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Quiz: No. 9

Time: 15 minutes

ME:5160, Fall 2023

The exam is closed book and closed notes.

SAE 30W oil at 20°C ($\rho=891 \text{ kg/m}^3$; $\mu=0.29 \text{ kg/m-s}$) flows through a straight horizontal pipe 25 m long, with diameter 4 cm. The average velocity is 2 m/s. (a) Is the flow laminar ($Re < 2300$)? Calculate (b) the pressure drop Δp and (c) the power required P . (d) If the pipe diameter is halved, for the same flow rate, by what factor does the required power increase?

Hint: $Power = Q\Delta p$

Energy equation:
$$\left(\frac{p}{\rho g} + \frac{V^2}{2g} + z \right)_1 = \left(\frac{p}{\rho g} + \frac{V^2}{2g} + z \right)_2 + h_f$$

Laminar pipe flow:
$$h_f = f \frac{L}{D} \frac{V^2}{2g}; \quad f = \frac{64}{Re_D}$$

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Solution:KNOWN: D, L, ρ, μ, V FIND: Flow regime, pressure drop, power, power if $D \rightarrow D/2$ (1)ASSUMPTIONS: $\alpha \approx 1$, no minor losses

ANALYSIS:

(a)

$$Re_d = \frac{\rho V d}{\mu} = \frac{(891)(2.0)(0.04)}{0.29} \approx 246 < 2300 \quad (1)$$

Yes, laminar flow.

(b)

$$\left(\frac{p}{\rho g} + \frac{V^2}{2g} + z \right)_1 = \left(\frac{p}{\rho g} + \frac{V^2}{2g} + z \right)_2 + h_f \quad (1)$$

$$V_1 = V_2; z_1 = z_2$$

$$\frac{\Delta p}{\rho g} = h_f$$

$$\Delta p = \rho g h_f = \rho g \left(\frac{64}{Re_D} \frac{L V^2}{D 2g} \right) = \frac{32 \mu L V}{D^2} \quad (2)$$

$$\Delta p = \frac{32(0.29)(25)(2.0)}{(0.04)^2} \approx 290,000 \text{ Pa} = 290 \text{ kPa}$$

(c)

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

$$Q = \frac{\pi}{4} (0.04)^2 (2.0) \approx 0.00251 \text{ m}^3/\text{s} \quad (1.5)$$

$$P = Q \Delta p = (0.00251)(290,000) \approx 728 \text{ W}$$

(d)

$$D = 2 \text{ cm} = 0.02 \text{ m}$$

$$Q = 0.00251 = \frac{\pi}{4} (0.02)^2 V$$

$$V = 8 \text{ m/s} \quad (1)$$

$$Re_d = \frac{\rho V d}{\mu} = \frac{(891)(8)(0.02)}{0.29} \approx 492 < 2300$$

Still laminar.

$$\Delta p = \frac{32 \mu L V}{d^2} = \frac{32(0.29)(25)(8.0)}{(0.02)^2} \approx 4,640,000 \text{ Pa}$$

$$P = Q \Delta p = (0.00251)(4,640,000) \approx 11,646 \text{ W} \quad (0.5)$$

$$factor = \frac{11,646}{728} \approx 16$$