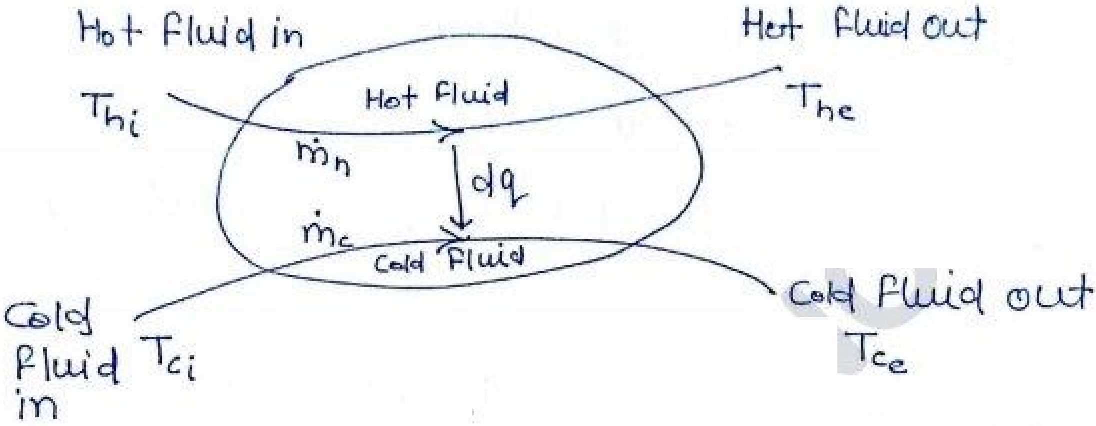
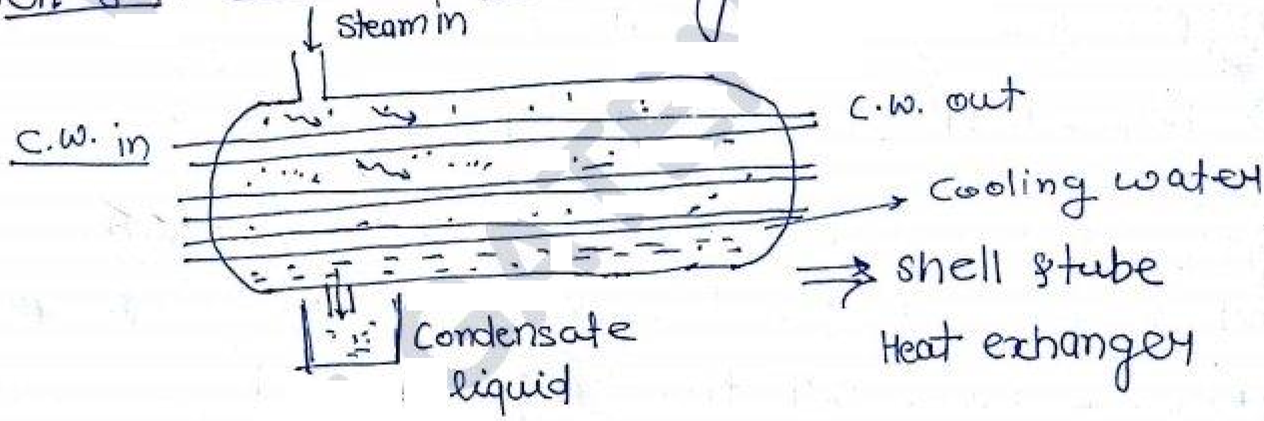
* Heat Exchanger *



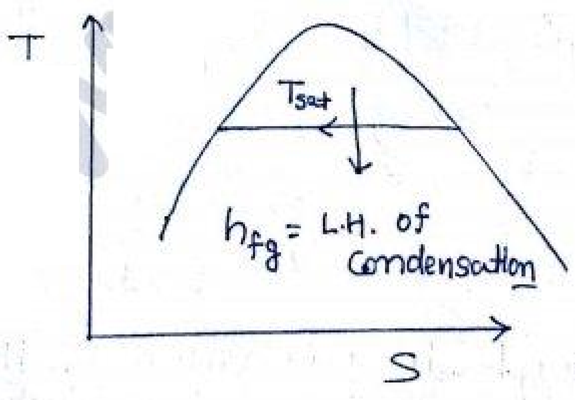
Heat exchanger is a steady flow adiabatic open system, in which two flowing fluid exchange or transfer heat between them without loosing or gaining any heat from ambient

