ChE 204 – Introduction to Transport Phenomena

Mid-term Exam

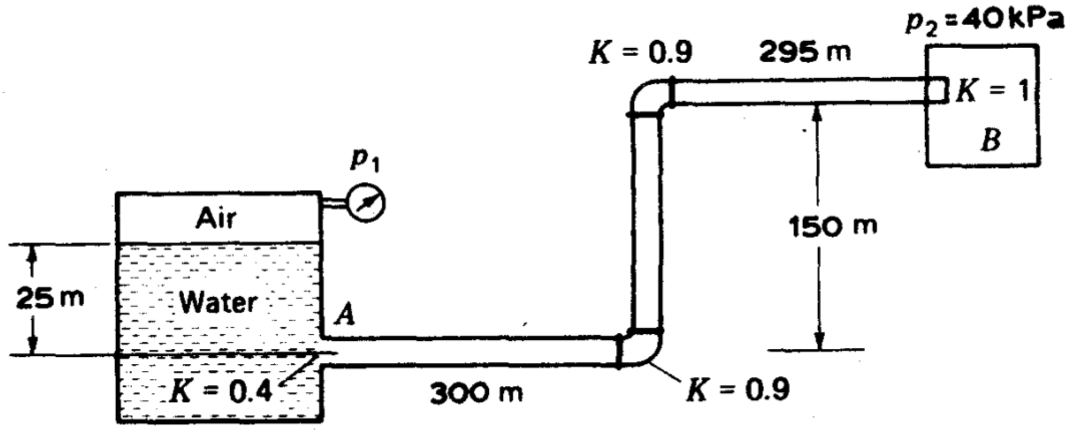
Question 1:

The system below carries water (ρ = 1000 kg/m^3; g = 9.8 m/s^2; μ= 8.9 x 10^{-4} Pa·s) at a volumetric rate of 0.1 m^3/s. If the pipe is stainless steel and has a diameter of 150mm, calculate the pressure P_1 in the following cases:

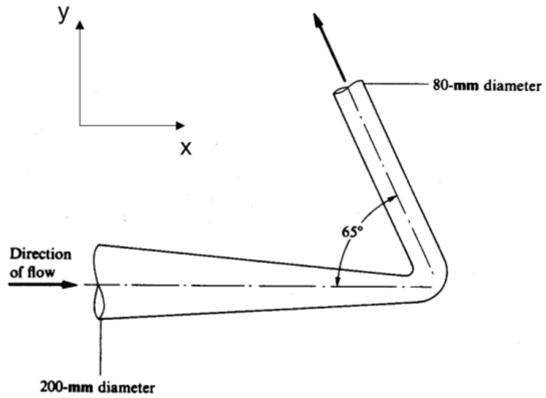
a) negletting losses

b) including losses

c) if water was finally discharged to the atmosphere in B (exclude losses)



Question 2:



The pipe bend on the left is in a horizontal plane. Water (ρ = 1000 kg/m^3; g = 9.8 m/s^2) enters the bend with a velocity of 3.5 m/s and a pressure of 280 kPa. Neglecting any energy losses in the bend, find the force required to hold the bend in place.

Question 3:

In a textile manufacturing plant, the waste dyeing water ($C_{p,h} = 4295\, J/kg \cdot$ °C) at 75°C is to be used to preheat fresh water ($C_{p,c} = 4180\, J/kg \cdot$ °C) at 15°C at the same flow rate of 2 kg/s in a double-pipe parallel flow heat exchanger. The overall heat transfer coefficient is 625 $W/m^2 \cdot$ °C and that the rate of heat transfer is 35 kW.

a) Calculate the outlet temperatures of each fluid stream

b) Calculate the heat transfer area

c) Knowing that h_h=1350 W/m^2· °C, h_C=1500 W/m^2· °C and the thickness of the inner tube wall is 0.1m, find the thermal conductivity of the inner tube wall.

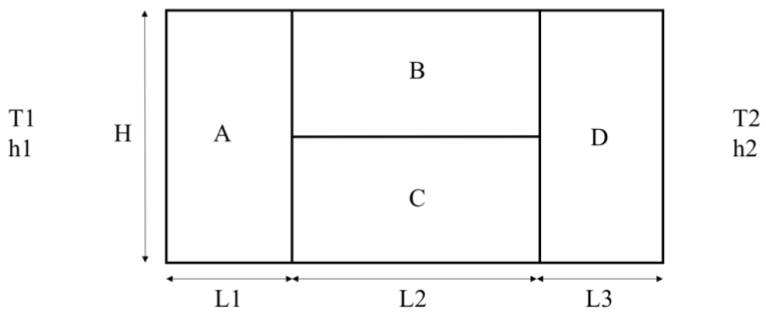
Question 4:

Consider the composite wall illustrated below for high H = 3m, thickness 1m, $H_B = H_C$ = 1.5 m, L1 = L3 = 0.05 m, L2 = 0.1 m, $k_A = k_D$ = 50 W/mK, k_B = 10 W/mK and k_C = 1 W/mK.

a) Sketch the thermal resistance circuit.

b) Under conditions for which T1 = 200 ºC, h1 = 50W/m^2K, T2=25ºC and h2=10W/m^2K, what is the rate of heat transfer through the wall ?

c) What are the interface temperatures ?



