The exam is closed book and closed notes.

When the pump in the Figure below draws 220 m³/hr of water at 20°C (ρ = 998 kg/m³) from the reservoir, the total friction head loss is 5 m. The flow discharges through a nozzle to the atmosphere. Estimate the pump power in kW delivered to the water.

**Energy Equation (for incompressible steady flow):**

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

Turbulent pipe flow kinetic correction factor \( \alpha = 1.11 \)

\( P_{pump} = \rho g Q h_{pump} \)
Solution: Format (+3)

Continuity:

\[
Q = 220 \frac{m^3}{hr} = \frac{(220)}{(3600)} \frac{m^3}{s} = 0.0611 \frac{m^3}{s}
\]

\[
Q = A_e V_e
\]

\[
V_e = \frac{Q}{A_e} = \frac{Q}{\frac{D_e^2}{\pi}} = \frac{(0.0611)}{\frac{(0.05)^2}{4}} = 31.12 \frac{m}{s}
\]  (+2)

Take point 1 at the free surface and 2 at the pipe exit:

\[
\frac{p_1}{\rho g} + \frac{\alpha_1 V_1^2}{2g} + z_1 = \frac{p_2}{\rho g} + \frac{\alpha_2 V_2^2}{2g} + z_2 + h_{turbine} - h_{pump} + h_{friction}
\]

Pressure is zero at the free surface and at the exit to atmosphere. Also assume that velocity at the free surface is almost zero:

\[
0 + 0 + z_1 = 0 + \frac{\alpha_e V_e^2}{2g} + z_2 + 0 - h_{pump} + h_{friction}
\]

\[
h_{pump} = \frac{\alpha_e V_e^2}{2g} + (z_2 - z_1) + h_{friction}
\]

\[
h_{pump} = \frac{(1.11)(31.12)^2}{2(9.81)} + (2 \text{ m}) + (5 \text{ m}) = 61.79 \text{ m}
\]

The pump power is:

\[
P_{pump} = \rho g Q h_{pump} = (998)(9.81)(0.0611)(61.79) = 36,962.3 \text{ W} = 36.96 \text{ kW}
\]  (+5)