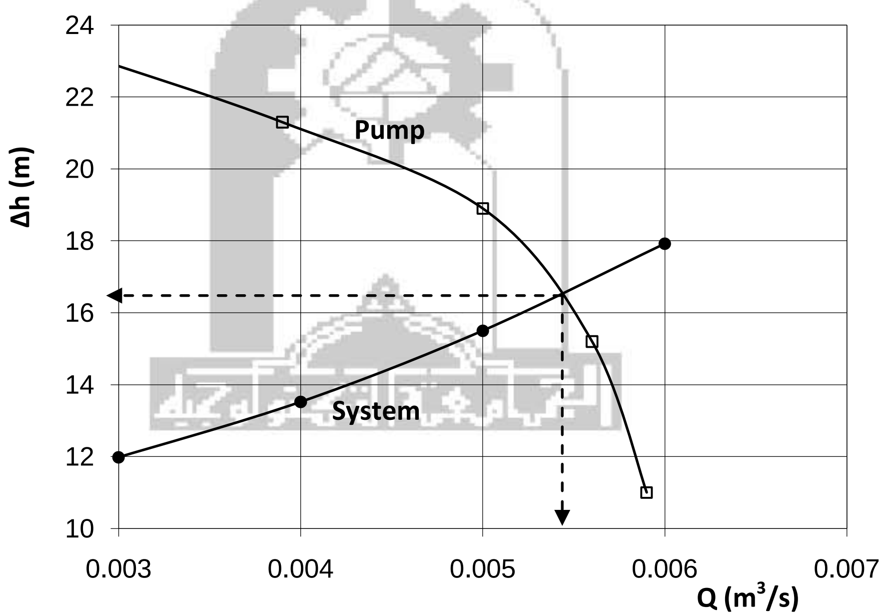
To draw the system curve

$Q\ (m^3/s)$	0.003	0.004	0.005	0.006
Δh (m)	11.98	13.52	15.5	17.92

From Figure

$Q = 0.0054\ m^3/s$

$\Delta h = 16.4$ m



Power required for pump = $\dfrac{Q\Delta h\,\rho\,g}{\eta}$ = (0.0054)(16.4)(1000)(9.81)/0.5

= 17.375 kW

u = 1.25 m/s $\Rightarrow \dfrac{\Delta u^2}{2g} = \mathbf{0.08\ m}$; Δz = 10 m; h_f = 6.415 m

Problem (6)

A Power-law liquid of density 961 kg/m^3 flows in steady state with an average velocity of 1.523 m/s through a tube 2.67 m length with an inside diameter of 0.0762 m. For a pipe consistency coefficient of 4.46 Pa.s^n [or 4.46 (kg / m.s^2) s^n], calculate the values of the apparent viscosity for pipe flow (μ a)P in Pa.s, the Reynolds number Re, and the pressure drop across the tube for power-law indices n = 0.3, 0.7, 1.0, and 1.5 respectively.

Solution

Apparent viscosity $(\mu_a)_P = Kp(\dfrac{8u}{d})^{n-1}$

= 4.46 (kg/m) s^{n-2} [8 (1.523)/0.0762]$^{n-1}$s^{n-1}

$\Rightarrow \quad (\mu_a)_P = 4.46\,(159.9)^{n-1}$ (Pa.s)----------------------------(1)

$$Re = \frac{\rho u d}{(\mu_a)_P} = \frac{\rho u d}{4.46\,(159.9)^{n-1}} = 961\,(1.523)(0.0762) / 4.46\,(159.9)^{n-1}$$

$\Rightarrow \quad Re = 25.006/\,(159.9)^{n-1}$ ----------------------------(2)

$-\Delta P_{fs} = 4f\,(L/d)\,(\rho u^2/2) = 4(16/Re)\,(2.67 / 0.0762)[961(1.523)^2/2]$ for laminar

