Heatexchanger

GTU Solved Numericals.

1. A heat exchanger is to be designed to condense 8 kg/sec of an organic liquid ($t_{sat} = 80^\circ C$, h_{fg} 600 kJ/kg) with cooling water available at $15^\circ C$ and at a flow rate of 60 kg/sec. The overall heat transfer co-efficient is $480 \ W/m^2\,^\circ C$.

Calculate.

a) The number of tube required. The tubes are to be of 25 mm outer diameter, 2 mm thickness & 4.85 m length.

b) The number of tube passes. The velocity of the cooling water is not to be exceed 2 m/sec. (DEC-2011)

→ $m_h = 8$ kg/sec $\quad TC_1 = 15^\circ C \quad Th_2 = 80^\circ C$

$T_s = 80^\circ C \quad m_c = 60$ kg/sec $\quad Th_1 = 80^\circ C$

$h_{fg} = 600$ kJ/kg. $\quad U = 480 \ W/m^2 C$.

$$Q = m_h \times h_{fg}$$
$$= 8 \times 600 \times 10^3$$
$$\boxed{Q = 48 \times 10^5 \ W}$$

Heat loss by Vapour = Heat gain by Water

$$m_h \times h_{fg} = m_c Cp_c (TC_2 - TC_1)$$

– $Q = m_c Cp_c (TC_2 - Tc_1)$

$$48 \times 10^5 = 60 \times 4186 (Tc_2 - 15)$$
$$\therefore \boxed{Tc_2 = 34.11^\circ C}$$

– $Q = UA\,\theta_m$

$$= UA \frac{(\theta_2 - \theta_1)}{\ln(\theta_2/\theta_1)}$$

$$\therefore 48 \times 10^5 = 480 \times A \times \frac{(80-15) - (80-34.11)}{\ln \frac{(80-15)}{(80-34.11)}}$$

$$= 480 \times A \times \frac{65 - 45.89}{0.348}$$

$$48 \times 10^5 = 26358.62 \times A$$

$$\boxed{\therefore A = 182.1 \ m^2}$$

- Number of tubes

Area of one tube = $\pi d L$ = $\pi \times 0.025 \times 4.85$
= 0.38

Number of tubes = $\frac{182.1}{0.38}$
= 480 tubes.

- No. of tube passes p;

The cold water flow mass passing through is given by.

$$m_c = \left(\pi/4 \,(d_o - 2t)^2 \times u \times \rho\right) \times N_p \qquad \frac{(0.025 - 2(0.02))}{0.021}$$

N_p = No. of tubes in each pass ($N = p \times N_p$).

$$60 = \pi/4 \times (0.021)^2 \times 2 \times 1000 \times N_p$$

$\therefore$ $N_p = 86.6$

No. of passes (p) = $\frac{N}{N_p}$

$= \frac{480}{86.6}$

$= 5.58$

$\boxed{\text{No. of passes (p)} \simeq 6}$

A counter flow heat exchanger is employed to cool oil of specific heat $C_p = 2.45$ kJ/kg°C with mass flow rate of 0.55 kg/sec from 115°C to 40°C by water. The inlet & outlet temp of cooling water are 15°C & 75°C respectively. The overall heat transfer co-efficient is 1450 W/m²°C. Using NTU method. Calculate.

i) Mass flow rate of water ii) The effectiveness of Heat exchanger. (iii) The surface area required. (MAY-2011)

$m_{oil} = 0.55$ kg/s

$C_{p\,oil} = 2.45$ kJ/kg°C

$T_{h_1} = 115°C$ $\quad T_{c_1} = 15°C$

$T_{h_2} = 40°C$ $\quad T_{c_2} = 75°C$

$U = 1450$ W/m²°C

(i) Mass flow rate of water.