Introduction to Transport Phenomena: Solutions to mid-term exam

Question 1

$$pipe\ area = \pi \times r^2$$

$$A = \pi \times 0.\frac{15^2}{4} = 0.0176\ m^2$$

$$velocity = Q \times \frac{1}{A}$$

$$velocity = 0.1 \times \frac{1}{0.0176} = 5.68\frac{m}{s}$$

a) Applying Bernoulli between point 1 and point 2

$$P_1 + \rho.g.h_1 + \frac{1}{2}.\rho.v_1^2 = P_2 + \rho.g.h_2 + \frac{1}{2}.\rho.v_2^2$$

$$P_1 + \rho.g.25 = 40 \times 10^3 + \rho.g.150 + \frac{1}{2}.\rho.5.68^2$$

$$P_1 = 1.28\ MPa$$

b) Now we must consider losses, so calculating the Reynolds number, relative roughness and the fanning friction factor

$$R_e = \rho \times v \times \frac{D}{\mu}$$

$$R_e = 1000 \times 5.68 \times 0.\frac{15}{8.9\times 10^{-4}} = 10^6$$

$$\frac{\varepsilon}{D} = 0.\frac{015}{150} = 10^{-4}$$

Checking the corresponding value on the moody chart for the fanning friction factor,

$$f_f = 0.0035$$

$$P_1 + \rho.g.h_1 + \frac{1}{2}.\rho.v_1^2 = P_2 + \rho.g.h_2 + \frac{1}{2}.\rho.v_2^2 + \frac{1}{2}.\rho.v_2^2\ (\frac{4f_f}{D}.\left(\sum L_i\right) + \sum K_j)$$

1 pts

$$P_1 + \rho.g.25 = \rho.g.150 + \frac{1}{2}.\rho.5.68^2 + 40\times 10^3 + \frac{1}{2}.\rho.5.68^2(\left(4 \times \frac{f_f}{0.15}(300+150+295)\right) + (0.4+0.9+0.9+1))$$

$$P_1 = 2.35\ MPa$$

c) Essentially same as part 1, just P_2 changes to atmospheric pressure

$$P_1 + \rho.g.h_1 + \frac{1}{2}.\rho.v_1^2 = P_2 + \rho.g.h_2 + \frac{1}{2}.\rho.v_2^2$$

$$P_1 + \ \rho . g . 25 = 100 \times 10^3 + \ \rho . g . 150 + \frac{1}{2} . \rho . 5.68^2$$

$P_1 \ = 1.34 \ MPa$

Question 2

$v_1 = 3.5\frac{m}{s}$

$P_1 = 280\ kPa$

In order to determine the anchoring force, we need to resolve the forces along x and y directions.

$$\Sigma F_{reaction} + \Sigma F_{pressure} + \Sigma F_{friction} = \Sigma F_{surface}$$

$$\Sigma F_{friction} = 0$$

$$\Sigma F_{reaction} + (-P_1 A_1 \hat{n}_1) + (-P_2 A_2 \hat{n}_2) = \int_{A_1} \rho v_1 (v_1 . \hat{n}_1) dA_1 + \int_{A_2} \rho v_2 (v_2 . \hat{n}_2) dA_2$$

We need to calculate P_2 and v_2.

Because of the continuity equation: $A_1 v_1 = A_2 v_2$

$$3.5 \times 0.2^2 = v_2 \times 0.08^2$$

$v_2 = 21.875\ m/s$

Regarding P_2, we apply Bernoulli's principle:

0 0

$$P_1 + \frac{1}{2}\rho . v_1^2 + \rho . g . h_1 = P_2 + \frac{1}{2}\rho . v_2^2 + \rho . g . h_2$$

$$280000 + 0.5 \times 1000 \times 3.5^2 = P_2 + 0.5 \times 1000 \times 21.875^2$$

$P_2 = 46.86\ kPa$

Resolving the forces along the +x direction:

$$\Sigma F_{reaction,x} - P_1 A_1 (-1) - P_2 A_2 (-1) cos65^o = -\rho v_1^2 A_1 - \rho v_2^2 A_2 cos65^o$$

$$\Sigma F_{reaction,x} = -P_1 A_1 - P_2 A_2 cos65^o - \rho v_1^2 A_1 - \rho v_2^2 A_2 cos65^o$$

$$= -A_1(P_1 + \rho v_1^2) - A_2 cos65^o(P_2 + \rho v_2^2)$$

$$= -3.14(0.1)^2(280000 + 1000 \times 3.5^2) - 3.14(0.04)^2 \times 0.42 \times (46860 + 1000 \times 21.875^2)$$

$$= -10200.04\ N = -10.2\ kN$$

Resolving the forces along the +y direction:

