HW 4.1

By

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MET 440 - Heat Transfer

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Ch7 Problems

Question 7-36

7-36 Atmospheric air at 27℃ with a velocity of 20 m/s flows across a single tube of outside diameter $D = 2.5$ cm. The surface of the cylinder is maintained at a uniform temperature of 127℃. Determine the average heat transfer coefficient and the heat transfer rate from the tube to the air per meter length of the tube.

Solution

Ch7: 36, 37 and Ch8: 45

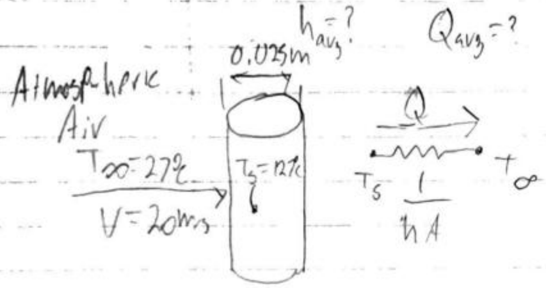
(282)

HW4.1

7-36) $T_\infty = 27°C$ $V = 20 m/s$ $D = 2.5 cm = 0.025 m$

$T_s = 127°C$

$h_{avg} = ?$ $Q_{avg} = ?$



$Q = hA(T_s - T_\infty)$

$A = \pi D L$

∴ Q is per meter length of tube so L = 1m

$Q = h \cdot \pi D L (T_s - T_\infty)$

h: $T_f = \frac{(T_s + T_\infty)}{2} = \frac{127°C + 27°C}{2} = 77°C$

Check to see if $Pe < 0.2$

$T_f = 77°C = 350.15 K$

$Pe = \frac{VD}{\alpha}$ $\alpha = 0.2991 \times 10^{-4}$

$= \frac{20 \frac{m}{s} \cdot 0.025 m}{0.2991 \times 10^{-4} \frac{m^2}{s}} = 16715 > 0.2$

350.15K

$\nu = 20.775 \times 10^{-6} \frac{m^2}{s}$

$Re = \frac{VD}{\nu} = \frac{20 \frac{m}{s} \cdot 0.025 m}{20.775 \times 10^{-6} \frac{m^2}{s}} = 24067$

Since 20,000 < 24067 < 400,000 equation 7-41 is used

$k = 0.03004 \frac{W}{m \cdot °C}$ $Pr = 0.697$

$$Nu = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1 + \left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}} \left[1 + \left(\frac{Re}{282{,}000}\right)^{\frac{1}{2}}\right]$$

$Re = 24067 \quad k = 0.03004 \frac{W}{m \cdot °C} \quad Pr = 0.697$

$$Nu = 0.3 + \frac{0.62 \cdot 24067^{1/2} \cdot 0.697^{1/3}}{\left[1+\left(\frac{0.4}{0.697}\right)^{2/3}\right]^{1/4}} \left[1+\left(\frac{24067}{282{,}000}\right)^{1/2}\right]$$

$$Nu = 0.3 + \frac{85.28}{1.14}\left[1.29\right]$$

$$Nu = 96.9$$

$$h = \frac{Nu\, k}{D} = \frac{96.9 \cdot 0.03004 \frac{W}{m \cdot °C}}{0.025m} = \boxed{116 \frac{W}{m^2 \cdot °C}}$$

$$Q = 116 \frac{W}{m^2 \cdot °C} \cdot \pi \cdot 0.025m \cdot 1m \cdot (127°C - 27°C)$$

$$\boxed{Q = 915\,W}$$

Question 7-37

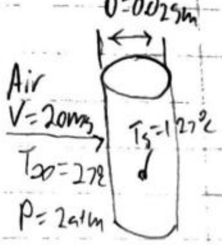
7-37 Determine the heat transfer rate from the tube to the air per meter length of the tube if the pressure of the air in Problem 7-36 is increased to 2 atm.