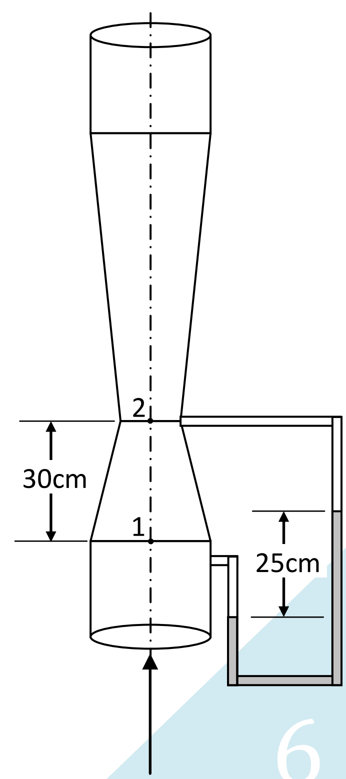
$\Rightarrow \quad -\Delta P_{fs} = 99950.56\,(159.9)^{n-1}$ (Pa)--------------------------(3)

n	$(\mu_a)_P$ Eq.(1)	Re Eq.(2)	$-\Delta P_{fs}$ Eq.(3)	$(-\Delta P_{fs})_{non\text{-}New} / (-\Delta P_{fs})_{New}$	($\eta = 0.6$) Power (W)
0.3	0.1278	872.44	2,865	0.0287	33
0.7	0.9732	114.6	21,809	0.218	252.5
1.0	4.46	25.006	99,950.56	1.0	1157
1.5	56.4	1.9776	1,263,890.541	12.7	14630

Problem (7)

A (30cm x 15cm) Venturi meter is provided in a vertical pipe-line carrying oil of sp.gr. = 0.9. The flow being upwards and the difference in elevations of throat section and entrance section of the venture meter is 30 cm. The differential U-tube mercury manometer shows a gauge deflection of 25 cm. Take Cd = 0.98 and calculate: -

i- The discharge of oil
ii- The pressure difference between the entrance and throat sections.



Solution

i- $$Q = u_2 A_2 = C_d \sqrt{\frac{2R(\rho_m - \rho)g}{\rho}}\,\frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}$$

$$= 0.98\sqrt{\frac{2(0.25)(12700)9.81}{900}}\left[\frac{0.3^2[\pi/4(0.15)^2]}{\sqrt{0.3^4 - 0.15^4}}\right]$$

$= 0.1488\ m^3/s$

ii- Applying Bernoulli's equation at points 1 and 2

$$\frac{P_1}{\rho g} + \frac{u_1^2}{2g} + \cancel{z_1} = \frac{P_2}{\rho g} + \frac{u_2^2}{2g} + z_2$$

$$\frac{P_1 - P_2}{\rho g} = z_2 + \frac{u_2^2 - u_1^2}{2g}$$

$u_1 = 0.1488/(\pi/4\ 0.3^2) = 2.1$ m/s, $u_2 = 0.1488/(\pi/4\ 0.15^2) = 8.42$ m/s

$\Rightarrow P_1 - P_2 = 900\,(9.81)\,[0.3 + (8.42^2 - 2.1^2)/2(9.81)]$

$= 32.5675$ kPa

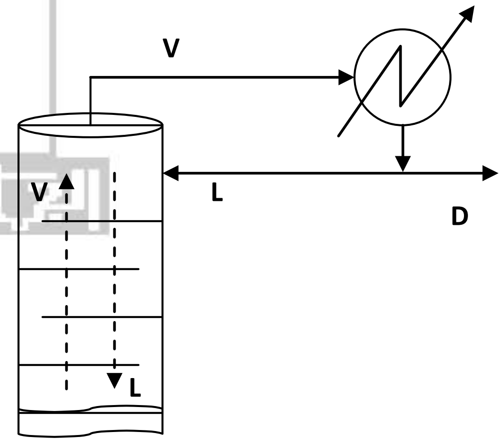
but $P_1 - P_2 = 0.25\,(13600 - 900)(9.81) = 31.1467$ kPa

% error = 4.36 %

Problem (8)

A vacuum distillation plant operating at 7 kPa pressure at top has a boil-up rate of 0.125 kg/s of xylene. Calculate the pressure drop along a 150 mm bore vapor pipe used to connect the column to the condenser. And also calculate the maximum flow rate if L = 6 m, e = 0.0003 m, Mwt = 106 kg/kmol, T = 338 K, μ = 0.01 mPa.s.

