UNIT-2

Chap 1 - HEAT TRANSFER

- there are three modes of heat transfer
  - (i) conduction
  - (ii) convection
  - (iii) Radiation

(i) CONDUCTION :- It is a mode of heat transfer that takes place with a medium. (or) between two solids which are in contact. It is due to free electrons and lattice vibrations.

Fouriers law of heat conduction

$$Q = -KA\frac{dT}{dx}$$

-ve → indicates decrease of temperature in x-direction.

(Q) ~~SI unit~~ = KJ/sec → kW

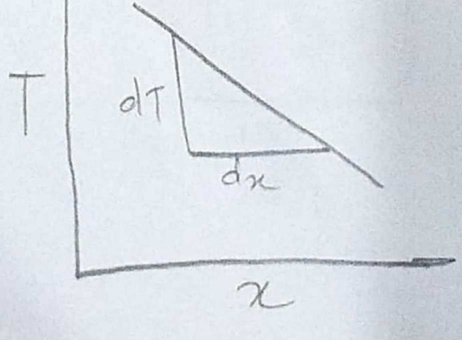
K = thermal conductivity. W/m°C (or) W/mK.

A = area (m^2)

dT = change in temperature (°C or K)

dx = thickness (m).

$\frac{dT}{dx}$ = temperature gradient.



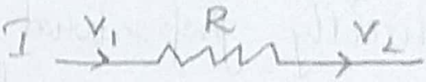
Thermal conductivity :-
It is defined as the amount of heat transfer per unit area for unit temperature difference accross a material of unit thickness.

Its unit is w/m°c .

- copper , $K = 385$ w/m°c
- Aluminium , $K = 225$ w/m°c
- concrete, $K = 1.2$ W/m°c

Analogy of electrical and thermal circuit

Electrical :-



$$V = IR$$

$$R = \frac{V}{I} = \frac{V_2 - V_1}{I}$$

$$I = \frac{V_1 - V_2}{R}$$

thermal :-

$$Q = \frac{-KA(T_2 - T_1)}{dx}$$

$$Q = \frac{T_2 - T_1}{dx/KA}$$

$$R = \frac{dx}{KA}$$

$\because L =$ thickness.

$$\boxed{R = L/KA}$$

Convection :- It is a mode of heat transfer that takes place between a surface and a flowing fluid due to movement of molecules of the fluid.

They are two types of convection:-

(i) Natural convection (movement of air)

(ii) forced convection (by external air)

Newtons law of Cooling:-

$$\frac{Q}{A} \propto (T_1 - T_2)$$

It is defined as heat transfer rate per unit area is directly proportional to temperature difference between a surface and a fluid.

$$Q = hA(T_s - T_a) \quad \therefore T_s > T_a$$

$$Q = \frac{T_s - T_a}{1/hA}$$

$$Q = \frac{T_s - T_a}{R} \qquad \text{where } R = \frac{1}{hA}$$

Radiation :- It is a mode of heat transfer that takes place by electromagnetic waves.

Eg:- Solar radiation

Stephen boltzman law :-

$$\frac{Q}{A} \propto T^4$$

The heat transfer by radiation of black body is directly proportional to 4th power of absolute temperature.

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$Q = \sigma A T^4$

σ = stephan constant

A = area

T = temperature (K)

One dimension steady state heat Conduction Equation

The heat conduction equation for three dimensional is given by equation;

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{g}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t} \quad \text{--- (1)}$$

