6.109 In Fig. P6.109 there are 125 ft of 2-in pipe, 75 ft of 6-in pipe, and 150 ft of 3-in pipe, all cast iron. There are three 90° elbows and an open globe valve, all flanged. If the exit elevation is zero, what horsepower is extracted by the turbine when the flow rate is 0.16 ft^3/s of water at 20°C?

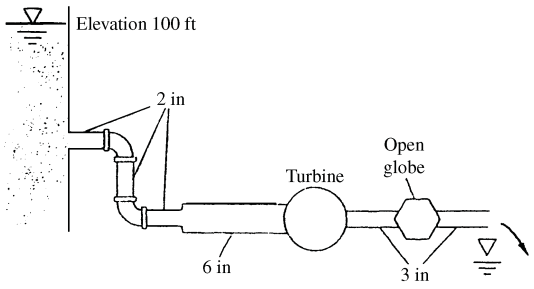

Fig. P6.109

Solution: For water at 20°C, take $\rho = 1.94$ slug/ft^3 and $\mu = 2.09E{-}5$ slug/ft·s. For cast iron, $\varepsilon \approx 0.00085$ ft. The 2″, 6″, and 3″ pipes have, respectively,

$$\text{(a)}\quad L/d = 750,\ \varepsilon/d = 0.0051; \quad \text{(b)}\quad L/d = 150,\ \varepsilon/d = 0.0017;$$

$$\text{(c)}\quad L/d = 600,\ \varepsilon/d = 0.0034$$

The flow rate is known, so each velocity, Reynolds number, and f can be calculated:

$$V_a = \frac{0.16}{\pi(2/12)^2/4} = 7.33\ \frac{ft}{s}; \quad Re_a = \frac{1.94(7.33)(2/12)}{2.09E{-}5} = 113500, \quad f_a \approx 0.0314$$

$$\text{Also, } V_b = 0.82 \text{ ft/s, } Re_b = 37800, \ f_c \approx 0.0266; \ V_c = 3.26, \ Re_c = 75600, \ f_c \approx 0.0287$$

Finally, the minor loss coefficients may be tabulated:

$$\text{sharp } 2'' \text{ entrance: } K = 0.5; \quad \text{three } 2'' \ 90° \text{ elbows: } K = 3(0.95)$$

$$2'' \text{ sudden expansion: } K \approx 0.79; \quad 3'' \text{ open globe valve: } K \approx 6.3$$

The turbine head equals the elevation difference minus losses and the exit velocity head:

$$h_t = \Delta z - \sum h_f - \sum h_m - V_c^2/(2g)$$

$$= 100 - \frac{(7.33)^2}{2(32.2)}[0.0314(750) + 0.5 + 3(0.95) + 0.79]$$

$$- \frac{(0.82)^2}{2(32.2)}(0.0266)(150) - \frac{(3.26)^2}{2(32.2)}[0.0287(600) + 6.3 + 1] \approx \mathbf{72.8\ ft}$$

The resulting turbine power = $\rho g Q h_t$ = (62.4)(0.16)(72.8) ÷ 550 ≈ **1.32 hp**. *Ans.*