UNIT IV-HEAT EXCHANGERS

Topic - Tutorial- LMTD Method - NTU - Effectiveness

UNIT-V

1. Water flows at the rate of 65 kg/min through a double pipe counter flow heat exchanger. Water is heated from 50° C to75°C by an oil flowing through the tube. The specific heat of the oil is 1.780 kj/kg.K. The oil enters at 115°C and leaves at 70°C.the overall heat transfer co-efficient is 340 W/m2K.calcualte the following

1. Heat exchanger area
2. Rate of heat transfer

Given:

Hot fluid – oil, Cold fluid – water

(T_1, T_2) (t_1, t_2)

Mass flow rate of water (cold fluid), m_c = 65 kg/min

= 65/60 kg/s

$\mathbf{m_c = 1.08}$ **kg/s**

Entry temperature of water, t_1 =50° C

Exit temperature of water, t_2 =75° C

Specific heat of oil (Hot fluid), C_{ph} = 1.780 KJ/kg K

= 1.780×10^3 J/kg K

Entry temperature of oil, T_1 =115° C

Exit temperature of water, T_2 =70° C

Overall heat transfer co-efficient, U = 340 w/m² K

To find:

1. Heat exchanger area, (A)
2. Rate of heat transfer, (Q)

Solution:

We know that,

Heat transfer, $Q = m_c\, c_{pc}\,(t_2 - t_1)$ (or) $m_h\, c_{ph}\,(T_1 - T_2)$

$Q = m_c\, C_{pc}\,(t_2 - t_1)$

$Q = 1.08 \times 4186 \times (75 - 50)$

[Specific heat of water, c_{pc} = 4186 J/kg K]

$\mathbf{Q = 113 \times 10^3\ W}$

We know that,

Heat transfer, $Q = U \times A\,(\Delta T)_m$ ……... (1)

[From HMT data book page no:152(sixth edition)]

$A = 11.34$ m

2. **A parallel flow heat exchanger is used to cool 4.2 kg/min of hot liquid of specific heat 3.5 kJ/kg K at 130° C. A cooling water of specific heat 4.18 kJ/kg K is used for cooling purpose of a temperature of 15° C. The mass flow rate of cooling water is 17 kg/min. calculate the following.**

   1. Outlet temperature of liquid
   2. Outlet temperature of water
   3. Effectiveness of heat exchanger

Take

Overall heat transfer co-efficient is 1100 W/m² K.

Heat exchanger area is 0.30m²

Given:

Mass flow rate of hot liquid, $m_h = 4.2$ kg/min

$m_h = 0.07$ kg/s

Specific heat of hot liquid, $c_{ph} = 3.5$ kJ/kg K

$c_{ph} = 3.5 \times 10^3$ J/kg K

Inlet temperature of hot liquid, $T_1 = 130^0$ C

Specific heat of hot water, $C_{pc} = 4.18$ kJ/kg K

$C_{pc} = 4.18 \times 10^3$ J/kg K

Inlet temperature of hot water, $t_1 = 15^0$ C

Mass flow rate of cooling water, $m_c = 17$ kg/min

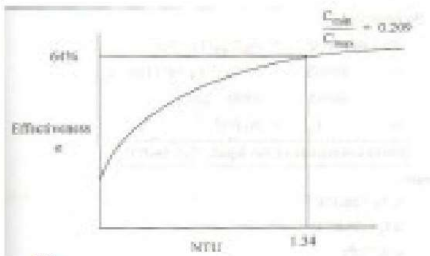
$$\mathbf{m_c = 0.28 \text{ kg/s}}$$

Overall heat transfer co – efficient, U = 1100 w/m² K

Area, A = 0.03 m²

To find :

1. Outlet temperature of liquid, (T_2)
2. Outlet temperature of water, (t_2)
3. Effectiveness of heat exchanger, (ε)



Solution :

Capacity rate of hot liquid, $C_h = m_h \times C_{ph}$

$= 0.07 \times 3.5 \times 10^3$

$\mathbf{C_h = 245}$ **W/K……… (1)**

Capacity rate of water, $C_c = m_c \times C_{pc}$

$= 0.28 \times 4.18 \times 10^3$

$\mathbf{C_c = 1170.4}$ **W/K ……… (2)**

From (1) and (2),

$C_{min} = 245$ W/K

$C_{max} = 1170.4$ W/K

$=> \quad \frac{C_{min}}{C_{max}} = \frac{245}{1170.4} = 0.209$

$\frac{C_{min}}{C_{max}} = \mathbf{0.209}$ **…………. (3)**

Number of transfer units, $NTU = \frac{UA}{C_{min}}$

[From HMT data book page no. 152]