$$\Sigma F_{reaction,y} + 0 - P_2A_2(+1)sin65^o = 0 + \rho v_2^2 A_2 sin65^o$$

$$\Sigma F_{reaction,y} = A_2 sin65^o(P_2 + \rho v_2^2)$$

$$= 3.14 \times (0.04)^2 \times 0.9(46860 + 1000 \times 21.875^2)$$

$$= 2375.53\ N = 2.375\ kN$$

$$F_{net} = \sqrt{(F_{reaction,x}^2} + F_{reaction,y}^2) = ((-10200.04)^2 + (2375.53)^2)^{1/2}$$

$$= 10473\ N = 10.473\ kN$$

Question 3:

a)$\dot{Q} = 35000W = \dot{m}c_{p,h}(T_{h,i} - T_{h,o})$

$$35000 = 2 * 4295 * (75 - T_{h,o})$$

$$T_{h,o} = 75 - (\frac{35000}{2 * 4295})$$

$\boldsymbol{T_{h,o} = 75 - 4.07 = 70.93}$℃

Similarly, $\dot{Q} = 35000W = \dot{m}c_{p,c}(T_{c,o} - T_{c,i})$

$$35000 = 2 * 4295 * (T_{c,o} - T_{c,i})$$

$$T_{c,o} = 15 + (\frac{35000}{2 * 4295})$$

$\boldsymbol{T_{c,o} = 15 + 4.07 = 19.07}$℃

b) Parallel flow recognition

$\Delta T_{LMTD} = \frac{(T_{h,i} - T_{c,i}) - (T_{h,o} - T_{c,o})}{\ln(\frac{T_{h,i} - T_{c,i}}{T_{h,o} - T_{c,o}})} = \frac{(75-15)-(71-19)}{\ln(\frac{75-15}{71-19})} = 57.1$℃

$Area = \frac{\dot{Q}}{U\Delta T_{LMTD}} = \frac{35000}{625*57.1} = \boldsymbol{0.98m^2}$

c)

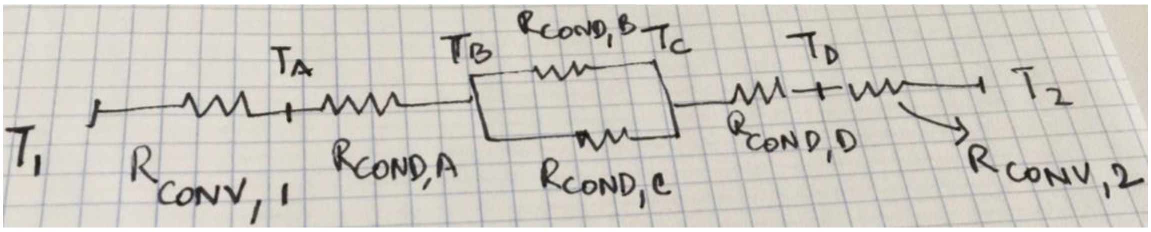
$\frac{1}{U} = \frac{1}{h_h} + \frac{0.1}{k} + \frac{1}{h_c}$

$$\frac{1}{625} = \frac{1}{1350} + \frac{0.1}{k} + \frac{1}{1500}$$

So, we get **k=500$\boldsymbol{Wm^{-1}}$**°C

Question 4:

a)



b)

$$R_{tot} = \frac{1}{h_1 A_1} + \frac{L_A}{k_A A_A} + \frac{1}{\frac{k_B A_B}{L_B} + \frac{k_C A_C}{L_C}} + \frac{L_D}{k_D A_D} + \frac{1}{h_2 A_2}$$

$$R_{tot} = \frac{1}{50*3} + \frac{0.05}{50*3} + \frac{1}{\frac{10*1.5}{0.1} + \frac{1*1.5}{0.1}} + \frac{0.05}{50*3} + \frac{1}{10*3}$$

$R_{tot} = 0.0067 + 0.0003 + 0.0060 + 0.0003 + 0.0333 = 0.0466°\text{C}W^{-1}$

$\dot{Q} = \frac{\Delta T}{R_{tot}} = \frac{200-25}{0.0466} = \mathbf{3755.4\ W}$

c)

For the interface temperatures,

$\dot{Q} = h_1 A_1 (T_1 - T_A)$

So, $T_A = T_1 - \frac{\dot{Q}}{h_1 A_1} = 200 - \frac{3755.4}{50*3} = \mathbf{174.96}°\text{C}$

Similarly, $\dot{Q} = h_2 A_2 (T_D - T_2)$

So, $T_D = T_2 + \frac{\dot{Q}}{h_2 A_2} = 25 + \frac{3755.4}{10*3} = \mathbf{150.18}°\text{C}$

$T_B = T_A - \frac{\dot{Q}}{\frac{k_A A_A}{L_A}}$

$$T_B = 174.96 - R_{COND,A}\dot{Q} = 174.96 - 0.0003 * 3755.4 = \mathbf{173.8}$$

Similarly,

$T_C = T_D + R_{COND,D}\dot{Q} = 150.18 + 0.0003 * 3755.4 = \mathbf{151.3}°\text{C}$