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COH29108
Due: Nov 28, 2016

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me263 – Fluids and Heat Transfer

Assignment 8 – Heat Exchangers

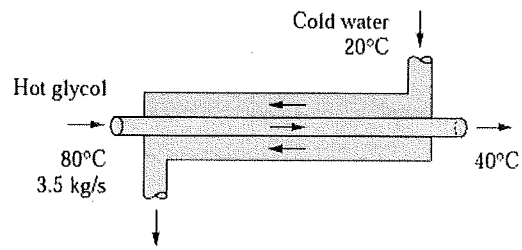
Question 1

Water at an average temperature of 110°C and an average velocity of 3.5 m/s flows through a 5 m long stainless steel tube (k = 14.2 W/m²·°C) in a boiler. The inner and outer diameters of the tube are D_i = 1.0 cm and D_o = 1.4 cm, respectively. If the convection heat transfer coefficient at the outer surface of the tube where boiling is taking place is h_o = 8400 W/m²·°C, determine:

a. The inner convective heat transfer coefficient, h_i (you know, using Nu and all that.)
b. The overall heat transfer coefficient U_i of this boiler based on the inner surface area of the tube.
c. The overall heat transfer coefficient U_i of this boiler based on the inner surface area of the tube with a fouling factor $R_{f,i}$ = 0.0005 m²·°C/W on the inner surface of the tube.

Question 2

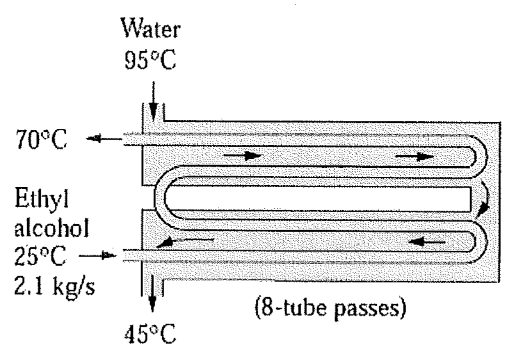
A double-pipe counter-flow heat exchanger is to cool ethylene glycol (Cp = 2560 J/kg·°C) flowing at a rate of 3.5kg/s from 80°C to 40°C by water (Cp = 4180 J/kg·°C) that enters at 20°C and leaves at 55°C. The overall heat transfer co-efficient based on the inner surface area of the tube is 250W/m²·°C. Determine:



a. The rate of heat transfer.
b. The mass flow rate of water.
c. The heat transfer surface area on the inner side of the tube.

Question 3

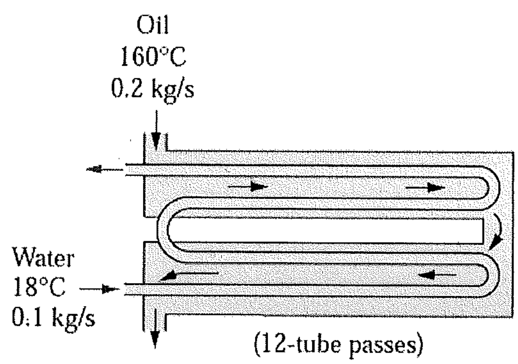
A shell-and-tube heat exchanger with 2-shell passes and 8-tube passes is used to heat ethyl alcohol (Cp = 2670 J/kg·°C) in the tubes from 25°C to 70°C at a rate of 2.1 kg/s. The heating is to be done by water (Cp = 4190 J/kg·°C) that enters the shell side at 95°C and leaves at 45°C. If the overall heat transfer coefficient is 950 W/m²·°C, based on the inner surface of the tube, determine:



a. The rate of heat transfer.
b. The heat transfer surface area of the heat exchanger.

Question 4

Hot oil (Cp = 2200 J/kg ·°C) is to be cooled by water (Cp = 4180 J/kg ·°C) in a 2-shell-passes and 12-tube-passes heat exchanger. The tubes are thin-walled and are made of copper with a diameter of 1.8 cm. The length of each tube pass in the heat exchanger is 3 m, and the overall heat transfer coefficient is 340 W/m² ·°C. Water flows through the tubes at a total rate of 0.1 kg/s, and the oil through the shell at a rate of 0.2 kg/s. The water and the oil enter at temperatures 18°C and 160°C, respectively.



Using the NTU method (note they only give the inlet temperatures and flowrates), determine the rate of heat transfer in the heat exchanger and the outlet temperatures of the water and the oil.
(Answers: 36.2 kW, 104.6°C, 77.7°C)

Question 5

Redo problem 2 but this time select a BASCO Heat Exchanger to do the job and use their method of selection.