Solution



$$G^2 \ln\left(\frac{P_1}{P_2}\right) + \frac{(P_2^2 - P_1^2)}{2\,P_1\upsilon_1} + 4\phi\frac{L}{d}G^2 = 0$$

$G = 0.125 / [\pi/4\,(0.15)^2] = 7.074$ kg/m^2.s

$P_1 = 7$ kPa, P_2 = Pressure at condenser

$$P_1\upsilon_1 = \frac{RT}{Mwt} = \frac{8314\,(\text{Pa.m}^3/\text{kmol.K})\,338\text{K}}{106\text{ kg/kmol}}$$

$$= 26510.68 \quad (J/kg \equiv m^2/s^2)$$

$Re = G\,d/\mu = 7.074(0.15)/0.01 \times 10^{-3} = 1.06 \times 10^5$

, $e/d = 0.002 \Rightarrow \quad \Phi = 0.003$ (Figure 3.7)

$$\Rightarrow \ln\left(\frac{7\times10^3}{P_2}\right) + 3.769\times10^{-7}[P_2^2 - (7\times10^3)^2] + 4(0.003)\frac{6}{0.15} = 0$$

$$\Rightarrow \quad P_2^2 = (7\times10^3)^2 - \frac{\ln(7\times10^3/P_2) + 0.48}{3.769\times10^{-7}} \quad \Rightarrow \quad P_2 = \sqrt{(7\times10^3)^2 - \frac{\ln(7\times10^3/P_2) + 0.48}{3.769\times10^{-7}}}$$

Solution by trial and error

P_2 Assumed	5 x 10^3	6.8435 x 10^3	6.904 x 10^3	6.9057 x 10^3
P_2 Calculated	6.8435 x 10^3	6.904 x 10^3	6.9057 x 10^3	6.9058 x 10^3

$\Rightarrow \quad P_2 = 6.9058 \times 10^3$ Pa

$-\Delta P = P_1 - P_2 = (7 - 6.9058) \times 10^3 = 94.2$ Pa

$[(P_1 - P_2)/P_1]$ % = 0.665 % we can neglect the K.E. term in this problem

For maximum flow rate calculations

$$\dot{m}_{max} = A\,P_w\sqrt{1/P_1\upsilon_1} \quad \Rightarrow \quad G_{max} = P_w\sqrt{1/P_1\upsilon_1}$$

To estimate P_w $$\ln\left(\frac{P_1}{P_w}\right)^2 + 1 - \left(\frac{P_1}{P_w}\right)^2 + 8\phi\frac{L}{d} = 0$$

Let $X \equiv (P_1/P_w)^2$

$\Rightarrow \quad \ln(X) + 1 - X + 8\,\Phi\, L/d = 0 \Rightarrow \; X = 1.96 + \ln(X)$

Solution by trial and error

X Assumed	1.2	2.14	2.72	2.96	3.074	3.086	3.087
X Calculated	2.14	2.72	2.96	3.074	3.086	3.087	3.087

$\Rightarrow \quad X = 3.087 = (P_1/P_w)^2 \qquad \Rightarrow \qquad P_w = P_1/(3.087)^{0.5} = 3984$ Pa

∴ This system did not reached maximum velocity (**<u>H.W. explain</u>**)

$\Rightarrow \quad G_{max} = 3984 / (26510.68)^{0.5} = 24.47$ kg/m^2.s

<u>Problem (9)</u>

Calculate the theoretical power in Watt for a 0.1 m diameter, 6-blade flat blade turbine agitator running at 16 rev/s in a tank system without baffles and conforming to the standard tank configuration. The liquid in the tank has a dynamic viscosity of 0.08 Pa.s, and a liquid density of 900 kg/m^3.