$$m_c C_{p_c} (t_{c_2} - t_{c_1}) = m_{oil} C_{p\,oil} (T_{h_1} - T_{h_2})$$

$$\therefore m_c = \frac{m_{oil} C_{p\,oil} (T_{h_1} - T_{h_2})}{C_{p_c} (t_{c_2} - t_{c_1})}$$

$$= \frac{0.55 \times 2.45 \times 10^3 (115 - 40)}{4.187 \times 10^3 (75 - 15)}$$

$$= \frac{101.06}{251.22}$$

$$\boxed{m_c = 0.402 \text{ kg/sec}}$$

(ii) Effectiveness of heat exchanger.

$$\varepsilon = \frac{Q_{actual}}{Q_{max}}$$

$$= \frac{m_{oil} C_{p\,oil} (T_{h_2} - T_{h_1})}{(mC_p)_{min} (T_{h_1} - T_{c_1})}$$

$m_w C_{pw} = 0.402 \times 4187 = 1683$

$m_{oil} C_{poil} = 0.55 \times 2450 = 1347.5$

Hence, $m_{oil} C_{poil} < m_w C_{pw}$

$$\therefore \varepsilon = \frac{m_{oil} C_{poil} (T_{h_1} - T_{h_2})}{m_{oil} C_{poi} (T_{h_1} - T_{c_1})}$$

$m_{oil} C_{poil} = C_{min}$.

$$= \frac{115-40}{115-15}$$

$$\boxed{\varepsilon = 0.75}$$

(iii) Surface Area Required.

$$R = \frac{C_{min}}{C_{max}} = \frac{1347.5}{1683} = 0.8$$

For counter flow H.E. $\varepsilon = \dfrac{1-e^{-(1-R)NTU}}{1-Re^{-(1-R)NTU}}$

$$0.75 = \frac{1-e^{-(1-0.8)NTU}}{1-0.8e^{-(1-0.8)NTU}}$$

$$\therefore 0.75 - 0.6e^{-0.2NTU} = 1 - e^{-0.2NTU}$$

$$\therefore 0.4e^{-0.2NTU} = 0.25$$

$$e^{-0.2NTU} = 0.625$$

$$e^{0.2NTU} = 1.6$$

Log = 0.20

$$0.2NTU = 0.47 \quad (\cdot \ln)$$

$$\boxed{\therefore NTU = 2.35}$$

— We know that $NTU = \dfrac{UA}{C_{min}}$

$$2.35 = \frac{1450 \times A}{1347.5}$$

$$\boxed{\therefore A = 2.18 \, m^2}$$

5.) A parallel flow heat exchanger has its tubes of 5cm internal and 6 cm external diameter. The air flows inside the tubes are recieves heat from hot gases circulated in the annular space of the tube at the rate of 100 kw. Inside and outside heat transfer coefficients are 250 w/m²K and 400 w/m²K respectively. Inlet temperature of hot gases is 500°C, outlet temperature of hot gases is 300°C, Inlet temperature of air 50°C, Exit temperature of air 140°C, Calculate:

1. Overall heat transfer co-efficient based on outer surface area.
2. Length of the tube required to affect the heat transfer rates, Neglect the thermal resistance of the tube.
3. If each tube is 3m length find the number of tubes required.

(May - 2012)

→ $Q = 100\ kW$.

$d_i = 5cm = 0.05\ m$, $h_i = 250\ w/m^2k$

$d_o = 6cm = 0.06m$, $h_o = 400\ w/m^2k$

$Th_1 = 500°C$, $Th_2 = 300°C$, $TC_1 = 50°C$, $TC_2 = 140°C$

$U_o = (?)$

$L = (?)$

$N = (?)$

(i) Overall heat transfer co-efficient based on outer surface area U_o.

$$\frac{1}{U_o} = \frac{r_o}{r_i} \times \frac{1}{h_i} + \frac{1}{h_o}$$

$$= \frac{d_o}{d_i} \times \frac{1}{h_i} + \frac{1}{h_o}$$

$$\therefore \frac{1}{U_o} = \frac{0.06}{0.05} \times \frac{1}{250} + \frac{1}{400}$$

$$= 0.0073$$

$$\boxed{U_o = 136.99\ w/m^2 k}$$

(ii) Length of tube, L required.