where, g = heat generation rate

k = thermal conductivity

α = thermal diffusivity

t = time

x, y, z – space coordinates

T = temperature

for steady state $\frac{\partial T}{\partial t} = 0$

for no heat generation $g = 0$,

then (1) will be

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0$$

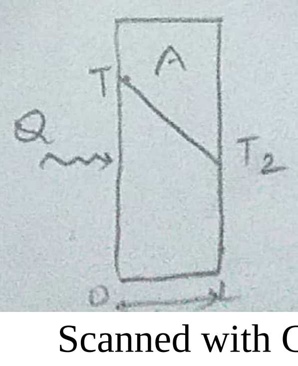
for one dimension,

$$\frac{\partial^2 T}{\partial x^2} = 0$$

One dimension steady state heat conduction Equation for a slab

By fourier's law,

$$Q = -KA\frac{dT}{dx}$$



$$Q\,dx = -KA\,dT$$

$$\int_0^L Q\,dx = -KA\int_0^L dT$$

$$Q\,x\int_0^L 1 = -KA\left[T_2 - T_1\right]_0$$

$$Q[L-0] = -KA[T_2 - T_1]$$

$$Q = \frac{KA(T_1 - T_2)}{L}$$

- for cylinder, $Q = \dfrac{2\pi KL(T_1 - T_2)}{\ln r_2/r_1}$

Q) If inner and outer surface temperatures of a simple brick wall are 50°c and 30°c. Calculate the rate of heat transfer per m^2? of surface area of the wall carrying a thickness of 200mm. Assume 'K' for brick wall 0.52 W/m°c

Given :-

$T_1 = 50°C$, $T_2 = 30°C$

$L = 200mm$

$\dfrac{Q}{A} = ?$

(heat flux) $\dfrac{Q}{A} = \dfrac{K(T_1 - T_2)}{L} = \dfrac{0.5(50-30)}{0.2}$

$$\frac{Q}{A} = 52 W/m^2.$$

(Q) A pipe having outside daimeter 120mm is covered with 40mm of insulation having thermal conductivity of 0.025 W/mk. The pipe is 50m long and the inside, outside temperature of insulation are 600K and 300 k respectively? Calculate the radial conduction heat transfer rate.

$r_1 = \frac{d_1}{2} = \frac{120}{2} = 60mm \rightarrow 0.06m$

$r_2 = 60 + 40 = 100mm \rightarrow 0.1m$

$k = 0.025 W/mk$

$L = 50m$

$T_1 = 600K, T_2 = 300K$

heat transfer through a cylinder,

$$Q = \frac{2\pi kL(T_1 - T_2)}{\ln r_2/r_1}$$

$$Q = \frac{2\pi \times 0.025 \times 50 \times 300}{\ln\left(\frac{0.1}{0.06}\right)}$$

$Q = 4612.5$ watt.

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exchanging of heat b/w the two liquids.

HEAT EXCHANGERS :- They are devices which are used for cooling or heating between the two surfaces by mixing fluids.

Eg:- radiator, compresor and condensors, cooling towers etc.

Applications :- Steam power plants, automobiles (IC engines) refrigators, ice plant, chemical industries.

Classification :-

1) Based on contact type

(a) Direct contact - cooling towers

(b) Indirect contact < Regeneration, Recuperators

2) Based on construction

(a) tube in tube

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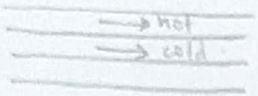
(b) shell and tube
(c) finned tube
(d) Compact heat exchanges.

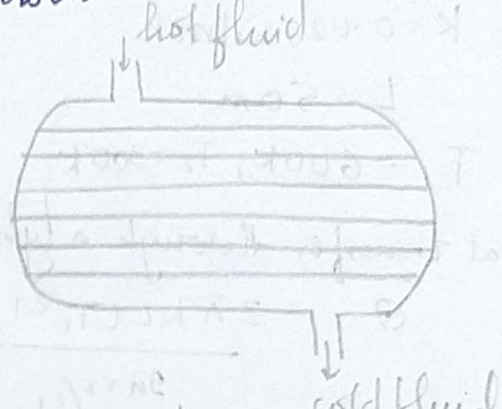
3) <u>Based on flow arrangement</u>

(a) Parallel flow
(b) counter flow
(c) cross flow.

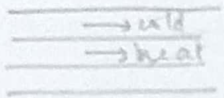
4) Evaporation and condensers.



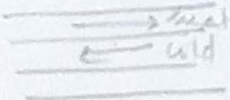
tube in tube



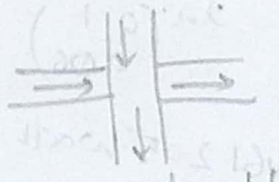
shell and tube.



