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Assignment :- 3

Solution 1

Given :- $\rho = 1109\ kg/m^3$, $C_p = 2428\ J/kg.K$, $K = 0.2530\ W/$

$\mu = 0.01545\ kg/m.s$ $\quad P_r = 148.5$

$$\dot{Q} = \dot{m} C_p (T_e - T_i) = 2.5 \times 2428 \times (40-25) = 91{,}050\ W$$

The fluid velocity is

$$V = \frac{\dot{m}}{\rho A_c} = \frac{2.5\ kg/s}{1109\ kg/m^3 [\pi (0.02)^2/4]} = 7.175\ m/s$$

The Reynold no.

$$Re = \frac{\rho V D}{\mu} = \frac{1109 \times (7.175) \times 0.02}{0.01545} = 10{,}300.4$$

$Re > 10000 \rightarrow$ turbulent flow.

$$Nu = \frac{hD}{k} = 0.023\, Re^{0.8} P_r^{0.4} = 0.023 (10{,}300)^{0.8} (145.5)^{0.4}$$
$$= 273.6$$

$$h_i = \frac{k}{D} Nu = \frac{0.253}{0.02} \times 273.6 = 3461.04\ W/m^2$$

assuming the wall temp. of $100^\circ C$

$$h_o = 9200 (T_g - T_w)^{-0.25} = 9200 (110-100)^{-0.25}$$
$$= 5174\ W/m^2 \cdot ^\circ C$$

Let's check the assumption of wall temp. holds.

$h_i A_i (T_w - T_{b,ave}) = h_o A_o (T_g - T_w)$

$\Rightarrow 3461.04 (\pi D_i L)(T_w - T_{b,ave}) = 5174 \times \pi D_o L (T_g - T_w)$

$= 3461.04 \times 0.02 (T_w - 32.5) = 5174 \times 0.025 \times (110 - T_w)$

$T_w = 83°C$

now assume 83°C as wall temp.

$h_o = 9200 (T_g - T_w)^{-0.25} = 4035.96 \ W/m^2 \cdot °C$

again checking:-

$3461.04 \times 0.02 \times (T_w - 32.5) = 4035.96 \times 0.025 (110 - T_w)$

$T_w = 78.46°C$

now both heat transfer coffiecient is available

the

$$U_o = \frac{1}{\frac{D_o}{h_i D_i} + \frac{D_o \ln (D_2/D_1)}{2 K_{copper}} + \frac{1}{h_o}} = \frac{1}{\frac{0.025}{3461.04 \times 0.02} + \frac{0.025 \ln(2.5/2)}{2 \times 386} + \frac{1}{4035.96}} = 1622.95 \ W/m^2 °C$$

$q = U_o A_o \Delta T_{lm}$

$$\Delta T_{lm} = \frac{(T_g - T_e) - (T_g - T_i)}{\ln \frac{(T_g - T_e)}{(T_g - T_i)}} = \frac{(110 - 40) - (110 - 25)}{\ln \left(\frac{110 - 40}{100 - 25}\right)}$$

$= 77.26°C$

$\Rightarrow \dot{q} = U_o A \Delta T_{lm} \rightarrow 91050 = 1622.95 \times \pi \times 0.025 \times L \times 77.2$

$$\boxed{L = 9.25\ m}$$

Solution no:- 2

given

$C_{ph} = 1.0\ Btu/lbm\,^\circ F$ (water) $\quad C_{pc} = 0.245\ Btu/lbm\,^\circ F$ (air)

$\dot{q} = \dot{m}\, C_{ph}\, (T_{h,in} - T_{h,out})$

$= (92{,}000)\ lbm/hr \times 1\ Btu/lbm\,^\circ F \times (190-140)\,^\circ F$

$= 4.6 \times 10^6\ Btu/hr$

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

$\Rightarrow T_{c,out} = \dfrac{\dot{q}}{\dot{m}_c C_{pc}} + T_{c,in}$

$\Rightarrow T_{c,out} = \dfrac{4.6 \times 10^6\ Btu/hr}{(400{,}000\ lbm/hr)(0.245\ Btu/lbm\,^\circ F)} + 90\,^\circ F$

$= 136.9\,^\circ F$

$\Delta T_{lm\,cf} = \dfrac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)} = \dfrac{(190-136.9)-(140-90)}{\ln[(190-136.9)/(140-90)]}$

$= 51.5\,^\circ F$

correction factor =

$$P = \frac{t_2 - t_1}{T_2 - t_1} = \frac{140 - 190}{90 - 190} = 0.5$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{90 - 136.9}{140 - 190} = 0.94$$

$F = 0.82$

the log mean temp. diff. is

$$\Delta T_{lm} = F \Delta T_{lm\,CF} = 0.92 \times 51.5 = 47.4°F$$

solution :- 3

$Q = m C_p \Delta T$

$Q_b = m_b C_{p,b} (\Delta T_b) = 5 \, kg/s \times 1839 \, J/kg \cdot K \times (75-45) K$
$= 274180 \, W$