<u>Solution</u>

$(Re)_m = \rho\, N\, D_A^2 / \mu = (900)(16)(0.1)^2/(0.08) = 1{,}800$

From Power curve Figure (2) $\Phi = 2.2$

The theoretical power for mixing $\quad P_A = \Phi\,[(Fr)_m]^y\,\rho\,N^3 D_A^5$

$$y = \frac{\alpha - \log(Re)_m}{\beta} \qquad \Rightarrow y = \frac{1-\log(1800)}{40} \quad = \quad -0.05638$$

$(Fr)_m = N^2 D_A / g = (16)^2 (0.1)/9.81 = 2.61$

$[(Fr)_m]^y = [2.61]^{-0.05638} = 0.9479$

$\Rightarrow P_A = 2.2\,(0.9479)(900)(16)^3(0.1)^5 = 76.88$ W

<u>Problem (10)</u>

In contact sulphuric acid plant the secondary converter is a tray type converter 2.3 m I.D. with the catalyst arranged in three layers, each 0.45 m thickness. The catalyst is in form of cylindrical pellets 9.5 mm I.D. and 9.5 mm long. The void fraction is 0.35. The gas enters the converter at 675 K and leaves at 720 K. Its inlet and outlet compositions are:-

Gas	SO_3	SO_2	O_2	N_2
mol % In	6.6	1.7	10	81.7
mol % Out	8.2	0.2	9.3	82.3

The gas flow rate is 0.68 kg/m^2.s. Calculate the pressure drop through the converter. Taken that the dynamic viscosity = 0.032 mPa.s.

<u>Solution</u>

$$\Phi' = J'_f = \frac{(-\Delta P)}{L}\frac{e^3}{S(1-e)\rho u^2} = \frac{5}{\mathrm{Re}'} + \frac{0.4}{\mathrm{Re}'^{0.1}} \quad \text{and} \quad \mathrm{Re}' = \frac{\rho u}{\mu s(1-e)}$$

$$S = \frac{A_P}{V_P} = \frac{\textbf{Surface area of particle}}{\textbf{Volume of particle}} = \frac{2(\pi/4\, d_p^2) + (\pi d_p L_P)}{\pi/4\, d_p^2 L_p} = \frac{\pi/2\, d_p^2 + \pi\, d_p^2}{\pi/4\, d_p^3} = \frac{6}{d_p}$$

$$\Rightarrow \mathrm{Re}' = \frac{\rho u d_p}{6(1-e)\mu} = \frac{G d_p}{6(1-e)\mu}$$

$$\rho_{gas} = \frac{(Mwt)_{avg} P}{R T_{avg}}, \quad T_{avg} = \frac{T_{in} + T_{out}}{2}, \quad (Mwt)_{avg} = \frac{Mwt_{in} + Mwt_{out}}{2}, (Mwt) = \sum_{i=1}^{n} x_i Mwt_i$$

$(Mwt)_{in}$ = 0.066(80) + 0.017(64) + 0.1(32) + 0.817(28) = 32.44 kg/kmol

$(Mwt)_{out}$ = 0.082(80) + 0.002(64) + 0.093(32) + 0.823(28) = 32.71 kg/kmol

$(Mwt)_{aug}$ = 32.58 kg/kmol; T_{avg}= 697.5 K

$$\rho_{gas} = \frac{32.58(1.01325\times10^5)}{8314(697.5)} = 0.569 kg/m^3$$

$$\Rightarrow \mathrm{Re}' = \frac{G d_p}{6(1-e)\mu} = \frac{0.68(9.5\times10^{-3})}{6(1-0.35)0.032\times10^{-3}} = 51.76 \qquad \Rightarrow \Phi' = \frac{5}{51.76} + \frac{0.4}{(51.76)^{0.1}} = 0.366$$

$$\Rightarrow -\Delta P = L\Phi' \frac{S(1-e)\rho u^2}{e^3} = \frac{\Phi' L 6(1-e) G^2}{d_p e^3 \rho} = \frac{0.366(3\times0.45)6(1-0.35)(0.68)^2}{9.5\times10^{-3}(0.35)^3 0.569} = 3844.65\ Pa$$

Problem (11)

What will be the settling velocity of a spherical steel particle, 0.4 mm diameter, in an oil of sp.gr 0.82 and viscosity 10 mPa.s? The spgr. of steel is 7.87.

