3.66 Determine the manometer reading, $h$, for the flow shown in Fig. P3.66.

\[
\frac{\rho_1}{\delta} + \frac{V_1^2}{2g} + z_1 = \frac{\rho_2}{\delta} + \frac{V_2^2}{2g} + z_2 \quad \text{where } z_1 = z_2, \ V_1 = 0, \ \text{and} \ V_2 = 0
\]

Thus,

\[\rho_1 = \rho_2\]

However, \[\rho_1 = \delta h \ \text{and} \ \rho_2 = \delta (0.37 \text{m})\]

so that

\[h = 0.37 \text{ m}\]
3.31 Water flows through the pipe contraction shown in Fig. P3.31. For the given 0.2-m difference in the manometer level, determine the flow rate as a function of the diameter of the small pipe, \( D \).

\[
\frac{\rho_1}{\delta} + \frac{V_1^2}{2g} + z_1 = \frac{\rho_2}{\delta} + \frac{V_2^2}{2g} + z_2 \quad \text{with} \quad A_1V_1 = A_2V_2
\]

Thus, with \( z_1 = z_2 \)

\[
\frac{\rho_1 - \rho_2}{\delta} = \frac{V_2^2 - V_1^2}{2g} = \frac{\left[\left(\frac{0.1}{D}\right)^4 - 1\right]V_i^2}{2g}
\]

but

\( \rho_i = \delta h_i \) and \( \rho_2 = \delta h_2 \) so that \( \rho_1 - \rho_2 = \delta(h_i - h_2) = 0.2 \delta \)

Thus,

\[
\frac{0.2 \delta}{\delta} = \frac{\left[\left(\frac{0.1}{D}\right)^4 - 1\right]V_i^2}{2g} \quad \text{or} \quad V_i = \sqrt{\frac{0.2 (2g)}{\left[\left(\frac{0.1}{D}\right)^4 - 1\right]}}
\]

and

\[
Q = A_iV_i = \frac{\pi}{4} (0.1)^2 \sqrt{\frac{0.2 (2 (9.81))}{\left[\left(\frac{0.1}{D}\right)^4 - 1\right]}}
\]

or

\[
Q = \frac{0.0156 D^2}{\sqrt{(0.1)^4 - D^4}} \quad \text{m}^3 / \text{s} \quad \text{when} \ D \sim m
\]
Water flows steadily downward through the pipe shown in Fig. P3.25. Viscous effects are negligible, and the pressure gage indicates the pressure is zero at point (1). Determine the flowrate and the pressure at point (2).

\[
\frac{P_1}{g} + Z_1 + \frac{V_1^2}{2g} = \frac{P_3}{g} + Z_3 + \frac{V_3^2}{2g}
\]

where \( Z_1 = 3 \text{ ft} \), \( Z_3 = 0 \), \( P_1 = P_3 = 0 \)

and

\[
V_1 = \frac{A_3}{A_1} V_3 = \left( \frac{T_1 (0.1 \text{ ft})}{T_3 (0.12 \text{ ft})} \right) \frac{V_3}{V_3} = 0.694 V_3
\]

Thus,

\[
\frac{(0.694)^2 V_3^2}{2(32.2 \text{ ft}/\text{s}^2)} + 3 \text{ ft} = \frac{V_3^2}{2(32.2 \text{ ft}/\text{s}^2)} \quad \text{or} \quad V_3 = 19.3 \text{ ft/s}
\]

so that

\[
Q_3 = A_3 V_3 = \frac{\pi}{4} (0.1 \text{ ft})^2 (19.3 \text{ ft/s}) = 0.152 \text{ ft}^3/\text{s}
\]

Also,

\[
\frac{P_2}{g} + Z_2 + \frac{V_2^2}{2g} = \frac{P_1}{g} + Z_1 + \frac{V_1^2}{2g}
\]

where \( P_1 = 0 \) and since \( A_1 = A_2 \) it follows that \( V_2 = V_1 \)

Thus,

\[
Z_2 - Z_1 = -\frac{P_2}{g} \quad \text{or} \quad \frac{P_2}{g} = -2 \text{ ft}
\]

or

\[
\frac{P_2}{g} = -2 \text{ ft} \left( 62.4 \frac{\text{lb}}{\text{ft}^2} \right) = -125 \frac{\text{lb}}{\text{ft}^2}
\]
Small-diameter, high-pressure liquid jets can be used to cut various materials as shown in Fig. P3.26. If viscous effects are negligible, estimate the pressure needed to produce a 0.10-mm-diameter water jet with a speed of 700 m/s. Determine the flowrate.

\[
\frac{\rho_1}{2g} + \frac{V_1^2}{2} + z_1 = \frac{\rho_2}{2g} + \frac{V_2^2}{2} + z_2
\]

where \( V_1 \approx 0 \), \( z_1 \approx z_2 \), and \( \rho_2 = 0 \)

Thus \( \rho_1 = \frac{1}{2} \frac{g}{V_2} \)

\[
Q = \frac{V_2 A_2}{s} = 700 \frac{m}{s} \left[ \frac{\pi}{4} (10^{-4} m)^2 \right] = 5.50 \times 10^{-6} \frac{m^3}{s}
\]

Also,

\[
Q = \frac{V_2 A_2}{s} = 700 \frac{m}{s} \left[ \frac{\pi}{4} (0.10 \text{ mm})^2 \right] = 2.45 \times 10^5 \frac{\text{KN}}{m^2}
\]
The pump shown in Fig. P8.75 delivers a head of 250 ft to the water. Determine the power that the pump adds to the water. The difference in elevation of the two ponds is 200 ft.

\[
\frac{P_1}{g} + \frac{V^2}{2g} - h_c + h_p = \frac{P_2}{g} + \frac{V_2^2}{2g},
\]

where \( P_1 = P_2 = 0 \), \( V_1 = V_2 = 0 \), \( Z_1 = 0 \), \( Z_2 = 200 \) ft, \( h_p = 250 \) ft.