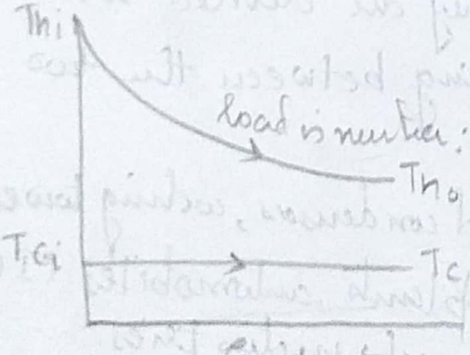
parallel flow



counter flow

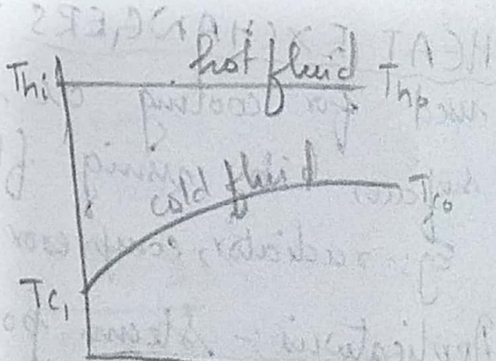


counter flow



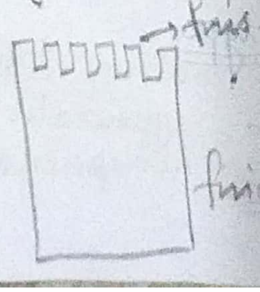
Evaporator

Evaporation heat exchanger.



condensor

condenser heat exchanger

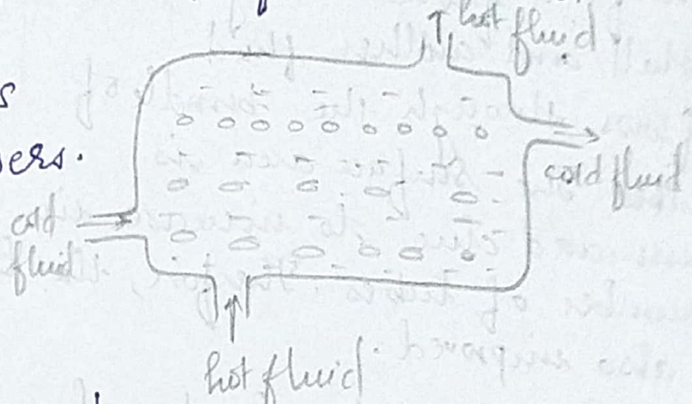


finned tube

Direct contact heat exchanger :-

In a direct contact heat exchanger, exchange of heat takes place by mixing of hot and cold fluids.

Ex :- 1) Cooling towers
2) Jet condensers.



Indirect contact heat exchanger :-

In this type of heat exchanger the heat transfer between the 2 fluids which are seperated by a wall.

Ex :- (i) Regenerator
(ii) Recuperator

(i) Regenerator :- The hot fluids pass alternately through a space containing solid particles which acts as a source and sink to the heat flow alternatively.

Eg :- I.C engines.

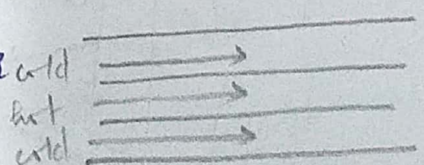
(ii) Recuperator :- In this device the flowing fluids exchange heat between them when they are either side of a dividing wall.

Ex :- Automobile radiators, oil coolers.

BASED ON CONSTRUCTION :-

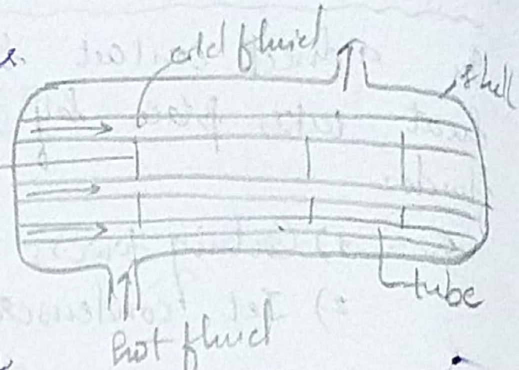
(a) Tube in tube :-

In this type of heat exchanger concentric tubes are used. The hot fluid flows through one tube and closed fluid flows through another tube. The flow maybe in the same direction or opposite direction.



