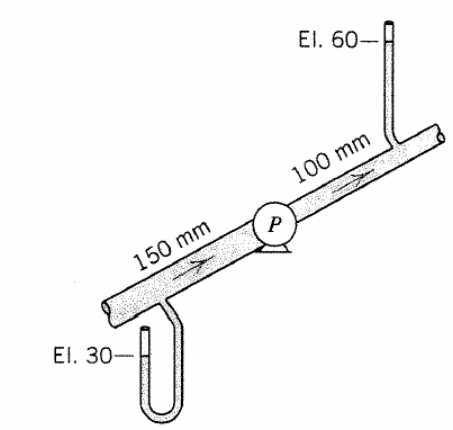
Water is flowing through the pipe shown below. Calculate the pump power for a flow rate of 28 L/s. The elevations shown are in units of meters.



First, we compute the velocities and the velocity heads at the two locations with the piezometer tubes.

$$V_{150} = \frac{Q}{\pi d_{150}^2/4} = \frac{0.028\ \text{m}^3/\text{s}}{\pi\left(0.150\ \text{m}\right)^2/4} = 1.584\ \text{m/s}; \qquad \frac{V_{150}^2}{2g} = \frac{\left(1.584\ \text{m/s}\right)^2}{2\left(9.8\ \text{m/s}^2\right)} = 0.128\ \text{m}$$

$$V_{100} = \frac{Q}{\pi d_{100}^2/4} = \frac{0.028\ \text{m}^3/\text{s}}{\pi\left(0.100\ \text{m}\right)^2/4} = 3.565\ \text{m/s}; \qquad \frac{V_{100}^2}{2g} = \frac{\left(3.565\ \text{m/s}\right)^2}{2\left(9.8\ \text{m/s}^2\right)} = 0.648\ \text{m}$$

Substituting the above values into the work-energy equation, and rearranging:

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

$$h_P = \left(z_2 + \frac{p_2}{\gamma}\right) - \left(z_1 + \frac{p_1}{\gamma}\right) + \frac{V_2^2}{2g} - \frac{V_1^2}{2g}$$

The height of water in each manometer tube indicates the piezometric head at the corresponding location in the pipe, i.e., it represents $z + p/\gamma$. Thus, the 30 m difference in the piezometric heads corresponds to the difference in the two terms in parentheses in the preceding equation. Substituting in these values, we find:

$$h_P = \left(60\ \text{m} - 30\ \text{m}\right) + 0.648\ \text{m} - 0.128\ \text{m} = 30.52\ \text{m} = 30.52\ \text{J/N}$$

The power input can then be computed as:

$$P = Q\gamma h_p = \left(0.028\ \text{m}^3/\text{s}\right)\left(9800\ \text{N/m}^3\right)\left(30.52\ \text{J/N}\right) = 8380\ \text{W} = 8.38\ \text{kW}$$

The HGL at the each location passes through the top of the water column in the manometer. The EL is above the HGL at each location by a height equal to the velocity head: 0.128 m in the 150 mm pipe, and 0.648 m in the 100 mm pipe. Assuming the fluid is ideal, both the HGL and the EL are flat everywhere except at the pump, where they both undergo instantaneous step increases. The EL is above the HGL by an amount equal to the velocity head; since the velocity head is larger in the 100-mm section than in the 150 mm section, the difference between the EL and the HGL is larger in the 100-mm section. Given the 30 m difference between the water level in the two piezometers, the gaps between the EL and the HGL would be extremely small at the scale shown in the figure, so those gaps have been greatly exaggerated.