$=> \quad NTU = \frac{1100 \times 0.30}{245}$

NTU = 1.34 ……………(4)

To find effectiveness ε, refer HMT data book page no 163

(Parallel flow heat exchanger)

From graph,

$X_{axis} \rightarrow$ NTU = 1.34

Curve $\rightarrow \frac{C_{min}}{C_{max}} = 0.209$

Corresponding Y_{axis} value is 64 %

i.e., **ε = 0.64**

from HMT data Book

$$\in = \frac{m_h cp_h (T_1 - T_2)}{C_{min} (T_1 - t_1)}$$

$$0.64 = \frac{130 - T_2}{130 - 15}$$

$T_2 = 56.4$ °C

To find t_2

$m_h\ cp_h(T_1 - T_2) = m_c Cp_c\ (t_2 - t_1)$

$0.07 \times 3.5 \times 10^3\ (130 - 56.4) = 0.28 \times 4186\ (t_2 - 15)$

$t_2 = 30.4$°C

Maximum possible heat transfer

$Q_{max} = C_{min}\ (T_1 - t_1)$

$= 245\ (130 - 15)$

$Q_{max} = 28.175$ W

Actual heat transfer rate

$Q = \varepsilon \times Q_{max}$

$= 0.64 \times 28.175$

$Q = 18.032$ W

We know that,

Heat transfer, $Q = m_c\ C_{pc}(t_2 - t_1)$

=> $18.032 = 0.28 \times 4.18 \times 10^3\ (t_2 - 15)$

=> $18.032 = 1170.4\ t_2 - 17556$

=> $t_2 = 30.40$°C

Outlet temperature of cold water, $t_2 = 30.40$°C

We know that,

Heat transfer, $Q = m_h\ C_{ph}(T_1 - T_2)$

=> $18.032 = 0.07 \times 3.5 \times 10^3\ (130 - T_2)$

=> $18.032 = 31850 - 245\ T_2$

=> $T_2 = 56.4$°C

Outlet temperature of hot liguid, $T_2 = 56.4$°C

3.Hot chemical products (C_{ph} = 2.5 kJ/kg K) at 600° C and at a flow rate of 30 kg/s are used to heat cold chemical products (C_p = 4.2 kJ/kg K) at 200°C and at a flow rate 20 kg/s in a parallel flow heat exchanger. The total heat transfer is 50 m² and the overall heat transfer coefficient may be taken as 1500 W/m² K calculate the outlet temperatures of the hot and cold chemical products.

Given: Parallel flow heat exchanger

T_{h1} = 600° C ; m_h = 30 kg/s

C_{ph} = 2.5 kJ/kg K

T_{c1} = 100°C ; m_c 28 kg/s

C_{pc} = 4.2kJ/kg K

A = 50m²

U = 1500 W/m²K

Find:

(i) T_{h2} (ii) T_{c2} ?

Solution

The heat capacities of the two fluids

$C_h = m_h c_{ph}$ = 30 x 2.5 =75 kW/K

$C_c = m_c c_{pc}$ = 28 x 4.2 = 117.6 kW/K

The ratio $\frac{C_{min}}{C_{max}} = \frac{75}{117.6} = 0.64$

$NTU = \frac{UA}{Cmin} = \frac{1500 \times 50}{75 \times 10^3} = 1.0$

For a parallel flow heat exchanger, the effectiveness from Fig. 13.15 corresponding to $\frac{C_{min}}{C_{max}}$ and NTU

$\epsilon = 0.48$

We know that

$$\epsilon = \frac{Actual\ heat\ transfer}{Max\ possible\ heat\ transfer}$$

$$= \frac{m_h C_{ph} (T_{h1} - T_{h2})}{C_{min}(T_{h1} - T_{c1})}$$

$$\epsilon = \frac{(T_{h1} - T_{h2})}{(T_{h1} - T_{c1})}$$

$$0.48 = \frac{600 - T_{h2}}{600 - 100}$$

$T_{h2} = 360°C$

We know that

Heat lost by the hot product = Heat gained by the cold product

$$m_h c_{ph} (T_{h1} - T_{h2}) = m_c c_{ph} (T_{c2} - T_{c1})$$

$$75(600 - 360) = 117.6\,(T_{c2} - 100)$$

$$\boldsymbol{T_{c2} = 253.06° C}$$

4. Estimate the diffusion rate of water from the bottom of a tube of 10mm diameter and 15cm long into dry air 25°C. Take the diffusion coefficient of water through air as 0.235 x 10^{-4}m^2/s

Given:

$D = 0.255 \times 10^{-4} m^2/s$

Area (A) $= \frac{\pi}{4} d^2 = \frac{\pi}{4} (0.01)^2 = 7.85 \times 10^{-5}$ m^2

$R_o = 8314$ J/kg – mole K

$T = 25 + 273 = 298$ K

M_w = molecular weight of water = 18

P = Total pressure = 1.01325×10^5 N/m^2

$X_2 - X_1 = 0.15$m

P_{w1} = partial pressure at 25° C = 0.03166×10^5 N/m^2

$P_{w2} = 0$

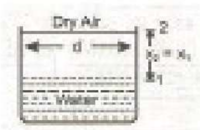
Find:

Diffusion rate of water (or) Mass transfer rate of water.