$Q_w = \cdot m_w C_{p,w} (\Delta T_w) = 3.5 \times 4187 \, J/kg \times (T_{w,out} - 15) K$

$Q_b = Q_w$

$T_{w,out} = \dfrac{-Q_b}{m_w C_{p,w}} + 15 = 49.23^\circ C$

Capacity ratio :-

$C_r = \dfrac{C_{min}}{C_{max}} = \dfrac{m_b \cdot C_{p,b}}{m_c C_{p,w}} = \dfrac{5 \times 1839}{3.5 \times 4187} = 0.607$

Effectiveness :-

$\varepsilon = \dfrac{Q_{act}}{Q_{max}} = \dfrac{C_r (1 - e^{N_t (1 - C_r)})}{(1 - \cdot C_r e^{-N_t (1 - C_r)})}$

for llrl $\Rightarrow N_t = \dfrac{UA}{C_{min}} \Rightarrow A = \dfrac{N_t \times m_{b,C_{p,b}}}{U} = \dfrac{0.958568}{750}$

for C.F. $\Rightarrow A = \dfrac{1.20668}{750}$

for shell and tube assume $F = 0.88$

$A = \dfrac{F \times (1.20665)}{750} = \dfrac{0.88 (1.20668)}{750}$

for cross-flow

Assuming the effectiveness is average of ||el and C.F. flow

$$A = \frac{1.09618}{750}$$

we can now plug N_t value into each expres.

$$A_p = \frac{0.98568}{750} = 1.314\,m^2$$

$$A_{CF} = \frac{1.20668}{750} = 1.609\,m^2$$

$$A_{ST} = \frac{0.88 \times (1.20665)}{750} = 1.417\,m^2$$

$$A_{a.x} = \frac{1.09615}{750} = 1.461\,m^2$$

solution 5

steps involves in selection process:-

1. Requirements:- identify the fluids, properties and flow rates
2. Heat Duty
3. select a type of Hex based on application.
4. Calculate LMTD
5. check the pressure drop across Hex.
6. choose material that is compatible with the fluids.
7. Design and Rating.
8. safety and maintenance
9. perform a cost analysis considering all cost.

solution 6 :-

large single heat exchanger :-

$$\dot{q} = \dot{m}_h C_{ph} (T_{h,in} - T_{h,out}) = \dot{m} C_{pc} (T_{c,out} - T_{c,in})$$

$$= \dot{m}_h C_{ph} (120 - 70) = 1.5 \times 2447 \times (50 - 10) = 146.82 \text{ KW}$$

$$C_h = \dot{m}_h C_{ph} = 2936.4 \text{ W/K}$$

$$C_c = \dot{m}_c C_{pc} = 1.5 \times 2447 = 3670.5 \text{ W/K}$$

$$C_{min} = C_h$$

(a) $$\varepsilon = \frac{\dot{q}}{Q_{max}} = \frac{C_c (T_{c,out} - T_{c,in})}{C_{min} (T_{h,in} - T_{h,out})} = \frac{(3670.5)(50-10)}{(2936.4)(120-10)} = 0.455$$

the capacity ratio of the large single Hx :-

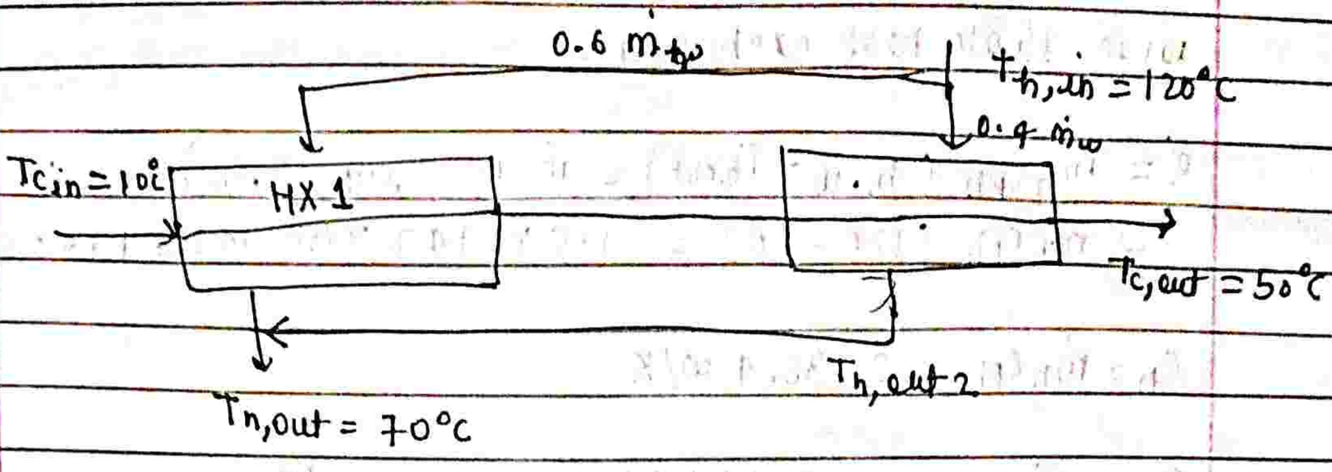
$$C = \frac{C_{min}}{C_{max}} = \frac{2936.4}{3670.5} = 0.8$$