Solution

7-37) $T_\infty = 27°C$ $V = 20 m/s$ $P = 2 atm$

$T_s = 127°C$ $D = 0.025 m$

$Q = ?$



$$Q = h(\pi D L)(T_s - T_\infty)$$

$$T_f = \frac{(T_s + T_\infty)}{2} = \frac{(127°C + 27°C)}{2} = 77°C = 350.15 K$$

α

K	1 bar	5 bar
340	28.3×10^{-6}	5.67×10^{-6}
360	31.4×10^{-6}	6.28×10^{-6}

K	2 bar
340	22.6×10^{-6}
360	25.1×10^{-6}

$\alpha = 23.9\times10^{-6}\ m^2/s$

ν

°C	1 bar	5 bar
40	17×10^{-6}	3.4×10^{-6}
80	21×10^{-6}	4.3×10^{-6}

°C	2 bar
40	13.6×10^{-6}
80	16.8×10^{-6}

$\nu = 16.6\times10^{-6}\ m^2/s$

K

°C	1 bar	5 bar
40	0.026	0.026
80	0.03	0.03

°C	2 bar
40	0.026
80	0.03

$K = 0.0297\ \frac{W}{m°C}$

Pr

K	1 bar	5 bar
340	0.703	0.705
360	0.701	0.703

K	2 bar
340	0.704
360	0.702

$Pr = 0.703$

Check to see if $Pe < 0.2$

$$Pe = \frac{VD}{\alpha} = \frac{20\frac{m}{s} \cdot 0.025m}{23.9\times10^{-6}\ m^2/s} = 20920 > 0.2$$

$$Re = \frac{VD}{\nu} = \frac{20\ m/s \cdot 0.025m}{16.6\times10^{-6}\ m^2/s} = 30121$$

$20{,}000 < 30121 < 400{,}000$, use eq. 7-41

$$Nu = 0.3 + \frac{0.62 Re^{1/2} Pr^{1/3}}{\left[1+\left(\frac{0.4}{Pr}\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re}{282{,}000}\right)^{1/2}\right]$$

$$Nu = 0.3 + \frac{0.62 \cdot 30121^{1/2} \cdot 0.703^{1/3}}{\left[1+\left(\frac{0.4}{0.703}\right)^{2/3}\right]^{1/4}}\left[1+\left(\frac{30121}{282{,}000}\right)^{1/2}\right]$$

$$Nu = 0.3 + \frac{95.7}{1.14} 1.33$$

$Nu = 111.7$

$$h = \frac{Nu\,k}{D} = \frac{111.7 \cdot 0.0297\frac{W}{m^{\circ}C}}{0.025m} = 132.7\ \frac{W}{m^2{}^{\circ}C}$$

$$Q = 132.7\frac{W}{m^2{}^{\circ}C}(\pi \cdot 0.025m \cdot 1m)(127^{\circ}C - 27^{\circ}C)$$

$Q = 1042\ W$

Ch8 Problem

Question 8-45

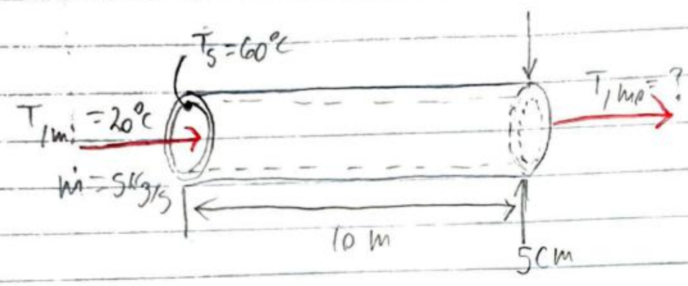
8-45 Water at 20℃ with a mass flow rate of 5 kg/s enters a 5-cm-ID, 10-m-long tube whose surface is maintained at a uniform temperature of 60℃. Calculate the outlet temperature of the water.