Ex:- ① Surface (steam) Condensor

Shell & tube heat exchanger



⟹ shell & tube Heat exchanger



Boiler Accessories

② Economiser (Hot flue gases to feed water)

③ Super heater (Hot flue gases to Dry sat steam)

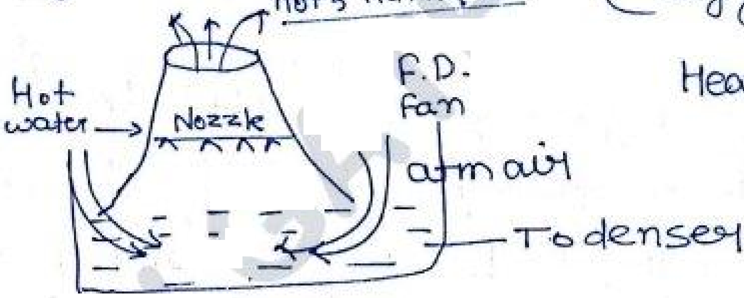
④ Air preheater (Hot flue gases to combustion air)

⑤ Cooling tower (Hot water to atm air)

⑥ Jet Condensor (steam to cooling water)

⑦ oil cooler (Hot ~~itl~~ oil to coolant water/air)

⑤ Cooling tower (Biggest ~~Cooling tower~~ Heat exchanger)



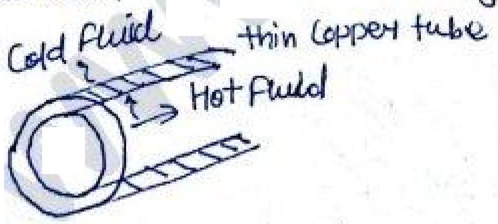
Classification of Heat exchanger's :-

① Direct transfer type HE's

② Direct contact type HE's

③ Regenerative (or) storage type of HEs

*① In direct transfer type heat exchanger's both hot and cold fluid do not have any physical contact between them but the transfer of heat occurs between them through ~~a~~ pipe wall of separation.



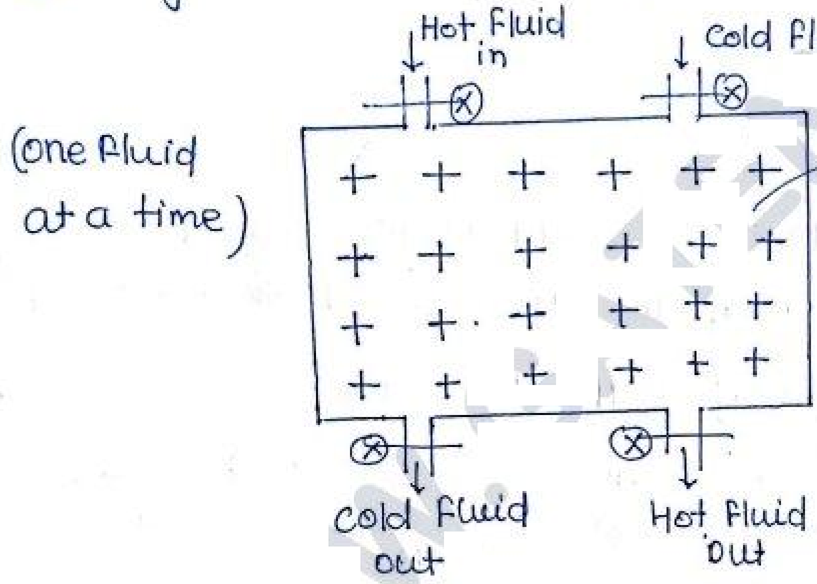
Ex ① Surface condencer
② Economiser
③ Air preheater

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2}$$ (Neglecting conduction thermal resistance

② In direct contact type HE's both Hot & Cold Fluid physically mixup with each other and exhange heat between them.