$$Q = UA\theta_m$$

$$\theta_m = \frac{\theta_1 - \theta_2}{\ln(\theta_1/\theta_2)} = \frac{(th_1 - tc_1) - (th_2 - tc_2)}{\ln\left(\frac{th_1 - tc_1}{th_2 - tc_2}\right)}$$

$$= \frac{450 - 160}{\ln\left(\frac{450}{160}\right)}$$

$$\boxed{\therefore \theta_m = 280.45^\circ C}$$

$$Q = U_o A_o \theta_m$$

$$= U_o \times (\pi d_o L) \times \theta_m$$

$$100 \times 10^3 = 136.99 \times (\pi \times 0.06 \times L) \times 280.45$$

$$\boxed{\therefore L = 13.8088 \text{ m}}$$

(iii) Number of tubes,
N if each tube is $l = 3$m long.

$$\therefore N = \frac{L}{l} = \frac{13.8088}{3\text{m}}$$

$$= 4.60$$

$$\boxed{N \cong 5 \text{ tubes}}$$

1.) A chemical having a specific heat of 3.3 kJ/kgK flowing at the rate 20,000 kg/h enters a parallel flow heat exchanger at 120°C. The flow rate of cooling water is 50,000 kg/h. with an inlet temperature of 20°C. The heat transfer area is 10 m² and overall heat transfer co-efficient is 1200 W/m²°C. Taking specific heat of water as 4.186 kJ/kgK calculate;

1. Effectiveness of the heat exchanger.
2. Outlet temperature of water and chemical.

(May-2012)

→ $C_{ph} = 3.3 \text{ kJ/kgK}$

$m_h = 20000 \text{ kg/hr} = \frac{20000}{3600} = 5.556 \text{ kg/s}.$

$Th_1 = 120°C$

$m_c = 50000 \text{ kg/hr} = \frac{50,000}{3600} = 13.889 \text{ kg/s}$

$Tc_1 = 20°C$

$C_{pc} = 4.186 \text{ kJ/kgK}$

$A = 10 m^2.$

$U = 1200 \text{ W/m}^2 C$

$\varepsilon = (?)$

$Th_2 = (?)$

$Tc_2 = (?)$

(i) Effectiveness of parallel flow Heat Exchanger

$C_h = m_h C_{ph} = 5.556 \times 3.3 = 18.3348 \text{ kW/K}$

$C_c = m_c C_{pc} = 13.889 \times 4.186 = 58.1394 \text{ kW/K}$

$\therefore C_h = C_{min}$

$C_c = C_{max}.$

Now, $NTU = \frac{UA}{C_{min}} = \frac{1200 \times 10}{18.3348 \times 10^3}$

$\boxed{NTU = 0.6545}$

- Capacity Ratio $R = \frac{C_{min}}{C_{max}} = \frac{18.3348}{58.1394}$

$$R = 0.3154$$

- Effectiveness $\varepsilon = \frac{1 - e^{-NTU(1+R)}}{1+R}$

$$= \frac{1 - e^{-0.6545(1+0.3154)}}{1+0.3154}$$

$$\boxed{\varepsilon = 0.4388}$$

(ii) Outlet temperatures of water T_{c_2} & Chemical T_{h_2}.

$$\varepsilon = \frac{C_h(T_{h_1} - T_{h_2})}{C_{min}(T_{h_1} - T_{c_1})}$$

$$0.4388 = \frac{18.3348(120 - T_{h_2})}{18.3348(120 - 20)}$$

$$\boxed{\therefore T_{h_2} = 76.12^\circ C}$$

- $C_h(T_{h_1} - T_{h_2}) = C_c(T_{c_2} - T_{c_1})$

$$18.3348(120 - 76.12) = 58.1394(T_{c_2} - 20)$$

$$\boxed{\therefore T_{c_2} = 33.84^\circ C}$$

5). A heat exchanger is used to cool hot water from 80°C to 60°C by transfering heat to other stream of cold water which enters the heat exchanger at 20°C and leave at 40°C. Should this heat exchanger operate under parallel flow or counter flow conditions? Also determine the exit temperatures if the flow rates of the fluids are doubled. (January - 2013)

