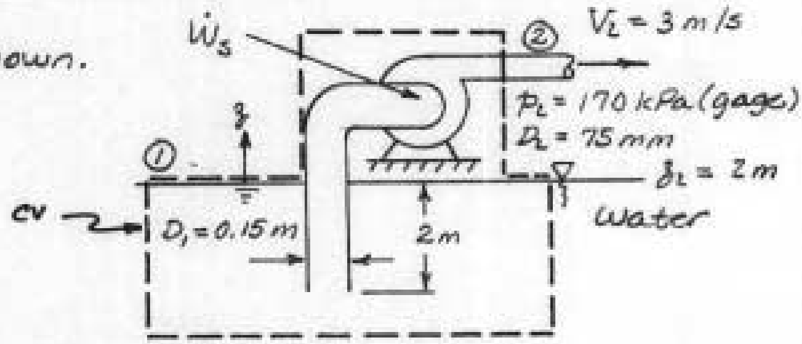
Problem 4.189

Given: Pump system as shown.

$\eta_{pump} = 0.75$



Find: Power required.

Solution: Apply first law to cv shown, noting that flow enters with negligible velocity at section ①.

Basic equation:

$$\dot{Q} - \dot{W}_{shaft} - \overset{=0(1)}{\dot{W}_{shear}} - \overset{=0(1)}{\dot{W}_{other}} = \overset{=0(2)}{\frac{\partial}{\partial t}\int_{CV} e\rho\, dV} + \int_{CS}\left(e + \frac{p}{\rho}\right)\rho \vec{V}\cdot d\vec{A}$$

$$e = u + \frac{V^2}{2} + gz$$

Assumptions: (1) $\dot{W}_{shear} = \dot{W}_{other} = 0$
(2) Steady flow
(3) $V_1 \simeq 0$
(4) $z_1 = 0$
(5) $p_1 = 0$ (gage)
(6) Uniform flow at each section
(7) Incompressible flow; $V_1 A_1 = V_2 A_2$

Then

$$\dot{Q} - \dot{W}_s = \Big(u_1 + \overset{\simeq 0(3)}{\frac{V_1^2}{2}} + \overset{=0(4)}{g z_1} + \overset{=0(5)}{\frac{p_1}{\rho}}\Big)\{-\dot{m}\} + \left(u_2 + \frac{V_2^2}{2} + g z_2 + \frac{p_2}{\rho}\right)\{\dot{m}\}$$

or

$$-\dot{W}_s = \dot{m}\left[\frac{p_2}{\rho} + \frac{V_2^2}{2} + g z_2 + \left(u_2 - u_1 - \frac{\delta Q}{dm}\right)\right]$$

Obtain the ideal or minimum power input by neglecting thermal effects. Thus

$$-\dot{W}_{s,ideal} = \dot{m}\left[\frac{p_2}{\rho} + \frac{V_2^2}{2} + g z_2\right]$$

For the system,

$$\dot{m} = \rho V_2 A_2 = 999\,\frac{kg}{m^3} \times 3\,\frac{m}{s} \times \frac{\pi}{4}(0.075)^2\,m^2 = 13.2\ kg/s$$

and

$$-\dot{W}_{s,ideal} = 13.2\,\frac{kg}{s}\left[1.70\times10^5\,\frac{N}{m^2}\times\frac{m^3}{999\,kg} + \frac{1}{2}(3)^2\frac{m^2}{s^2}\times\frac{N\cdot s^2}{kg\cdot m} + 9.81\,\frac{m}{s^2}\times 2\,m \times \frac{N\cdot s^2}{kg\cdot m}\right]$$

$$\dot{W}_{s,ideal} = -2560\,\frac{N\cdot m}{s} \times \frac{kW\cdot s}{10^3\,N\cdot m} = -2.56\ kW$$

Finally

$$\dot{W}_{s,actual} = \frac{\dot{W}_{s,ideal}}{\eta} = \frac{-2.56\ kW}{0.75} = -3.41\ kW$$

$\dot{W}_{s,actual}$