Subject Name & Code:

FLUID MECHANICS - BE04000161

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Assignment – 3

Q-1: Reynolds Number & Flow Regime: Jatropha oil (Specific Gravity = 0.92, dynamic viscosity = 0.035 Pa.s) flows through a 50 mm diameter pipe. Calculate the maximum volumetric flow rate (Q) for which the flow will remain strictly laminar (Assume critical Reynolds number Re = 2000).

Answer:

Given:
SG = 0.92 → $\rho = 920\ \text{kg/m}^3$

$$\mu = 0.035\ \text{Pa}\cdot\text{s}$$
$$D = 50\ \text{mm} = 0.05\ \text{m}$$
$$Re_{crit} = 2000$$

To Find: Max volumetric flow rate Q for laminar flow

Formula:
$Re = \frac{\rho V D}{\mu} = 2000 \rightarrow V = \frac{2000}{\rho D}$

$$Q = V \times \frac{\pi D^2}{4}$$

Solution:

$$V = \frac{2000 \times 0.035}{920 \times 0.05} = \frac{70}{46} = 1.5217\ \text{m/s}$$
$$Q = 1.5217 \times \frac{\pi (0.05)^2}{4} = 1.5217 \times 0.0019635 = 0.002988\ \text{m}^3/\text{s}$$
$$Q \approx 2.99\ \text{lps}$$

Final Answer:

$$\boxed{Q_{max} = 0.00299\ \text{m}^3/\text{s} \approx 3\ \text{lps}}$$

Q-2: Hagen-Poiseuille Flow: For the laminar flow of the Jatropha oil calculated in Question 1, determine the pressure drop over a 15 m length of the horizontal pipe. Also, calculate the maximum velocity and the shear stress at the pipe wall.

Answer:

Given:
From Q1: $Q = 0.002988 \text{ m}^3/\text{s}$

$$D = 0.05 \text{ m}$$
$$L = 15 \text{ mm} = 0.015 \text{ m}$$
$$\mu = 0.035 \text{ Pa} \cdot \text{s}$$
$$\rho = 920 \text{ kg/m}^3$$

To Find: ΔP, max velocity u_{max}, wall shear stress τ_w

Solution:
$V = \frac{Q}{A} = \frac{0.002988}{0.0019635} = 1.5217 \text{ m/s}$ (same as above)

$$\Delta P = \frac{128\mu LQ}{\pi D^4} = \frac{128 \times 0.035 \times 0.015 \times 0.002988}{\pi \times (0.05)^4}$$
$$\text{Num} = 128 \times 0.035 \times 0.015 \times 0.002988 = 128 \times 1.5687 \times 10^{-6} = 0.0002008$$

Denom = $\pi \times 6.25 \times 10^{-6} = 1.9635 \times 10^{-5}$

$$\Delta P = \frac{0.0002008}{1.9635 \times 10^{-5}} = 10.23 \text{ Pa}$$
$$u_{max} = 2V = 3.0434 \text{ m/s}$$
$$\tau_w = \frac{\Delta P \cdot D}{4L} = \frac{10.23 \times 0.05}{4 \times 0.015} = \frac{0.5115}{0.06} = 8.525 \text{ Pa}$$

Final Answer:

$$\boxed{\Delta P = 10.23 \text{ Pa}, u_{max} = 3.04 \text{ m/s}, \tau_w = 8.53 \text{ Pa}}$$

Q-3: Darcy-Weisbach & Friction: Water flows through a rough pipe of diameter 400 mm and length 2500 m at a rate of 0.4 m3/s. If the kinematic viscosity of water is 1 x 10-6 m2/s and the absolute roughness is 0.05 mm, use the Moody diagram concept (or Colebrook equation) to find the friction factor and subsequently calculate the major head loss.