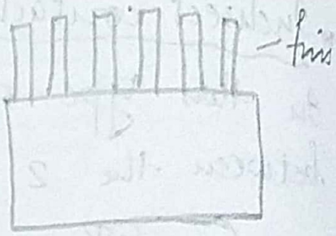
(b) Shell and tube :-

In this type of heat exchanger one fluid flows through the shell and another fluid flows through the bundle of tubes. The surface area is increased due to increase in number of tubes. Therefore, the heat transfer rate is also improved.



(c) finned tube heat exchanger :-

fins are the extended surface that are provided on a surface which has to be cooled. There are many/may be rectangular, circular in shape.



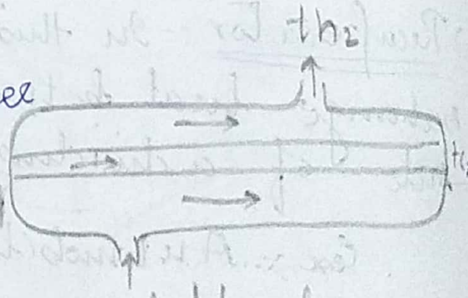
(d) Compact heat exchanger :-

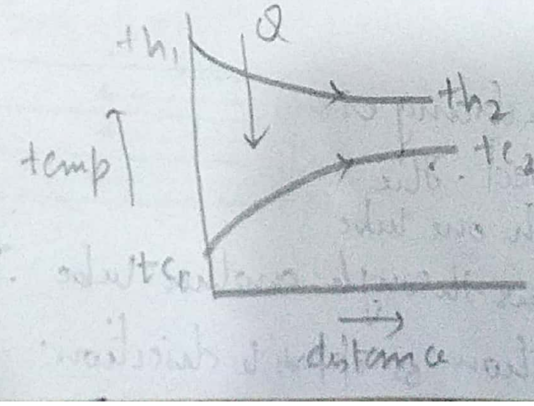
They have very large surface area per unit volume $> 700 m^2/m^3$.

BASED ON FLOW ARRANGEMENT :-

(a) Parallel flow :-

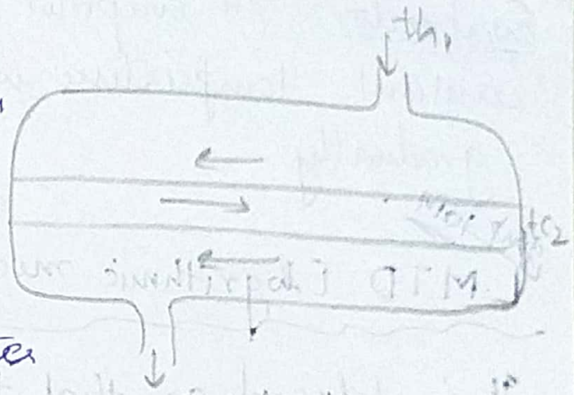
In parallel flow heat exchanger both hot and cold fluid are flows in the same direction. Both the fluid enters the heat exchanger at one end and leaves at another end

