6.21 In Tinyland, houses are less than a foot high! The rainfall is laminar! The drainpipe in Fig. P6.21 is only 2 mm in diameter. (a) When the gutter is full, what is the rate of draining? (b) The gutter is designed for a sudden rainstorm of up to 5 mm per hour. For this condition, what is the maximum roof area that can be drained successfully? (c) What is Red?

**Solution:** If the velocity at the gutter surface is neglected, the energy equation reduces to

\[ \Delta z = \frac{V^2}{2g} + h_f, \quad \text{where} \quad h_{f,\text{laminar}} = \frac{32 \mu LV}{\rho g d^2} \]

For water, take \( \rho = 998 \, \text{kg/m}^3 \) and \( \mu = 0.001 \, \text{kg/m-s} \). (a) With \( \Delta z \) known, this is a quadratic equation for the pipe velocity \( V \):

\[ 0.2 = \frac{V^2}{2(9.81 \, \text{m/s}^2)} + \frac{32(0.001 \, \text{kg/m-s})(0.2 \, \text{m})V}{(998 \, \text{kg/m}^3)(9.81 \, \text{m/s}^2)(0.002 \, \text{m})^2} \]

or: \( 0.051V^2 + 0.1634V - 0.2 = 0 \). Solve for \( V = 0.945 \, \frac{m}{s} \),

\[ Q = \frac{\pi}{4} (0.002 \, \text{m})^2 (0.945 \, \frac{m}{s}) = 2.97E-6 \, \frac{m^3}{s} = 0.0107 \, \frac{m^3}{h} \quad \text{Ans. (a)} \]

(b) The roof area needed for maximum rainfall is \( 0.0107 \, \text{m}^3/h : 0.005 \, \text{m}/h = 2.14 \, \text{m}^2 \). Ans. (b)

(c) The Reynolds number of the gutter is \( \text{Red} = (998)(0.945)(0.002)/(0.001) = 1890 \, \text{laminar} \). Ans. (c)