Answer:

Given:
$D = 0.4 \text{ m}, L = 2500 \text{ m}$

$$Q = 0.4 \text{ m}^3/\text{s}$$
$$\nu = 1 \times 10^{-6} \text{ m}^2/\text{s}$$

Absolute roughness $\varepsilon = 0.05 \text{ mm} = 5 \times 10^{-5} \text{ m}$

To Find: Friction factor f, major head loss h_f

Solution:

$$V = \frac{Q}{A} = \frac{0.4}{\pi/4 \times (0.4)^2} = \frac{0.4}{0.12566} = 3.183 \text{ m/s}$$

$$Re = \frac{VD}{\nu} = \frac{3.183 \times 0.4}{1 \times 10^{-6}} = 1.273 \times 10^6$$

Relative roughness $\varepsilon/D = \frac{5\times10^{-5}}{0.4} = 1.25 \times 10^{-4}$

From Moody chart for $Re = 1.27 \times 10^6$, $\varepsilon/D = 0.000125$:
$f \approx 0.014$ (smooth pipe zone?) Check Colebrook: For such low roughness, f close to smooth pipe: $f = 0.012$ to 0.014. Let's take $f = 0.013$.

$$h_f = f\frac{L}{D}\frac{V^2}{2g} = 0.013 \times \frac{2500}{0.4} \times \frac{(3.183)^2}{2 \times 9.81}$$

$$= 0.013 \times 6250 \times \frac{10.13}{19.62} = 0.013 \times 6250 \times 0.5165$$

$$= 0.013 \times 3228 = 41.96 \text{ m of water}$$

Final Answer:

$$\boxed{f \approx 0.013, h_f \approx 42.0 \text{ m}}$$

Q-4: Minor Losses: An engine cooling system features a sudden expansion in a pipe from 50 mm to 100 mm diameter. If the flow rate of the coolant is 12 lps, calculate the head loss due to the sudden expansion.

Answer:

Given:

$$D_1 = 50 \text{ mm} = 0.05 \text{ m}$$

$$D_2 = 100 \text{ mm} = 0.1 \text{ m}$$

$$Q = 12 \text{ lps} = 0.012 \text{ m}^3/\text{s}$$

Water: $\rho = 1000$

To Find: Head loss h_L

Formula:

$h_L = \frac{(V_1 - V_2)^2}{2g}$ or $h_L = K\frac{V_1^2}{2g}$ with $K = \left(1 - \frac{A_1}{A_2}\right)^2$

Solution:

$A_1 = 0.0019635 \text{ m}^2$, $A_2 = 0.007854 \text{ m}^2$

$$V_1 = 0.012/0.0019635 = 6.112 \text{ m/s}$$

$$V_2 = 0.012/0.007854 = 1.528 \text{ m/s}$$

$$h_L = \frac{(6.112 - 1.528)^2}{2 \times 9.81} = \frac{(4.584)^2}{19.62} = \frac{21.01}{19.62} = 1.071 \text{ m}$$

Final Answer:

$$\boxed{h_L = 1.07\text{ m}}$$

Q-5: Pipes in Series & Parallel: Two pipes of lengths 1000 m and 800 m, and diameters 300 mm and 200 mm respectively, are connected in series. Find the diameter of an equivalent pipe of length 1800 m that will carry the same discharge for the same total head loss.

Answer:

Given:
Pipe 1: $L_1 = 1000\text{ m}, D_1 = 0.3\text{ m}$
Pipe 2: $L_2 = 800\text{ m}, D_2 = 0.2\text{ m}$
Series connection.
Equivalent pipe: $L_e = 1800\text{ m}$, find D_e

Formula (Darcy-Weisbach, same f for all pipes):
$h_f = h_{f1} + h_{f2} \rightarrow \frac{fL_eQ^2}{12.1D_e^5} = \frac{fL_1Q^2}{12.1D_1^5} + \frac{fL_2Q^2}{12.1D_2^5}$
Cancel common terms:

$$\frac{L_e}{D_e^5} = \frac{L_1}{D_1^5} + \frac{L_2}{D_2^5}$$

Solution:

$$\frac{1800}{D_e^5} = \frac{1000}{(0.3)^5} + \frac{800}{(0.2)^5}$$

$(0.3)^5 = 0.00243\,,\,(0.2)^5 = 0.00032$

$$\frac{1000}{0.00243} = 411522, \frac{800}{0.00032} = 2.5 \times 10^6$$

Sum = 2,911,522

$$D_e^5 = \frac{1800}{2911522} = 0.0006183$$
$$D_e = (0.0006183)^{1/5} = (6.183 \times 10^{-4})^{0.2}$$

Let's calculate: $\log\, D_e = \frac{1}{5}(\log\, 6.183 \times 10^{-4}) = \frac{1}{5}(0.7912 - 4) = \frac{1}{5}(-3.2088) = -0.64176$

$$D_e = 10^{-0.64176} = 0.228\text{ m} \approx 228\text{ mm}$$

Final Answer:

$$\boxed{D_e = 228\text{ mm}}$$