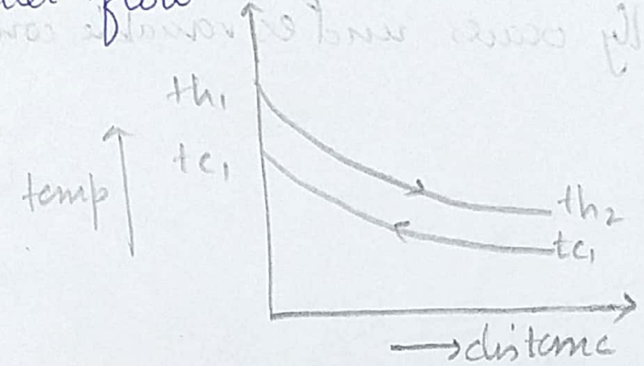




(b) Counter flow :-

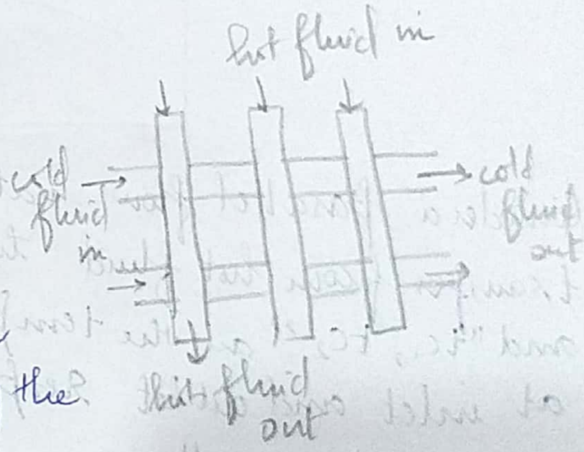
In this type of heat exchanger hot and cold fluids flows in opp direction. flow direction is shown in the graph. The effectiveness of counter flow heat exchanger is more than parallel flow.



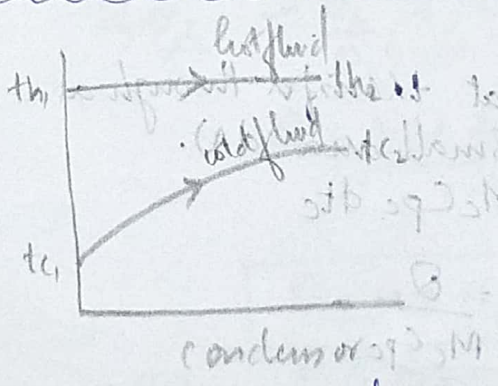


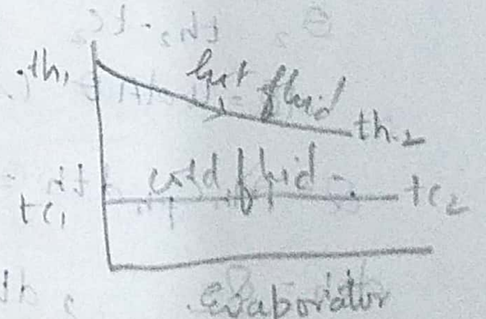
(c) Cross flow :-

In cross flow heat exchanger the hot and cold fluid flowing flows in perpendicular direction to each other. The fluids may be separated or maybe mixed during the flow to exchange the heat.



EVAPORATORS AND CONDENSORS





Condensors :- In condensors the condensing fluid remains at constant temperature throughout the heat exchanger and and cold fluid temperature gradually increases from inlet to outlet.

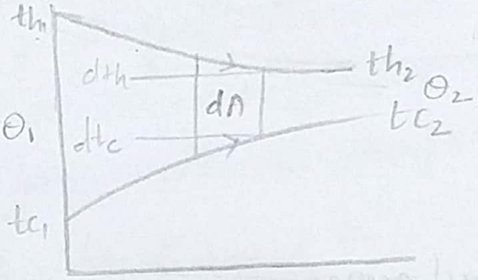
Evaporator:- In evaporator cold fluid remains at constant temperature whereas hot fluid temp decreases gradually.

Imp 10M.

LMTD [Logarithmic mean temp difference]

It is defined as that temperature difference which if constant would give same rate of heat transfer ~~of temp diff~~ as actually occurs under variable condition of heat transfer.

*** (i) Parallel flow:-



Consider a parallel flow heat exchanger in which heat transfer from hot fluid to cold fluid. let "t_{h_1}, t_{h_2}" and "t_{c_1}, t_{c_2}" are the temperatures for hot and cold fluid at inlet and outlet resp.

dA = small area.

$\theta = t_h - t_c$.