(b) $$NTU = \frac{1}{C-1} \ln\left(\frac{\varepsilon - 1}{\varepsilon C - 1}\right) = \frac{1}{0.8-1} \ln\left(\frac{0.455-1}{0.455 \times 0.8 - 1}\right)$$

$$= 0.77$$

(c) $$A_s = \frac{NTU \, C_{min}}{U} = \frac{0.77 \times 2936.4}{950} = 2.38 \text{ m}^2$$

now let's consider two small HXs :-



$C_{h,1} = 0.6 \times 2936.4 = 1761.8$ W/K

$C_{h,2} = 0.4 \times 2936.4 = 1174.6$ W/K

$C_c = 3670.5$ W/K

the capacity ratio :-

for 1st HX :-

$$c_1 = \frac{C_{min}}{C_{max}} = \frac{1761.8}{3670.5} = 0.45$$

for 2nd HX :-

$$c_2 = \frac{1174.6}{3670.5} = 0.32$$

effectiveness ⇒

for 1st HX :-

$$\varepsilon_1 = \frac{\dot{q}}{q_{max}} = \frac{C_c(T_{c,out} - T_{cin})}{C_{min}(T_{h,in} - T_{c,in})} = \frac{3670.5\,(T_{cin} - 10)}{1761.8\,(120 - 10)}$$

$$= 0.0189\,(T_{c,in} - 10) \quad \text{---(1)}$$

for 2nd HX :-

$$\varepsilon_2 = \frac{3670(50 - T_{c,in})}{1174.6(120 - T_{c,in})} = 3.125 \frac{(50 - T_{c,in})}{(120 - T_{c,in})} \quad \text{---(2)}$$

energy balance :-

$$\dot{m}_{h,out\,1}\, C_{ph}\, T_{h,out1} + \cancel{0.4}\; \dot{m}_{h,out\,1}\, C_{ph}\, T_{h,out2} = \dot{m}_{h,out}\, C_{ph}\, T_{out}$$

$$\Rightarrow 0.6\, \dot{m}_{h,out}\, T_{,out1} + 0.4\, \dot{m}_{h,out}\, T_{h,out2} = \dot{m}_{h,out}\, C_{ph}\, T_{h,out}$$

$$\Rightarrow \cancel{0.6\, \dot{m}_{h,out}}$$

$$\Rightarrow 0.6\, T_{h,out1} + 0.4\, T_{h,out2} = 70^\circ C \quad \text{---(3)}$$

for 2nd Hex

$$\dot{m}_h\, C_{ph1}(T_{h,in} - T_{h,out}) = \dot{m}_c\, C_{pc}(T_{c,out} - T_{c,in})$$

$$\therefore (1174.6)(120 - T_{h,out2}) = 3670.5 \times (50 - T_{c,in}) \quad \text{---(4)}$$

$$NTU_1 = \frac{1}{C_1 - 1} \ln \frac{\varepsilon_1 - 1}{C_1\varepsilon_1 - 1} \quad \text{---(5)}$$

$$NTU_2 = \frac{1}{C_2 - 1} \ln \left(\frac{\varepsilon_2 - 1}{C_2\varepsilon_2 - 1}\right) \quad \text{---(6)}$$

surface aree is same

$$A_{s1} = A_{s2}$$

$$\frac{NTU_1\, C_{ph,1}}{U} = \frac{NTU\, C_{ph,2}}{U} \quad \text{---(7)}$$

solving 1 to 7

$T_{h,out1} = 70.82°C$

$T_{h,out2} = 68.77°C$

$T_{c\,in} = 33.61°C$

(a) the value of effectiveness $\varepsilon_1 = 0.447$ and $\varepsilon_2 = 0.593$

(b) $NTU_1 = 0.675$ & $NTU_2 = 1.012$

(c) The surface area of small Hex $= 1.252 m^2$

(d) for one Hex $A = 1.252 m^2$ for two Hex in series $A = 2.5 m^2$. this area is about 5% higher than that of a single large Hex. more-over the constru. cost of a small exchanger is 15% higher than the large Hex. this translates about 2% ↑ increase in construction cost.
Hence it is recomended to use one large Hex instead of two Hexs in series.