→ $Th_1 = 80°C$, $Tc_1 = 20°C$
$Th_2 = 60°C$, $Tc_2 = 40°C$

$$m_h Cp_h (Th_1 - Th_2) = m_c Cp_c (Tc_2 - Tc_1)$$
$$m_h Cp_h (80-60) = m_c Cp_c (40-20)$$

$\therefore m_h Cp_h = m_c Cp_c$

$\therefore$ Capacity ratio $C = \dfrac{m_h Cp_h}{m_c Cp_c} = 1.$

Since, capacity ratio $C=1$, both flow arrangements will give same performance.

Effectiveness $\varepsilon = \dfrac{m_h Cp_h (Th_1 - Th_2)}{m_h Cp_h (Th_1 - Tc_1)}$

$$\varepsilon = \frac{80-60}{80-20} = 0.334$$

- If $C=1$ then

$$\varepsilon = \frac{NTU}{1+NTU}$$

$\therefore 0.334 = \dfrac{NTU}{1+NTU}$

$\therefore NTU = 0.334 + 0.334\,NTU$

$\boxed{\therefore NTU = 0.5}$

- Exit temperatures when flow is doubled.

$m_{h_1} = 2 m_h$

$m_{c_1} = 2 m_c$

$2 m_h C_{P_h} = 2 m_c C_{P_c}$

$\therefore \quad C = 1.$

$$NTU_1 = \frac{UA}{2 m_h C_{P_h}} = \frac{NTU}{2}$$

$$\boxed{NTU_1 = \frac{0.5}{2} = 0.25}$$

$$\varepsilon_1 = \frac{NTU_1}{1+NTU_1} = \frac{0.25}{1+0.25} = 0.2$$

$$\varepsilon_1 = \frac{T_{h_1} - T'_{h_2}}{T_{h_1} - T_{c_1}}$$

$$0.2 = \frac{80 - T'_{h_2}}{80 - 20}$$

$$\boxed{T'_{h_2} = 68^\circ C}$$

- Similarly. $\varepsilon_1 = \dfrac{T'_{c_2} - T_{c_1}}{T_{h_1} - T_{c_1}}$

$$0.2 = \frac{T'_{c_2} - 20}{80 - 20}$$

$$\boxed{T'_{c_2} = 32^\circ C}$$

6.) Water ($C_p = 4.2$ kJ/kg°C) is heated at the rate of 1.4 kg/sec from 40°C to 70°C by an oil (C_p = 2 kJ/kg°C) entering at 110°C and leaving at 60°C in a counter flow heat exchanger. If U = 350 W/m²°C, calculate the surface area required. Using the same entering fluid temperatures and the same oil flow rate, calculate the exit temperature of oil and water and rate of heat transfer, when the mass flow rate of water is halved.

(May-2013)

→ $Th_1 = 110°C$ $\qquad$ $Tc_1 = 40°C$ $\qquad$ $m_c = 1.4$

$Th_2 = 60°C$ $\qquad$ $Tc_2 = 70°C$ $\qquad$ $Cp_c = 4200$

(a) For water as cold fluid

$$Q = m_c Cp_c (Tc_2 - Tc_1)$$

$$= 1.4 \times 4200 (70 - 40)$$

$$Q = 176400 \text{ W}$$

$$Q = m_h Cp_h (Th_1 - Th_2)$$

$$176400 = m_h \times 2000 (110 - 60)$$

$$\boxed{\therefore m_h = 1.764 \text{ kg/s (oil)}}$$

$$Q = UA\theta_m$$

$$= UA \frac{\theta_1 - \theta_2}{\ln(\theta_1/\theta_2)}$$

$$176400 = 350 \times A \times \frac{(110-70) - (60-40)}{\ln\left(\frac{110-70}{60-40}\right)}$$

$$176400 = A \times 350 \times \frac{20}{\ln(40/20)}$$

$$\boxed{\therefore A = 17.467 \text{ m}^2}$$

(b) when water flow is halved.