Meng 263 Assignment #8

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1) $L = 5m$ $T_{AVG} = 110°C$
$D_i = 1.0cm$ $V_{AVG} = 3.5\frac{m}{s}$
$D_o = 1.4cm$
$K = 14.2\frac{W}{m^2 °C}$ $h_o = 8400\frac{W}{m^2 °C}$

(a) Find h_i

$\rho @ 110°C = 950.6\frac{kg}{m^3}$
$\mu @ 110°C = 2.55\times10^{-4}\frac{kg}{m\cdot s}$

$Re = \frac{VD_i\rho}{\mu} = \frac{(3.5)(0.01)(950.6)}{(2.55\times10^{-4})}$

$\therefore Re = 130474$ ✓

$Cp @ 110°C = 4229\frac{J}{kg °C}$
$K @ 110°C = 0.682\frac{W}{m °C}$

$Pr = \frac{\mu C_p}{K}$

$= \frac{(2.55\times10^{-4})(4229)}{(0.682)}$

$\therefore Pr = 1.581 \Rightarrow (1 < Pr < 20)$

So... $Nu = 0.0155 Pr^{0.5} Re^{0.83}$
$= 0.0155(1.581)^{0.5}\cdot(130474)^{0.83}$
$\therefore Nu = 343.3$ ✓

$Nu = \frac{h_i D}{K} \Rightarrow h_i = \frac{Nu\cdot K}{D_i} = \frac{(343.3)(0.682)}{(0.01)}$

$\therefore h_i = 23413\frac{W}{m^2 °C}$ ✓

(b) $R = R_i + R_o + R_{WALL}$
$= \frac{1}{h_i A_i} + \frac{1}{h_o A_o} + \frac{\ln(D_o/D_i)}{2\pi K L} = \left[\frac{1}{(23413)(0.01\pi)(5)}\right] + \left[\frac{1}{(8400)(0.014\pi)(5)}\right] + \frac{\ln\left(\frac{0.014}{0.01}\right)}{2\pi(14.2)(5)}$

$\therefore R = 0.00157$

$\frac{1}{U_i A_i} = R$ $\therefore U_i = \frac{1}{RA_i} = \frac{1}{(0.00157)(0.01\pi)(5)}$

$\therefore U_i = 4061.4\frac{W}{m^2 °C}$ ✓

c) $R_{f,i} = 0.0005 \frac{m^2 °C}{W}$

$R = R + \frac{R_{f,i}}{A_i} = (0.00157) + \left(\frac{0.0005}{(0.01\pi)(5)}\right)$

$\therefore R = 0.00475 \frac{m^2 °C}{W}$

(5/5)

→ $U_i = \frac{1}{R A_i} = \frac{1}{(0.00475)(0.01\pi)(5)}$ $\therefore U_i = 1340.3$ ← ✓

2) $C_{ph} = 2560 \frac{J}{kg °C}$ $C_p = 4180 \frac{J}{kg °C}$

$\dot{m}_h = 3.5 \frac{kg}{s}$ $T_i = 20°C$

$T_{in} = 80°C$ $T_f = 55°C$

$T_{out} = 40°C$ $U_i = 250 \frac{W}{m^2 °C}$

a) $\dot{Q} = \dot{m}_h C_{ph}(T_{in} - T_{out})$

$= (3.5)(2560)(80 - 40)$

→ $\therefore \dot{Q} = 358.4\,kW$ ✓

b) $\dot{Q} = \dot{m}_c C_{pc}(T_{out} - T_{in}) \Rightarrow \dot{m}_c = \frac{\dot{Q}}{C_{pc}(T_{out} - T_{in})} = \frac{(358.4\,kW)}{(4180)(55-20)}$

→ $\therefore \dot{m}_c = 2.5 \frac{kg}{s}$ ✓

c) $\Delta t_1 = t_{h in} - t_{c out} = 80 - 55 = 25$

→ $\Delta t_2 = t_{h out} - t_{c in} = 40 - 20 = 20$

$\Delta T_{lm} = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)} = \frac{(25) - (20)}{\ln\left(\frac{25}{20}\right)}$ $\therefore \Delta T_{lm} = 22.41°C$

$\dot{Q} = U_i A_i \Delta t_{lm} \Rightarrow A_i = \frac{\dot{Q}}{U_i \Delta t_{lm}} = \frac{(358.4\,kW)}{(250)(22.41)}$

Seems really big →

→ $\therefore A_i = 64 m^2$ ✓

└ IT IS BIG!