Solution

For a sphere

$$C_D(\mathrm{Re})_p^2 = \frac{4}{3}Ga \qquad , \qquad Ga = \frac{\rho(\rho_p - \rho) g d_p}{\mu^2} = 36.29$$

$$\Rightarrow C_D(\mathrm{Re})_p^2 = 48.34 \qquad \Rightarrow \frac{C_D}{2}(\mathrm{Re})_p^2 = 24.2$$

From Figure at $\frac{C_D}{2}(\mathrm{Re})_p^2 = 24.2$, $(\mathrm{Re})_p$ = 1.667

$$\Rightarrow u_p = \frac{(\mathrm{Re})_p \mu}{\rho d_p} = \frac{1.667(10\times10^{-3})}{820(0.0004)} = 0.051 m/s$$

Problem (12)

A mixture of gas and liquid flows through a tube of ID 0.02m at a steady total flow rate of 0.2 kg/s. Calculate the pressure gradient in the pipe using the Lockhart-Martinelli correlation. Given that e = 0.0015 mm, μG = 0.01 and μL = 2 mPa.s, ρG = 60 and ρL = 1000 kg/m^3, and the quality w =0.149.

Solution

$G = 0.2/(\pi/4\ 0.02^2) = 636.62\ kg/m^2s$

$Re_L = [636.62\ (1-0.149) \times 0.02)/\ 2 \times 10^{-3} = 5.417 \times 10^3$ turbulent

$Re_G = [636.62\ (0.149) \times 0.02)/\ 0.01 \times 10^{-3} = 1.897 \times 10^5$ turbulent

$$X_{tt} = \left(\frac{1-w}{w}\right)^{0.9}\left(\frac{\mu_L}{\mu_G}\right)^{0.1}\left(\frac{\rho_G}{\rho_L}\right)^{0.5} = 1.996$$

$$\Phi_L^2 = 1 + \frac{C}{X} + \frac{1}{X^2}, \text{ for tt C = 20} \quad \Rightarrow \quad \Phi_L^2 = 11.27$$

$Re_L = 5.417 \times 10^3$, $e/d = 0.000075 \Rightarrow f = 0.009$

$$\left(\frac{dP}{d\ell}\right)_L = 4f\frac{1}{d}\frac{G^2(1-w)^2}{2\rho_L} = 4(0.009)\frac{1}{0.02}\frac{636.62^2(1-0.149)^2}{2(1000)} = 264.157\ Pa/m$$

$$\left(\frac{dP}{d\ell}\right)_T = \Phi_L^2\left(\frac{dP}{d\ell}\right)_L = 11.27(132.078) = 2977.05\ Pa/m$$

Problem (12)

A cylindrical tank 0.9 m ID and 2 m high open at top is filled with water to a depth of 1.5 m. it is rotated about its vertical axis at N rpm. Determine the value of N which will raise water level even with the brim.

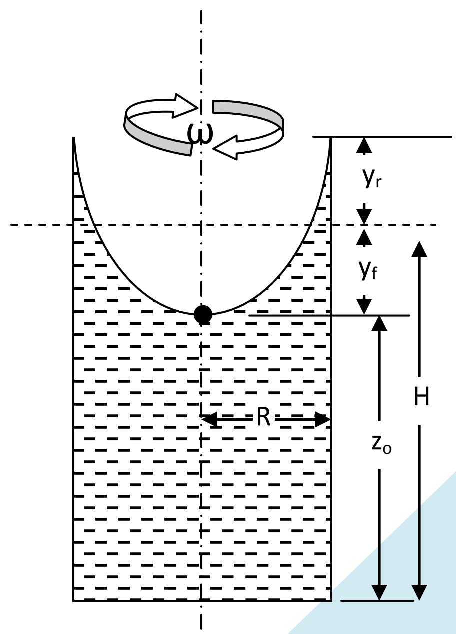
Solution

The water level even with brim $P = P_o$, z = 2 m

The rise of liquid at wall $y_r = 2 - 1.5 = 0.5$ m

The fall of liquid at wall $y_f = y_r = 0.5$ m

$z_o = H - y_f = 1$ m, z = 2 m at r = R



$$z = z_o + \frac{\omega^2}{2g}r^2$$

$$\Rightarrow 2 = 1 + \frac{\omega^2}{2(9.81)}0.45^2$$

$\omega = 9.843$ rad/s

$$\omega = \frac{2\pi N}{60} \Rightarrow N = \frac{60(9.843)}{2\pi} \approx 94\ rpm$$