1. (35 p) Water at 80 °C is being pumped from the tank into a 2 1/2-in Schedule 40 steel pipe through an inward-projecting tube (Entrance resistance coefficient $K=1.0$) at the rate of 475 L/min shown in Figure given below. Compute the pressure at the inlet of the pump. Required Data: Steel tube roughness ($\varepsilon = 4.6 \times 10^{-5}$ m); Globe valve-fully open $\left( \frac{L_e}{D} = 340 \right)$; 90° standard elbow $\left( \frac{L_e}{D} = 30 \right)$

2. (35 p) A furnace heat exchanger has a cross section like that shown in Figure below. The air flows around the three thin passages in which hot gases flow. The air is at 60 °C and has a density of 1.06 kg/m$^3$ and a dynamic viscosity of $\mu = 1.98 \times 10^{-5}$ Pa.s. Compute the Reynolds number for the flow if the velocity is 6.1 m/s.

3. (30 p) A pitot-static tube is connected to a differential manometer using water at 30 °C as the gage fluid. The velocity of air at 30 °C and atmospheric pressure is to be measured, and it is expected that the maximum velocity will be 90 km/h. Calculate the expected manometer deflection.
1. Write the general energy equation between point 1 (at the reservoir surface) and point 2 (at pump inlet) according to the Figure given:

\[
\frac{p_1}{\gamma_w} + z_1 + \frac{v_1^2}{2g} - h_L = \frac{p_2}{\gamma_w} + z_2 + \frac{v_2^2}{2g}
\]

Given:

\[
p_1 = 0 \text{ (surface of the reservoir exposed to the atmosphere)}
\]
\[
v_1 \approx 0 \text{ (large surface area of the reservoir)}
\]
\[
Q = 475 \text{ L/min}
\]
\[
z_1 - z_2 = 0.75 \text{ m} - 1.40 \text{ m} = -0.65 \text{ m}
\]

\[
v_2 = \frac{Q}{A_2} = \frac{475 \frac{\text{L}}{\text{min}}}{3.09 \times 10^{-3} \text{m}^2} = 2.56 \text{ m/s}
\]

\[A_2 \text{ flow area was taken from Table F. 1}
\]

Arrange the general energy equation to find \(p_2\):

\[
p_2 = \gamma_w \left[ (z_1 - z_2) - \frac{v_2^2}{2g} - h_L \right]
\]

\(h_L\) includes entrance loss \((h_L)_{\text{Ent}}\), losses in two standard elbows \((h_L)_{\text{Elbow}}\), globe valve \((h_L)_{\text{Valve}}\), and straight 2\(\frac{1}{2}\)” Schedule 40 steel tube friction loss \((h_L)_{\text{StrPipe}}\) according to Darcy equation as follows:

\[
h_L = (h_L)_{\text{Ent}} + 2(h_L)_{\text{Elbow}} + (h_L)_{\text{Valve}} + (h_L)_{\text{StrPipe}}
\]

\[
= \left[ K + 2f_T \left( \frac{L_e}{D} \right)_{\text{Elbow}} + f_T \left( \frac{L_e}{D} \right)_{\text{Valve}} + f \left( \frac{L}{D} \right)_{\text{StrPipe}} \right] \frac{v_B^2}{2g}
\]

The straight pipe length \(L\) can be found from the figure as \([11.5+1.40]=12.90 \text{ m}\). The friction factor \((f)\) should be read from Moody chart according to the Reynolds number \((N_R)\) and relative roughness \((D/\varepsilon)\) as follows:

\[
N_R = \frac{Dv_B}{\nu} = \frac{(62.7x10^{-3}\text{m})(2.56 \frac{\text{m}}{\text{s}})}{3.60x10^{-7} \text{m}^2/\text{s}} = 4.46x10^5
\]

\[
\frac{D}{\varepsilon} = \frac{62.7x10^{-3}\text{m}}{4.6x10^{-5} \text{m}} = 1363
\]

\[
f = 0.0195 \text{ (read)}
\]

