5.117 Water is supplied at 150 ft³/s and 60 psi to a hydraulic turbine through a 3-ft inside diameter inlet pipe as indicated in Fig. P5.117. The turbine discharge pipe has a 4-ft inside diameter. The static pressure at section (2), 10 ft below the turbine inlet, is 10-in. Hg vacuum. If the turbine develops 2500 hp, determine the power lost between sections (1) and (2).
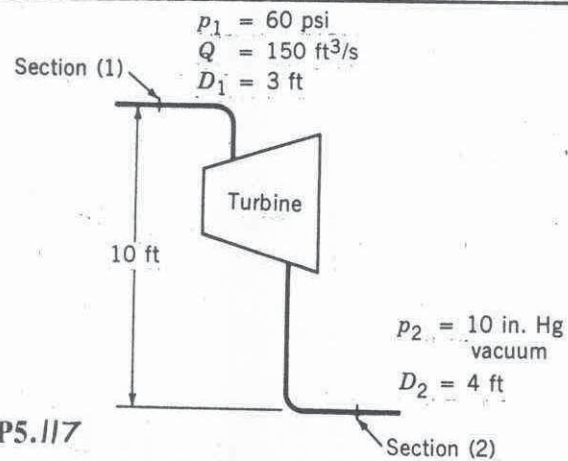
Section (1)

p_1 = 60 psi
Q = 150 ft³/s
D_1 = 3 ft

Turbine

10 ft

p_2 = 10 in. Hg vacuum

D_2 = 4 ft

Section (2)

FIGURE P5.117

For flow between sections (1) and (2), Eq. 5.82 leads to

$$\text{power loss} = \rho Q\left[\left(\frac{P_1 - P_2}{\rho}\right) + g(z_1 - z_2) + \left(\frac{V_1^2 - V_2^2}{2}\right)\right] - \dot{W}_{\substack{shaft \\ net\ out}} \quad (1)$$

From given data

$$P_2 = \frac{(-10\ in.\ Hg)(13.6)\left(1.94\ \frac{slugs}{ft^3}\right)\left(32.2\ \frac{ft}{s^2}\right)}{\left(12\ \frac{in.}{ft}\right)}\left(\frac{1\ lb}{slug.\frac{ft}{s^2}}\right) = -708\ \frac{lb}{ft^2}$$

Also

$$V_1 = \frac{Q}{A_1} = \frac{Q}{\frac{\pi D_1^2}{4}} = \frac{(4)\left(150\ \frac{ft^3}{s}\right)}{\pi(3ft)^2} = 21.22\ \frac{ft}{s}$$

From conservation of mass (Eq. 5.13)

$$V_2 = V_1\frac{A_1}{A_2} = V_1\frac{D_1^2}{D_2^2} = \left(21.22\ \frac{ft}{s}\right)\frac{(3ft)^2}{(4ft)^2} = 11.94\ \frac{ft}{s}$$

From Eq. 1

$$\text{power loss} = \frac{\left(1.94\ \frac{slugs}{ft^3}\right)\left(150\ \frac{ft^3}{s}\right)}{\left(550\ \frac{ft.lb}{s.hp}\right)}\left\{\frac{\left(60\ \frac{lb}{in.^2}\right)\left(144\ \frac{in.^2}{ft^2}\right) + \left(708\ \frac{lb}{ft^2}\right)}{\left(1.94\ \frac{slugs}{ft^3}\right)}\right.$$

$$+ \left(32.2\ \frac{ft}{s^2}\right)(10\ ft)\left(\frac{1\ lb}{slug.\frac{ft}{s^2}}\right) + \left[\frac{\left(21.22\ \frac{ft}{s}\right)^2 - \left(11.94\ \frac{ft}{s}\right)^2}{2}\right]\left(\frac{1\ lb}{slug.\frac{ft}{s^2}}\right)\right\}$$

$$- 2500 hp$$

or

$$\text{power loss} = \underline{301}\ hp$$