$\theta_1 = t_{h_1} - t_{c_1}$

$\theta_2 = t_{h_2} - t_{c_2}$

$dQ = U\, dA\, \theta$ (heat transfer through a small area dA).

$$Q = M_h C_{ph}\, dt_h = M_c C_{pc}\, dt_c$$

$$dt_h = \frac{Q}{M_h C_{ph}}, \quad dt_c = \frac{Q}{M_c C_{pc}}$$

$$\theta = t_h - t_c$$

$$d\theta = dt_h - dt_c$$

$$\Rightarrow \frac{Q}{M_h C_{ph}} - \frac{Q}{M_c C_{pc}}$$

$$\Rightarrow -Q\left[\frac{1}{M_h C_{ph}} + \frac{1}{M_c C_{pc}}\right]$$

$C_h = M_h C_{ph}, C_c = M_c C_{pc}$

$$\Rightarrow -Q\left[\frac{1}{C_h} + \frac{1}{C_c}\right].$$

$$d\theta = -u\,dA\,\theta\left[\frac{1}{C_h} + \frac{1}{C_c}\right]$$

$$\int_{\theta_1}^{\theta_2} \frac{d\theta}{\theta} = \int_0^A -u\,dA\left[\frac{1}{C_h} + \frac{1}{C_c}\right]$$

$$\ln\theta \Big|_{\theta_1}^{\theta_2} = -uA\left[\frac{1}{C_h} + \frac{1}{C_c}\right]$$

$$\ln\frac{\theta_2}{\theta_1} = -uA\left[\frac{1}{C_h} + \frac{1}{C_c}\right]_1$$

$$Q = M_h C_{ph}(th_1 - th_2)$$

$$Q = C_h(th_1 - th_2)$$

$$\frac{1}{C_h} = \frac{th_1 - th_2}{Q}$$

$$\frac{1}{C_c} = \frac{tc_2 - tc_1}{Q}$$

$$\ln\frac{\theta_2}{\theta_1} = -uA\left[\frac{th_1 - th_2}{Q} + \frac{tc_2 - tc_1}{Q}\right]$$

$$= \frac{-uA}{Q}\left[(th_1 - tc_1) - (th_2 - tc_2)\right]$$

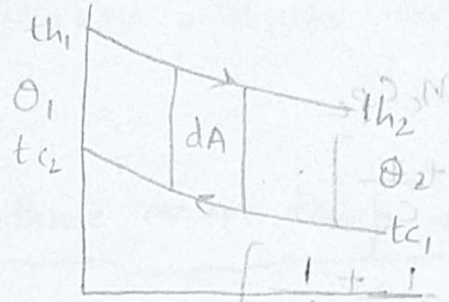
$$\ln\frac{\theta_2}{\theta_1} = \frac{-uA}{Q}\left[\theta_1 - \theta_2\right]$$

$$Q = \frac{+uA[\theta_1 - \theta_2]}{\ln\frac{\theta_1}{\theta_2}}$$

$$\boxed{Q = uA\theta_m}$$

where, $\dfrac{\theta_1 - \theta_2}{\ln\frac{\theta_1}{\theta_2}} = \theta_m \rightarrow$ LMTD.

(ii) Counter flow :-



$$dQ = U\,dA\,\theta$$

$$dQ = -M_h C_{ph}\, dt_h - M_c C_{pc}\, dt_c$$ (-ve because hot fluid looses heat and cold flowing back)

$$\theta = t_h - t_c$$

$$d\theta = dt_h - dt_c$$

$$= \frac{-dQ}{M_h C_{ph}} + \frac{dQ}{M_c C_{pc}}$$

$$d\theta = -dQ\left[\frac{1}{C_h} - \frac{1}{C_c}\right]$$

$$d\theta = -U\,dA\,\theta\left[\frac{1}{C_h} - \frac{1}{C_c}\right]$$

$$\frac{d\theta}{\theta} = -U\,dA\left[\frac{1}{C_h} - \frac{1}{C_c}\right]$$

$$\int_{\theta_1}^{\theta_2}\frac{d\theta}{\theta} = \int_0^A -U\,dA\left[\frac{1}{C_h} - \frac{1}{C_c}\right]$$

$$\ln\frac{\theta_2}{\theta_1} = -UA\left[(t_{h_1} - t_{h_2}) - (t_{c_2} - t_{c_1})\right]$$

$$= -UA\left[\theta_1 - \theta_2\right]$$

$$\ln\frac{\theta_2}{\theta_1} = -\frac{UA}{Q}\left[\theta_1 - \theta_2\right)$$

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

$$Q = UA\,\frac{\theta_1 - \theta_2}{\ln\frac{\theta_1}{\theta_2}}$$ where, $\frac{\theta_1 - \theta_2}{\ln\frac{\theta_1}{\theta_2}} = \theta_m$.

$$\boxed{Q = UA\,\theta_m}$$

Assumptions :-

1) Steady flow
2) Mass flow rate and sp. heat - constant.
3) Overall heat transfer co-eff. constant.
4) No phase change.
5) Change in K.E and P.E. are constant.