Kinematic viscosity \((\nu)\) and specific weight \((\gamma_w)\) of water at \(T=80 \text{ °C}\) was taken from Table A.1; inside diameter of the 2\(\frac{1}{2}\)” Sch40 steel tube was taken from Table F.1, roughness of steel tube \((\varepsilon)\) was given in the question sheet at the top. \(f_T\) was read from the zone of complete turbulence of Moody chart depending on the relative roughness as follows:

\[
\frac{D}{\varepsilon} = \frac{62.7x10^{-3}\text{m}}{4.6x10^{-5} \text{m}} = 1363 \rightarrow f_T \approx 0.018
\]
\[ h_L = \left[ K + 2f_T \left( \frac{L_e}{D} \right)_{\text{Elbow}} + f_T \left( \frac{L_e}{D} \right)_{\text{Valve}} + f \left( \frac{L}{D} \right) \right] \frac{v_B^2}{2g} \]

\[ = \left[ 1.0 + 2(0.018)(30) + (0.018)(340) + (0.0195) \right] \frac{12.90 \text{ m}}{62.7 \times 10^{-3} \text{ m}} \frac{(2.56 \frac{m}{s})^2}{2 \left( \frac{9.81 \frac{m}{s^2}}{s} \right)} \]

\[ h_L = 4.08 \text{ m} \]

\[ p_2 = \left( 9.53 \frac{kN}{m^3} \right) \left[ (-0.65 \text{ m}) - \frac{(2.56 \frac{m}{s})^2}{2 \left( \frac{9.81 \frac{m}{s^2}}{s} \right)} - 4.08 \text{ m} \right] = -48.3 \text{ kPa} \]

2. **Shell (Outside of the 3 thin passages):** Air at 60 °C.

\[ A = (71.1 \text{ cm})(35.6 \text{ cm}) - 3 \left[ (20.3 \text{ cm})(5 \text{ cm}) + \frac{\pi}{4} (5 \text{ cm})^2 \right] = 2168 \text{ cm}^2 = 0.217 \text{ m}^2 \]

\[ WP = 2(71.1 \text{ cm}) + 2(35.6 \text{ cm}) + 3[2(20.3 \text{ cm}) + \pi(5 \text{ cm})] = 382 \text{ cm} = 3.82 \text{ m} \]

\[ R = \frac{A}{WP} = \frac{0.217 \text{ m}^2}{3.82 \text{ m}} = 0.057 \text{ m} \]

\[ N_R = \frac{(4R) v_p \rho}{\mu} = \frac{4(0.057 \text{ m}) \left( 6.1 \frac{m}{s} \right) \left( 1.06 \frac{kg}{m^3} \right)}{(1.98 \times 10^{-5} \text{ Pa.s})} = 7.5 \times 10^4 \]

3. Pitot-static tube equation for the velocity given below should be solved for the deflection of differential manometer \((h)\) as follows:

\[ v_1 = \sqrt{\frac{2g(p_s - p_1)}{\gamma_f}} = \sqrt{\frac{2gh(\gamma_g - \gamma_f)}{\gamma_f}} \]

\[ h = \frac{v_1^2 \gamma_f}{2g(\gamma_g - \gamma_f)} \]

Given:

Gage fluid: Water \(\gamma_g = 9.77 \frac{kg}{m^3}, \text{ taken from Table A.1}\)

Fluid: Air \(\gamma_f = 11.42 \frac{N}{m^3}, \text{ taken from Table E.1}\)

Velocity of air \((v_1 = 90 \text{ km/h})\)

Substitution of these quantities in the pitot tube equation gives the velocity as follows:

\[ h = \frac{\left( 90 \frac{km}{h} \right)^2 1 \text{ h}}{2 \left( 9.81 \frac{m}{s^2} \right) \left( 9.77 \times 10^3 \frac{N}{m^3} - 11.42 \frac{N}{m^3} \right)} = 0.037 \text{ m} = 37 \text{ mm} \]