Ex. Cooling ~~co~~ tower, Jet Condensor

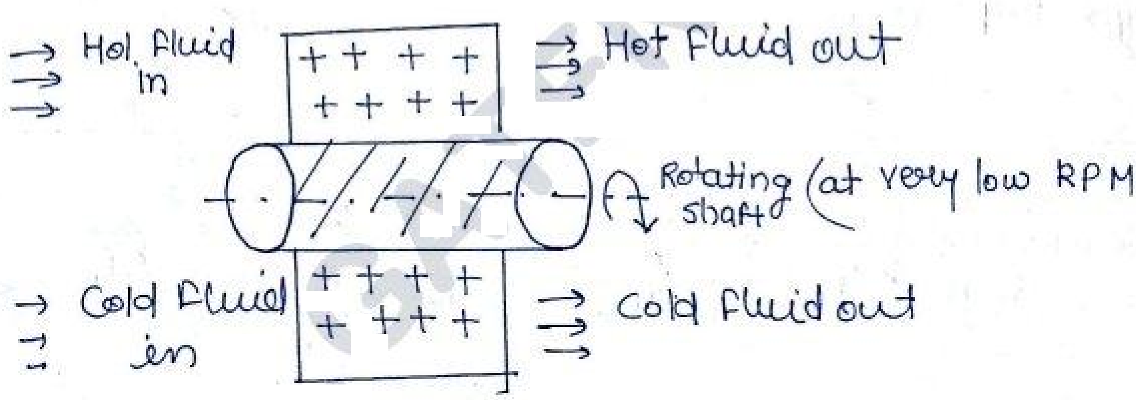
③ Regenerative (OR) storage type of HE's :-



→ Hot & Cold Fluids alternatively Flow through the HE

→ Hot Fluid heat the matrix and cold Fluid picking up heat from it.

Rotating Matrix type Regenerative HE :-



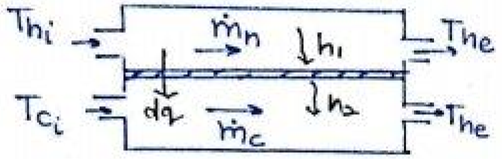
advantage :- continuity of Fluid flows can be maintained. No need to ~~sp~~ stoping and restarting the Fluid flow.

Disadvantage :- There may be some kind of fluid mixing

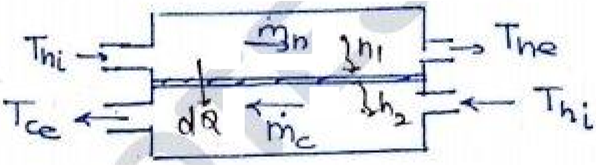
Practical Exampe :→ Ljungstorm Air preheater used in Gas turbine power plant

