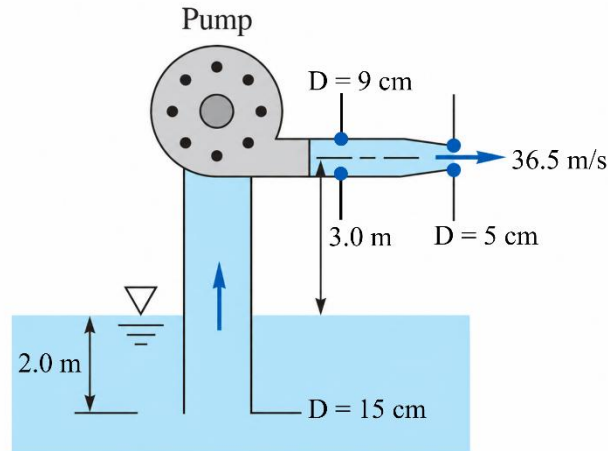


A fireboat draws seawater ($SG = 1.025$) from a reservoir and discharges it horizontally through a nozzle 3.0 m above the water surface. The total friction head loss is 2.0 m, and the pump efficiency is 75%. The nozzle inlet and exit diameters are 9 cm and 5 cm, respectively. The exit velocity is 36.5 m/s, and the gage pressure at the nozzle inlet is 620 kPa. (a) Find the required pump input power in kW. (b) Determine the horizontal force exerted by the water on the nozzle.



$$\rho_{\text{water}} = 1000 \text{ kg/m}^3$$

Continuity equation: $-(d/dt) \int_{\text{CV}} \rho \, dV = \int_{\text{CS}} \rho (\mathbf{V} \cdot \mathbf{n}) \, dA$

Momentum equation: $\Sigma \mathbf{F} = (d/dt) \int_{\text{CV}} \rho \mathbf{V} \, dV + \int_{\text{CS}} \rho \mathbf{V} (\mathbf{V} \cdot \mathbf{n}) \, dA$

Energy Equation (for incompressible steady flow):

$$\left(\frac{p}{\rho g} + \frac{V^2}{2g} + z \right)_1 = \left(\frac{p}{\rho g} + \frac{V^2}{2g} + z \right)_2 + h_{\text{turbine}} - h_{\text{pump}} + h_{\text{friction}}$$

Hint: For part (a), use the reservoir free surface as point 1 and the nozzle outlet as point 2 in the energy equation.

For part (b), use only the nozzle as the control volume.

$$P_{\text{pump}} = \rho g Q h_{\text{pump}}$$

$$P_{\text{input}} = \frac{P_{\text{pump}}}{\text{efficiency}}$$

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Given: $\rho = 1025 \text{ kg/m}^3$, $D_1 = 0.09 \text{ m}$, $D_2 = 0.05 \text{ m}$, $V_2 = 36.5 \text{ m/s}$, $p_1 = 620 \text{ kPa (gage)}$, $h_f = 2.0 \text{ m}$, $\eta = 0.75$, $z_2 - z_0 = 3.0 \text{ m}$

Solution:

(a) Required pump power

From continuity:

$$Q = A_2 V_2 = [\pi(0.05)^2/4](36.5) = 0.0717 \text{ m}^3/\text{s} \quad +1$$

Energy equation:

$$p_1/(\rho g) + V_1^2/(2g) + z_1 + h_p = p_2/(\rho g) + V_2^2/(2g) + z_2 + h_f \quad +1$$

$$p_1 = p_2 = 0 \text{ (gage)}, V_1 \approx 0$$

$$h_p = (z_2 - z_1) + V_2^2/(2g) + h_f \quad +2$$

$$= 3.0 + (36.5)^2/[2(9.81)] + 2.0 = 72.9 \text{ m} \quad +0.5$$

Alternative solution: using a point 2.0 m below the free surface

Let point 1 be the free surface, point 2 be a point in the reservoir 2.0 m below the free surface, and point 3 be the nozzle outlet.

Bernoulli equation (1 $\rightarrow$ 2):

$$\frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

$$V_1 \approx V_2 \approx 0$$

$$\frac{p_2}{\rho g} = \frac{p_1}{\rho g} + z_1 - z_2$$

Energy equation (2 $\rightarrow$ 3):

$$\frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 + h_p = \frac{p_3}{\rho g} + \frac{V_3^2}{2g} + z_3 + h_f$$

$$\frac{p_1}{\rho g} + z_1 - z_2 + \frac{V_2^2}{2g} + z_2 + h_p = \frac{p_3}{\rho g} + \frac{V_3^2}{2g} + z_3 + h_f$$

$$p_1 = p_3 = 0 \text{ (gage)}, \quad V_2 \approx 0$$

$$h_p = \frac{V_3^2}{2g} + z_3 - z_1 + h_f = \frac{(36.5)^2}{2(9.81)} + 3.0 + 2.0 = 72.9 \text{ m}$$

Pump input power:

$$P_{\text{pump}} = \rho g Q h_p = (1025)(9.81)(0.0717)(72.9) = 52.5 \text{ kW} \quad +0.5$$

$$P_{\text{input}} = P_{\text{pump}}/\eta = 52.5/0.75 = 70.0 \text{ kW} \quad +0.5$$

(b) Horizontal force exerted by the water on the nozzle

Continuity:

$$A_1 V_1 = A_2 V_2 \quad +1$$

$$V_1 = (D_2/D_1)^2 V_2 = (0.05/0.09)^2 (36.5) = 11.27 \text{ m/s} \quad +0.5$$

$$\dot{m} = \rho Q = (1025)(0.0717) = 73.46 \text{ kg/s} \quad +0.5$$

Momentum equation in the x direction:

$$\Sigma F_x = \dot{m}(V_2 - V_1)$$

$$p_1 A_1 + F_N = \dot{m}(V_2 - V_1), p_2 = 0 \text{ (gage)} \quad +2$$

$$A_1 = \pi(0.09)^2/4 = 6.362 \times 10^{-3} \text{ m}^2$$

$$(620000)(6.362 \times 10^{-3}) + F_N = 73.46(36.5 - 11.27)$$

Name:.....

Quiz: No. 4

Time: 20 minutes

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$$F_N = -2.09 \text{ kN} \quad +0.5$$
$$F_{\text{water}} \text{ on nozzle} = 2.09 \text{ kN to the right}$$