(5/5)

3) $C_{pc} = 2670 \frac{J}{kg°C}$ $\quad C_{pH} = 4190 \frac{J}{kg°C}$

$T_{in} = 25°C$ $\quad T_{in} = 95°C$

$T_{out} = 70°C$ $\quad T_{out} = 45°C$

(a) $\dot{m}_c = 2.1 \frac{kg}{s}$

$\dot{Q} = \dot{m}_c C_{pc}(T_{out} - T_{in})$

$= (2.1)(2670)(70-25)$

→ $\therefore \dot{Q} = 252.3 kW$ ✓

(b) $U_i = 950 \frac{W}{m^2°C}$

$\Delta t_1 = t_{hin} - t_{cout} = 95° - 70° = 25°C$

$\Delta t_2 = t_{hout} - t_{cin} = 45° - 25° = -25°C = 20°C$

$R = \frac{\Delta t_h}{\Delta t_c} = \frac{95-45}{70-25} = 1.11$

$P = \frac{\Delta t_c}{t_{hin} - t_{cin}} = \frac{45}{70} = 0.643$

$\Delta t_{lm} = \frac{\Delta t_1 - \Delta t_2}{\ln\left(\frac{\Delta t_1}{\Delta t_2}\right)} = \frac{(25)-(20)}{\ln\left(\frac{25}{20}\right)}$

$\therefore F = 0.81$ ✓

$\therefore \Delta t_{lm} = 22.41°C$ ✓

→ $\dot{Q} = U_i A_i \Delta t_{lm} F \Longrightarrow A_i = \frac{\dot{Q}}{U_i \Delta t_{lm} F} = \frac{(252.3 kw)}{(950)(22.41)(0.81)}$

→ $\therefore A_i = 14.6 m^2$ ✓

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4) $C_{ph} = 2200 \frac{J}{kg°C}$ $\quad C_{pc} = 4180 \frac{J}{kg°C}$ $\quad$ Copper pipe (thin walled)

$\dot{m}_h = 0.2 \frac{kg}{s}$ $\quad \dot{m}_c = 0.1 \frac{kg}{s}$ $\quad D = 1.8 cm$

$T_{in} = 160°C$ $\quad T_{in} = 18°C$ $\quad L = 3m$

$U = 340 \frac{W}{m^2°C}$

$C_c = \dot{m}_c C_{pc} = (0.1)(4180) = 418$ $\quad \therefore C_{min} = C_c$

$C_h = \dot{m}_h C_{ph} = (0.2)(2200) = 440$ $\quad C_{MAX} = C_h$ ✓

$A_s = \pi DL = (0.018\pi)(3 \frac{m}{pass} \times 12 pass)$

$\therefore A_s = 2.035 m^2$

$C = \frac{C_{min}}{C_{MAX}} = \frac{418}{440} = 0.95$ ✓

$NTU = \frac{UA_s}{C_{min}} = \frac{(340)(2.035)}{418}$

$\therefore \varepsilon = 0.60$ ✓

$\therefore NTU = 1.66$ ✓

$\dot{Q}_{MAX} = C_{min}(T_{hin} - T_{cin}) = (418)(160-18)$

$\therefore \dot{Q}_{MAX} = 59 kW$ ✓

Why is it not the Same as your Answer?

So...

$\dot{Q} = \varepsilon Q_{max} = (0.6)(59kw)$

$\dot{Q} = 35.6 kw$ ✓

ONLY BECAUSE YOUR CHART SELECTION OF ε IS A BIT DIFFERENT. NO BIG DEAL

$\dot{Q} = C_c(T_{cout} - T_{cin}) \Rightarrow T_{cout} = \frac{\dot{Q}}{C_c} + T_{cin} = \frac{(35.6kw)}{418} + 18$

$\therefore T_{cout} = 103.2°C$ ✓

$\dot{Q} = C_h(T_{hin} - T_{hout}) \Rightarrow T_{hout} = \frac{-\dot{Q}}{C_h} + T_{hin} = \frac{-(35.6kw)}{440} + (160)$

$\therefore T_{hout} = 79°C$

5/5

5) $\dot{Q} = \Delta t \times \text{thermal duty value} \times L/min$

$\dot{Q} = (80-40)(203)(197)$

$\dot{Q} = 1.6 \times 10^6 \frac{BTU}{hr}$ ok

$\rho @ 40°C = Sg \times \rho_{water}$ (Because that is when its is most dense; Engineering toolbox)

$= (1.064)(1000 \frac{kg}{m^3})$

$\rho = 1064 \frac{kg}{m^3}$

$Q = \frac{\dot{m}}{\rho} = \frac{(3.5)}{(1064)} = 3.29 \times 10^{-3} \frac{m^3}{s}$

$Q = 3.29 \times 10^{-3} \frac{m^3}{s} \times 1000 \frac{L}{m^3} \times 60 \frac{s}{min}$

$\therefore Q = 197 L/min$

$\dot{Q} = \Delta t \times \text{Flow constant} \times L/min$

$\Rightarrow L/min = \frac{\dot{Q}}{\Delta t \times \text{Flowconst}} = \frac{(1.6 \times 10^6)}{(55-20)(238)}$

