Thus $h_f = z_1 - z_2 > 0$ by definition. Therefore, **flow is down**. *Ans.*

While flowing down, the pressure drop due to friction exactly balances the pressure rise due to gravity. Assuming laminar flow and noting that Δz = L, the pipe length, we get

$$h_f = \frac{128\mu LQ}{\pi\rho g d^4} = \Delta z = L,$$

$$\text{or:}\quad Q = \frac{\pi(8.70)(9.81)(0.025)^4}{128(0.104)} = 7.87E\text{–}4\ \frac{m^3}{s} = \mathbf{2.83\ \frac{m^3}{h}} \quad \textit{Ans.}$$

6.24 Two tanks of water at 20°C are connected by a capillary tube 4 mm in diameter and 3.5 m long. The surface of tank 1 is 30 cm higher than the surface of tank 2. (a) Estimate the flow rate in m^3/h. Is the flow laminar? (b) For what tube diameter will Re_d be 500?

Solution: For water, take ρ = 998 kg/m^3 and μ = 0.001 kg/m·s. (a) Both tank surfaces are at atmospheric pressure and have negligible velocity. The energy equation, when neglecting minor losses, reduces to:

$$\Delta z = 0.3\ m = h_f = \frac{128\mu LQ}{\pi\rho g d^4} = \frac{128(0.001\ kg/m\cdot s)(3.5\ m)Q}{\pi(998\ kg/m^3)(9.81\ m/s^2)(0.004\ m)^4}$$

$$\text{Solve for}\quad Q = 5.3E\text{–}6\ \frac{m^3}{s} = \mathbf{0.019\ \frac{m^3}{h}} \quad \textit{Ans. (a)}$$

Check $Re_d = 4\rho Q/(\pi\mu d) = 4(998)(5.3E\text{–}6)/[\pi(0.001)(0.004)]$

$\mathbf{Re_d = 1675}$ ***laminar.*** *Ans.* (a)

(b) If $Re_d = 500 = 4\rho Q/(\pi\mu d)$ and $\Delta z = h_f$, we can solve for both Q and d:

$$Re_d = 500 = \frac{4(998\ kg/m^3)Q}{\pi(0.001\ kg/m\cdot s)d}, \quad \textbf{or} \quad Q = 0.000394d$$

$$h_f = 0.3\ m = \frac{128(0.001\ kg/m\cdot s)(3.5\ m)Q}{\pi(998\ kg/m^3)(9.81\ m/s^2)d^4}, \quad or \quad Q = 20600d^4$$

Combine these two to solve for $Q = 1.05E\text{–}6\ m^3/s$ *and* **d = 2.67 mm** *Ans.* (b)