Q1) The flow rates of hot and cold water through a parallel flow heat exchanger are 0.2 kg/sec and 0.5 kg/sec resp. The inlet temp on the hot and cold sides are 75°C and 20°C resp. The exit temp of hot water is 45°C, if the individual heat transfer co-eff on both the sides are 650 Watt/m²°C. Calculate the area of heat exchanger?

Sol :- $h = 650\ W/m^2\,°C$

$M_h = 0.2\ kg/s$, $M_c = 0.5\ kg$

$t_{h_1} = 75°C$, $t_{c_1} = 20°C$

$t_{h_2} = 45°C$

to find A

heat transfer,

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

$= M_c C_{pc} (t_{c_2} - t_{c_1})$

$0.2 \times 4.187 \times (75 - 45) = 0.5 \times 4.187 (t_{c_2} - 20)$

$\boxed{t_{c_2} = 32°C}$

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

$$25.122 = 325 \times A \frac{(\theta_1 - \theta_2)}{\ln(\theta_1/\theta_2)}$$

$\theta_1 = th_1 - tc_1$, $\theta_2 = th_2 - tc_2$

$= 75 - 20$, $\theta_2 = 45 - 32$

$\theta_1 = 55^\circ C$, $\theta_2 = 13^\circ c$

$$25.122 = \frac{325 \times A (42)}{\ln(4.23)}$$

$$\cancel{25.122 = \frac{325 \times 2.65 \times 10^{-3} \times 10^3}{1.442}}$$ (KJ → J × 10³).

$A = 2.65 \times 10^{-3} \times 10^3$

$A = 2.65 m^2$

Q) In a counter flow double pipe heat exchanger water is heated from 25°C – 65°C by an oil. In a specific heat of ~~1.45 kg~~ 1.45 KJ/kg K and mass flow rate of 0.9 kg/s. The oil is cooled from 230°C to 160°C. If the overall heat transfer co-efficient is 420 watt/m²°C. Calculate the following:-

(i) rate of heat transfer – Q

(ii) mass flow rate of water – M_c

(iii) surface area of heat exchanger – A

heated → tc_1 and tc_2

cooled → th_1 and th_2

Given

$tc_1 = 25^\circ C$, $th_1 = 230^\circ C$

Cp_c = water ~~4×10³~~ ⇒ 4.187×10^3 , $tc_2 = 65^\circ C$, $th_2 = 160^\circ C$

$Cp_h = 1.45 KJ/kgK$, $M_h = 0.9 kg/sec$

(i) $Q = M_h Cp_h (th_1 - th_2)$

$Q = 0.9 \times 1.45 (230 - 160)$

$Q = 0.9 \times 1.45 \times 70$

$Q = 91.35 \times 10^3$ Watt.

(ii) $Q = M_c Cp_c (tc_2 - tc_1)$

$91.35 \times 10^3 = M_c \times 4.187 \times 10^3 \times (65 - 25)$

$$M_c = \frac{91.35 \times \cancel{10^3}}{4.187 \times \cancel{10^3} \times 40}$$

$M_c = 0.545\ kg/s.$

iii) $U = 420\ watt/m^2 {}^\circ C$

$\theta_1 = th_1 - tc_2 = 230^\circ - 65^\circ = 165^\circ$

$\theta_2 = th_2 - tc_1 = 160^\circ - 25^\circ = 135^\circ$

$$Q = \frac{UA(\theta_1 - \theta_2)}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

$$\frac{Q \ln\left(\frac{\theta_1}{\theta_2}\right)}{U(\theta_1 - \theta_2)} = A.$$

$$\frac{91.35 \times 10^3 \ln\left(\frac{165}{135}\right)}{420(165 - 135)} = A$$

$A = 1.45\ m^2.$