Classification of Direct type transfer type HE's

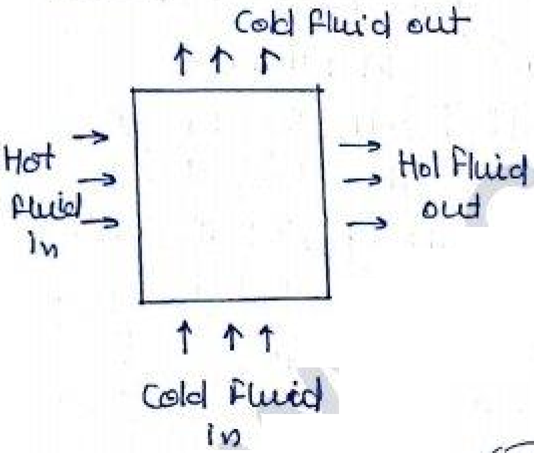
Parallel Flow HE



Counter Flow HE

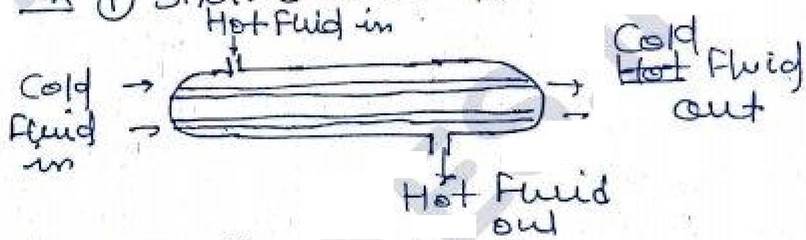


Cross Flow HE



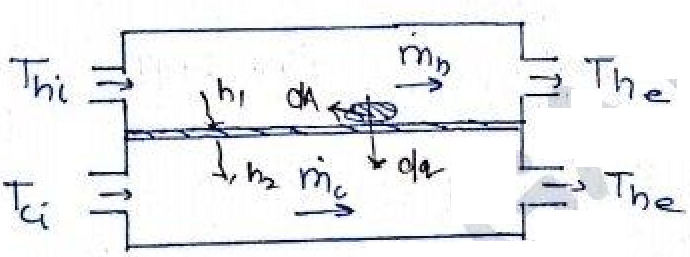
Hot and cold fluids travel at ⊥er direction w.r.t. each other

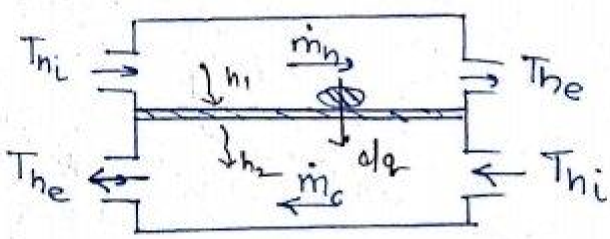
Ex ① shell & tube HE

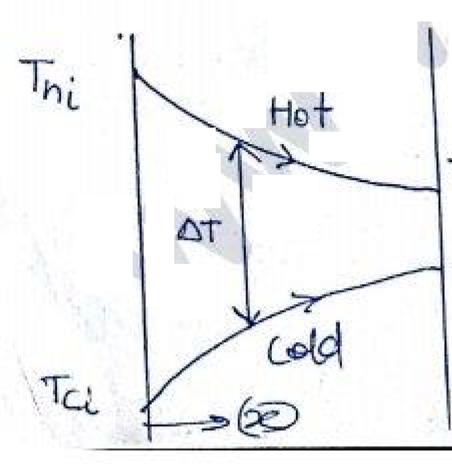


② Automobile Radiator

Temperature profile :-

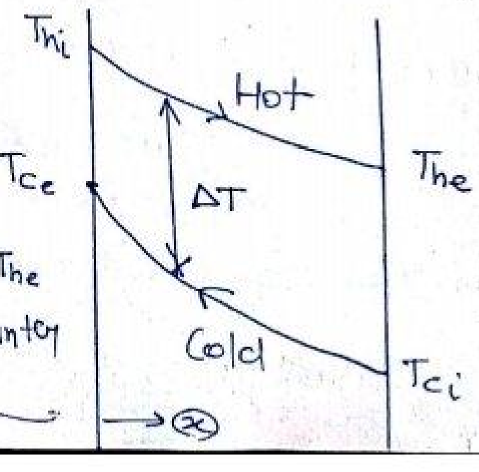






* x is the direction of Hot fluid in both HE's

T_{ce} can be > T_{he} (only in counter flow H.E)



taking differential area dA, writing H.T. equⁿ.

$$dq = U\,dA\,\Delta T$$

U → overall heat transfer Constant

$$\frac{1}{U} = \frac{1}{h_1} + \frac{1}{h_2}$$ ⇒ In heat exchanger Case (Always)

$$\Delta T = T_h - T_c$$
$$= f(x) \text{ in both HE's}$$

* The variation of ΔT w.r.t. x is much more pronounced in parallel flow H.E. as compared to that in counter flow H.E.

* Irreversibility associated with heat transfer in parallel flow H.E. is higher than the irreversibility associated with heat transfer in counter flow, H.E

$$(\Delta S)_{\text{T.D. Universe in llel flow HE}} > (\Delta S)_{\text{T.D. univ Counter flow HE}}$$

(Thermodynamic

⇒ due to high temp diff. (variation)

* Hence counter flow heat exchanger is ~~mor~~ thermo-dynamically more efficient than parallel flow H.E.