$m_c = \frac{1.4}{2} = 0.7$ kg/s

$m_h = 1.764$ kg/s

- since exit temperatures are required NTU method will now be used

$m_c C p_c = 0.7 \times 4200$
$= 2940 \quad = C_{min}$

and $m_h C p_h = 1.764 \times 2000$
$= 3528 \quad = C_{max}.$

- Capacity ratio $= \frac{2940}{3528} = 0.833$

- $NTU = \frac{UA}{C_{min}} = \frac{350 \times 17.467}{2940} = 2.08$

- $\varepsilon = \frac{1 - e^{-(1-R)NTU}}{1 - Re^{-(1-R)NTU}} = \frac{1 - e^{-(1-0.833) \times 2.08}}{1 - 0.833 e^{-(1-0.833) \times 2.08}}$

$= \frac{1 - e^{-0.347}}{1 - 0.833 e^{-0.347}}$

$= \frac{0.2932}{0.4112}$

$\boxed{\varepsilon = 0.713}$

- $\varepsilon = \frac{m_c C p_c (T c_2 - T c_1)}{m_c C p_c (T h_1 - T c_1)} = \frac{m_c C p_c (T c_2 - 40)}{m_c C p_c (110 - 40)}$

$0.713 = \frac{T c_2 - 40}{70}$

$\boxed{\therefore T c_2 = 89.91^\circ C}$

- $m_c C p_c (T c_2 - T c_1) = m_c C p_c (T h_1 - T h_2)$

$2940 (89.91 - 40) = 3528 (110 - T h_2)$

$\boxed{\therefore T h_2 = 68.41^\circ C}$

(1.) In a double pipe counter flow heat exchanger, oil (C_p = 1.45 kJ/kgK) is cooled from 230°C to 160°C using water (C_p = 4.187 kJ/kgK) from 25°C to 65°C. The mass flow rate of oil is 0.9 kg/sec. Take overall heat transfer co-efficient 420 W/m²K. Calculate the
1) heat transfer rate,
2) The mass flow rate of water and
3) The surface area of heat exchanger.

(December. 2013)

→ $m_h = 0.9$ kg/sec

$t_{h_1} = 230°C$

$t_{h_2} = 160°C$

$t_{c_1} = 25°C$

$t_{c_2} = 65°C$

$C_{pc} = 4.187$ kJ/kgK, $C_{ph} = 1.45$ kJ/kgK

$U = 420$ W/m²K.

1) The rate of heat transfer.

$$Q = m_h C_{ph} (t_{h_1} - t_{h_2})$$

$$= (0.9)(1.45)(230-160)$$

$$\boxed{Q = 91.35 \text{ kW}}$$

2) The mass flow rate of water

$$m_h C_{ph} (t_{h_1} - t_{h_2}) = m_c C_{pc} (t_{c_2} - t_{c_1})$$

$$(0.9)(1.45)(230-160) = m_c \times (4.187) \times (65-25)$$

$$\boxed{\therefore m_c = 0.545 \text{ kg/sec}}$$

3) Surface area of heat exchanger. A

$$\theta_m = \frac{\theta_1 - \theta_2}{\ln(\theta_1/\theta_2)}$$

$$= \frac{(th_1 - tc_2) - (th_2 - tc_1)}{\ln\left(\frac{th_1 - tc_2}{th_2 - tc_1}\right)}$$

$$= \frac{(230-65) - (160-25)}{\ln\left(\frac{230-65}{160-25}\right)}$$

$$\boxed{\theta_m = 149.5^\circ C}$$

- Now,

$$Q = UA\theta_m$$

$$\therefore A = \frac{Q}{U\theta_m}$$

$$= \frac{91.35 \times 10^3}{420 \times 149.5}$$

$$\boxed{A = 1.45\ m^2}$$