Solution

We know that

Molar rate of water (M_a)



$$M_a = \frac{DA}{R_o T} \cdot \frac{P}{x_2 - x_1} \ln\left(\frac{P_{a2}}{P_{a1}}\right)$$

$$= \frac{0.255 \times 10-4 \times 7.85 \times 10-5 \times 1.01325 \times 105}{8314 \times 298 \times 0.15} \times \left(\frac{1.01325-0}{1.01325-0.03166}\right)$$

Here $P_{a2} = P - P_{w2}$, $P_{a1} = P - P_{w1}$

$$\boldsymbol{M_a = 1.72 \times 10^{-11}} \textbf{ kg-mole/s}$$

Mass transfer rate of water (or) Diffusion rate of water } = Molar rate of water X molecular weight of steam

$M_w = 1.72 \times 10^{-11} \times 18$

Diffusion rate of water (M_w) = 3.1 x 10^{-10} kg/s

6. A counter flow heat exchanger is employed to cool 0.55 kg/s (C_p = 2.45 kj/kg°C) of oil from 115°C to 40°C by the use of water. The inlet and outlet temperature of cooling water are 15°C and 75°C respectively. The overall heat transfer coefficient is expected to be 1450 W/m²°C.

Using NTU method, calculate the following:

(i) The mass flow rate of water.

(ii) The effectiveness of heat exchanger.

(iii) The surface area required.

Given:

Counter flow HE

$M_h = 0.55$ kg/s

$C_{ph} = 2.45$ kj/kg°C

$T_1 = 115$°C

$T_2 = 40$°C

$t_1 = 15$°C

$t_2 = 75$°C

U= 1450 W/m²°C

To find:

1.The mass flow rate of water. (m_c)

2.The effectiveness of heat exchanger. (∈)

3.The surface area required.(A)

Solution:

For ∈ $-NTU$ method from HMT date book

$$Q = \in C_{min} (T_1 - t_1)$$

To find m_c

Use energy balance equation.

Heat lost by hot fluid = Heat gained by cold fluid

$$m_h C_{p_h} (T_1 - T_2) = m_c C_{p_c} (t_2 - t_1)$$

$$0.55 \times 2450 (115 - 40) = m_c \times 4186 (75 - 15)$$

$$\mathbf{m_c = 0.40 kg/s}$$

Heat capacity rate of hot fluid = $C_h = m_h \cdot C_{ph}$

$$= 0.55 \times 2.45$$

$$C_h = 1.35 \text{ kw/K}$$

Heat capacity rate of cold fluid = $C_c = m_c \cdot C_{pc}$

$$= 0.40 \times 4.186$$

$$C_c = 1.67 \text{kw/K}$$

$$C_h < C_c$$

$$C_h = C_{min}$$

$$\epsilon = \frac{m_h C_{p_h} (T_1 - T_2)}{C_{min} (T_1 - t_1)}$$

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

$$\epsilon = 0.75 = 75\%$$

$$Q = 0.75 \times 1350 (115 - 15)$$

$$\mathbf{Q = 101.250 W}$$

$$Q = UA (\Delta T)_{lm}$$

$$\mathbf{A = Q / U (\Delta T)_{lm}}$$

$$(\Delta T)_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left[\frac{(T_1 - t_2)}{(T_2 - t_1)}\right]}$$

$$= \frac{(115 - 75) - (40 - 15)}{\ln\left[\frac{115 - 75}{40 - 15}\right]}$$

$$(\Delta T)_{lm} = 31.9°C$$

$$A = \frac{101.250}{1450 \times 31.9}$$

$$A = 2.19 \text{ m}^2$$

References:

1. Kothandaraman C.P "Fundamentals of Heat and Mass Transfer" New Age International, New Delhi,4th Edition 2012 (Unit I, II, III, IV, V).
2. Frank P. Incropera and David P. DeWitt, "Fundamentals of Heat and Mass Transfer", John Wiley and Sons, New Jersey,6th Edition1998(Unit I,II,III,IV, V)
3. MIT open courseware – https://ocw.mit.edu/courses/mechanical-engineering

Other web sources