Thus,

\[-f \int \frac{V^2}{2g} - \sum L_i \frac{V^2}{2g} + h_p = Z_2 \quad \text{so that} \quad \sum L_i \frac{V^2}{2g} = (0.8 + 4(1.5) + 5.0 + 1) \frac{V^2}{2g} = 12.8 \frac{V^2}{2g} \]

\[
\left[-f \left(\frac{500}{0.75}\right) - 12.8\right] \frac{V^2}{2(32.2)} + 250 = 200
\]

or

\[(667\ f + 12.8)V^2 = 3220\]

Also, \( Re = \frac{\rho \cdot V \cdot D}{\mu} = \frac{(1.94 \text{ slug/ft}^3) \cdot V(0.75 \text{ ft})}{2.34 \times 10^{-5} \text{ lb/s ft}^2} \)

or

\[Re = 6.22 \times 10^4 V\]

and from Fig. 8.20:

\[
\frac{f}{D} = 0
\]

Trial and error solution. Assume \( f = 0.02 \)

\[
\frac{V}{f} = 11.1 \frac{ft}{s} \rightarrow Re = 6.9 \times 10^5
\]

\[
f = 0.012 \neq 0.02
\]

Assume \( f = 0.012 \)

\[
\frac{V}{f} = 12.4 \frac{ft}{s} \rightarrow Re = 7.7 \times 10^5 \rightarrow f = 0.012 \approx 0.012
\]

Thus, \( V = 12.4 \frac{ft}{s} \) and

\[
\dot{W} = \delta Q \cdot \dot{h} = (62.4 \frac{lb}{ft^2}) \frac{ft}{s} (0.75 \text{ ft})^2 (12.4 \frac{ft}{s})(2.50 \text{ ft}) = 8.55 \times 10^4 \frac{ft \cdot lb}{s}
\]

\[
= 8.55 \times 10^4 \frac{ft \cdot lb}{s} \times \frac{hp}{550 \frac{ft \cdot lb}{s}} = 155 \dot{h}_p
\]
8.52 Gasoline flows in a smooth pipe of 40-mm diameter at a rate of 0.001 m³/s. If it were possible to prevent turbulence from occurring, what would be the ratio of the head loss for the actual turbulent flow compared to that if it were laminar flow?

Let \( h_t \) denote the turbulent flow and \( h_l \) the laminar flow. Thus, 
\[
h_t = f_t \frac{L}{D} \frac{V^2}{2g} \quad \text{and} \quad h_l = f_l \frac{L}{D} \frac{V^2}{2g}
\]

where 
\[
V = V_t = \frac{Q}{A} = \frac{0.001 \text{ m}^3}{\pi \left(0.04 \text{ m}\right)^2} = 0.796 \text{ m/s}
\]

From Table 1.6 \( \rho = 680 \frac{\text{kg}}{\text{m}^3} \) and \( \mu = 3.1 \times 10^{-4} \frac{\text{N s}}{\text{m}^2} \) so that
\[
Re = \frac{\rho V D}{\mu} = \frac{\left(680 \frac{\text{kg}}{\text{m}^3}\right) \left(0.796 \frac{\text{m}}{\text{s}}\right) \left(0.04 \text{ m}\right)}{3.1 \times 10^{-4} \frac{\text{N s}}{\text{m}^2}} = 6.98 \times 10^4
\]

Hence, from Fig. 8.20, for a smooth pipe, \( f_t = 0.0192 \) while for laminar flow \( f_l = \frac{64}{Re} = \frac{64}{6980} = 9.16 \times 10^{-4} \)
A 2-in.-diameter sphere weighing 0.14 lb is suspended by the jet of air shown in Fig. P9.69 and Video V3.1. The drag coefficient for the sphere is 0.5. Determine the reading on the pressure gage if friction and gravity effects can be neglected for the flow between the pressure gage and the nozzle exit.

For equilibrium, \( \mathcal{F} = W \) or
\[
C_D \frac{1}{2} \rho V_a^2 A = W, \quad \text{where} \quad A = \frac{\pi D^2}{4}
\]

Thus,
\[
V_a = \left[ \frac{2W}{C_D \rho \frac{\pi D^2}{4}} \right]^{\frac{1}{2}}
\]

\[
= \left[ \frac{8 (0.14 \text{ lb})}{0.5 (0.00238 \text{ slugs} \text{ ft}^{-3}) \pi (\frac{1}{4} \frac{\text{ft}}{\text{ft}})^2} \right]^{\frac{1}{2}} = 104 \frac{\text{ft}}{s}
\]

Also,
\[
V_1 A_1 = V_2 A_2 \quad \text{or} \quad V_1 = V_2 \frac{A_2}{A_1} = (104 \frac{\text{ft}}{s}) \frac{0.3 \frac{\text{ft}}{\text{s}}^2}{0.6 \frac{\text{ft}}{\text{s}}^2} = 52.0 \frac{\text{ft}}{s}
\]

and
\[
\rho_1 + \frac{1}{2} \rho V_1^2 = \rho_2 + \frac{1}{2} \rho V_2^2 \quad \text{where} \quad \rho_2 = 0
\]

Thus,
\[
\rho_1 = \frac{1}{2} \rho [V_2^2 - V_1^2] = \frac{1}{2} (0.00238 \text{ slugs} \text{ ft}^{-3}) [(104 \frac{\text{ft}}{s})^2 - (52.0 \frac{\text{ft}}{s})^2]
\]

\[
= 9.65 \frac{\text{lb} \text{s}^2}{\text{ft}^4}
\]