Solution

8-45) $T_{1mi} = 20°C$ $\dot{m} = 5 \frac{Kg}{s}$

$D = 5cm = 0.05m$ $L = 10m$ $T_s = 60°C$

$T_{1mo} = ?$



$Q = \dot{m} C_p (T_{mo} - T_{mi})$

$Q = hA \Delta t_{lm}$

$\Delta t_{lm} = \frac{\Delta T_o - \Delta T_i}{\ln\left(\frac{\Delta T_o}{\Delta T_i}\right)}$

$\Delta T_o = T_s - T_{mo}$

$\Delta T_i = T_s - T_{mi}$

$hA \frac{(T_s - T_{mo}) - (T_s - T_{mi})}{\ln\left(\frac{T_s - T_{mo}}{T_s - T_{mi}}\right)} = \dot{m} C_p (T_{mo} - T_{mi})$

1. Guess T_{mo} and Calculate $\bar{T} = \frac{T_{mo} + T_{mi}}{2}$
2. Compute $R_e = VD/\nu$
   $V = \frac{\dot{m}}{\rho A} = \frac{4\dot{m}}{\pi D^2 \cdot \rho}$

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3. Comput Nu
4. $h = \frac{Nu K}{D}$
5. RHS, LHS,
6. Compare

$$\frac{L}{D} = \frac{10}{0.05m} = 200 > 60$$

$0.7 < Pr < 160$

$Re > 10,000$

$$Nu = 0.023 Re^{0.8} Pr^{0.4}$$

After iteration, in excel, $T_{mo} = 34.5°C$

Tmi	20	degC		
mdot	5	kg/s		
dia	5	cm	0.05	m
L	10	m		
Ts	60	degC		

Iteration	Tmo Guess	Tbar	visocity	density	Velocity	Re	Pr	Nu	k	h	cp	RHS	Area	delta t0	delta ti	LHS	%diff
1	40	10	1.397E-06	1001.4	2.542919003	9.101E+04	10.31	542.3956558	0.5745	6232.126085	4199.8	419980	1.570796327	20	40	282462.3987	49%
2	30	5	1.593E-06	1001.84	2.541802173	7.981E+04	11.955	518.0521927	0.56325	5835.857951	4208.8	210440	1.570796327	30	40	318648.4356	-34%
3	35	7.5	1.495E-06	1001.62	2.542360466	8.504E+04	11.1325	529.7558638	0.568875	6027.29734	4204.3	315322.5	1.570796327	25	40	302156.9175	4%
4	34	7	1.514E-06	1001.664	2.542248787	8.394E+04	11.297	527.3439795	0.56775	5987.990887	4205.2	294364	1.570796327	26	40	305682.4966	-4%
5	34.5	7.25	1.505E-06	1001.642	2.542304625	8.449E+04	11.21475	528.5453074	0.568312	6007.5781	4204.75	304844.3	1.570796327	25.5	40	303935.093	0%

Activity

Regarding the concepts covered in the last few days, are they more relevant to the project you are in charge of? Why? Be specific

Chapters 7 and 8 were covered in the last few classes. Chapter 7 goes over the topic of External Forced Convection Heat Flow and Chapter 8 goes over Internal Forced Convection Heat Flow which are needed for the project because it will help us understand a big-picture view of the heat flow nature in objects. We observed that in a heat transfer system that internal and external convection forces can work upon an object simultaneously. The application problems worked through in the lecture shows us the many details that apply to the big picture. For example, we see how outside convection forces act upon pipes; this can be applied to the project because every convection force will count towards the chilling time to the two six-packs.

Based on the design that we are working on, the barrel that we are putting everything into will act as insulation which will allow the system to keep the cold temperature in while building it. This layer of insulation will also shield and buffer the hotter temperature from affecting the chilling process. With this design idea, we would need to utilize both chapters almost equally because, within the barrel, there is our cooling substance that will act upon the six packs' inside fluid which is external convection. Additionally, we will need to study the internal convection inside the barrel to see if it is enough to chill the six-pack fluid after getting past its container layer. This could be concluded as a paradox of different boundary layers or resistances all needing to be considered for the system to be effective in chilling the six-packs in five minutes or less.

From Chapter 7, we could utilize what we can learn from the fourth section about flow across a single circular cylinder as this can be used to get what kind of flow we need to subject the individual bottles to. It should be taken into account that the flow be turbulent as the goal is to chill in five minutes or less. From Chapter 8, we could utilize the fourth section that deals with the nature of turbulent flow internally because it will be turbulent flow inside of the barrel. This turbulent flow will be achieved by the pump we are going to use to circle the warm water out to a chiller and pump that cold water back into the barrel.