$\therefore L/min = 192 L/min \Rightarrow \dot{m} = Q\rho = (3.2 \times 10^{-3})(1000)$

$\therefore \dot{m} = 3.2 \frac{kg}{s}$

$GTTD = 80-20 = 60$
$LTTD = 55-40 = 15$ } $LMTD = 32°C$

$R = \frac{80-40}{55-20} = 1.14$

$P = \frac{55-20}{80-20} = 0.583$

} Correction $= 0.77$

$t_{hin} = 80°C$ $t_{cin} = 20°C$

$t_{hout} = 40°C$ $t_{cout} = 55°C$

$A = \frac{\dot{Q}}{U \times LMTD \times Corr} = \frac{1.6 \times 10^6}{(250)(32)(0.77)}$

$\therefore A = 259.7 ft^2$ ✓

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Use standard Strait-tube Type 500 heat exchanger

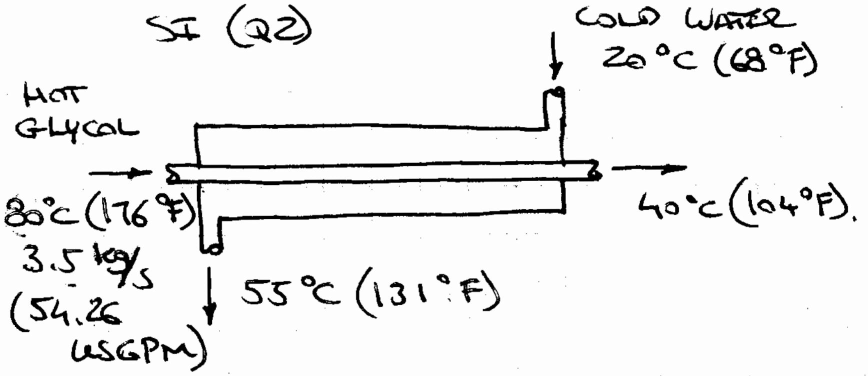
MODEL: 10120 ETC.

See the next page for another solution to question 5

ASSIGNMENT 8

QUESTION 5 (BASED ON QUESTION 2).

SI (Q2)



CONVERT TO US (IMPERIAL) UNITS

20°C → 68°F } WATER
55°C → 131°F }
80°C → 176°F } GLYCOL
40°C → 104°F }

3.5 kg/s HOT GLYCOL ?

- FROM THE TABLE IN THE BASCO CATALOG 'TYPICAL THERMAL DUTY VALUES' ...
- 50% ETHYLENE GLYCOL HAS A SG = 1.04

$\therefore \rho_{GLYCOL} = \rho_{H_2O} \times 1.04$

ASSUMING AN AVERAGE TEMPERATURE OF $\frac{80+40}{2} = 60$

$\rho_{H_2O} = 983.3 \ kg/m^3$

$\therefore \rho_{GLYCOL} = 1,022.63 \ kg/m^3$

SO $Q_{GLYCOL} = \dot{m} / \rho_{GLYCOL}$

$= \frac{3.5 \ kg/s}{1022.63 \ kg/m^3}$

$= 0.0034 \ m^3/s$

$Q_{GLY} = 54.26$ USGPM

NOW WE CAN USE THE BASCO EXAMPLE METHOD AS A GUIDE

$Q = (\Delta T)(\text{THERMAL DUTY VALUE})(\text{USGPM})$

$= (176 - 104)(428)(54.26)$

$= 1,672,076$ BTU/HR. ← GLYCOL SIDE

$\text{USGPM (WATER)} = \frac{Q}{\Delta T \times \text{THERMAL DUTY VALUE}}$ ← WATER SIDE

$= \frac{1,672,076 \ BTU/HR}{(131-68)(500)}$

$= 53.08$ USGPM

GTTD = 176 − 131 = 45°F

LTTD = 104 − 68 = 36°F

$\Delta T_m = \frac{GTTD - LTTD}{\ln(GTTD/LTTD)} = \frac{9}{0.223} = 40.33°F$

SELECT 'U' FROM BASCO TABLE 'TYPICAL OVERALL U-VALUES'

U = 150 TO 180 → USE: **U = 160**

$\therefore \text{AREA} = \frac{Q}{U \times LMTD}$

$= \frac{1,672,076}{(160)(40.33)} = 259.12 \ FT^2 = A$

HEAT EXCHANGER SELECTION

CHOOSE: ASME/TEMA-C STRAIGHT-TUBE HX

MODEL: 10120

- 3/8" TUBES
- 338 FT^2 A_s ← OK
- 4 PASS (158 USGPM MAX)
- 2½" & 4" FLANGE CONNECTIONS