* Hence the result is for the same H.T. Rate required in both the cases, counter flow HE occupy lesser H.T. area are more compact in size than parallel H.E.

* In parallel flow H.E.

limiting ease is $T_{ce} = T_{he}$

* In Counter flow H.E.

T_{ce} can be $>$ T_{he} (only in Counter

limiting case $T_{hi} = T_{ci}$ {when infinite large H.E used.

* $dT_h = f(x)$, $dT_c = f(x)$

$T_h = f(x)$, $T_c = f(x)$

$\Delta T = f(x)$, $dq = f(x)$

only $U \neq f(x)$

Mean temprature difference :- (ΔT_m)

It is a parameter which takes into account the variation of ΔT w.r.t. x(direction of Hot Fluid flow) by averaging it all along the length of the HE from inlet to exit and hence is define from the q equation

$$\boxed{Q = UA\Delta T_m}$$

where Q = total H.T. Rate between Hot & Cold Fluids in ~~exite~~ entire H.E

U = overall heat transfer Coefficient.

A = total H.T. area of HE (contact area)

ΔT_m - MTD

I law of T.D. (SFEE)
(to any HE)

$$\Delta \cancel{Q}^{0} - \cancel{\Delta W}^{0} = \Delta H + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0}$$

$$\therefore (\Delta H)_{HE} = 0$$

$$(\Delta H)_{\text{Hot fluid}} + (\Delta H)_{\text{Cold fluid}} = 0$$

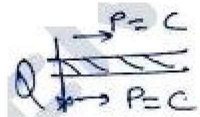
$$\Rightarrow \quad -(\Delta H)_{\text{Hot fluid}} = +(\Delta H)_{\text{Cold fluid}}$$

The rate of enthapy decrease hot fluid
= the rate of enthapy increase of Cold fluid.

energy balance equation or Heat balance equation

$$\boxed{\dot{m}_h C_{p_h} (T_{h_i} - T_{h_e}) = \dot{m}_c C_{p_c} (T_{c_e} - T_{c_i})}$$

from T.D. $\quad Q_{P=C} = \Delta H$

Assume 

* From thermodynamic we know the HT in any constant pressure or isobaric process is equal to change enthaphy of fluid
* Also we assume that the pressure both Hot and Cold fluid remain constant as they flow through H.E.

By combining above two statement we may conclude that the rate of H.T. b/w Hot and Cold fluid in any heat exhanger is equal to rate of enthapy change of either of the fluid.

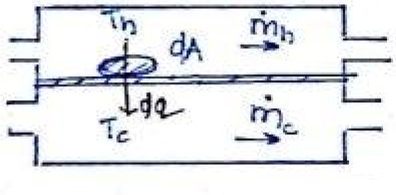
Q = Rate of H.T. between hot and cold fluid

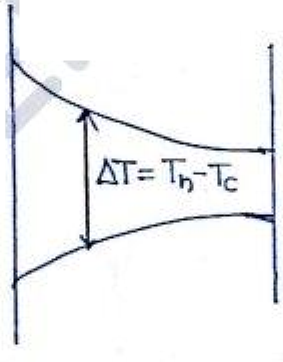
$$\boxed{Q = \dot{m}_h C_{ph}(T_{hi} - T_{he}) = \dot{m}_C C_{pc}(T_{ce} - T_{hi})}$$

$$\boxed{Q = UA\,\Delta T_m}$$

* But precaution is that do not use above format of equation for calculating enthapy change of any fluid if it is undergoing phase change. Ex steam Condensation

To get Mathematically expression of MTD (ΔT_m)
(Valid for





Consider differancial H.T. area dA of the H.E. through with differancial H.T. rate b/w Hot and Cold Fluid is dq with a temp. diff. of ΔT between them. then.—

$$dq = U\,\Delta T\,dA$$

$$\int_{Inlet}^{exit} dq = \int_{Inlet}^{exit} U \Delta T \, dA$$

$$\Rightarrow \quad Q = \text{total H.T. Rate} = U \int_{Intel}^{exit} \Delta T \, dA \quad -①$$

But $\quad Q = U A \Delta T_m \quad -②$

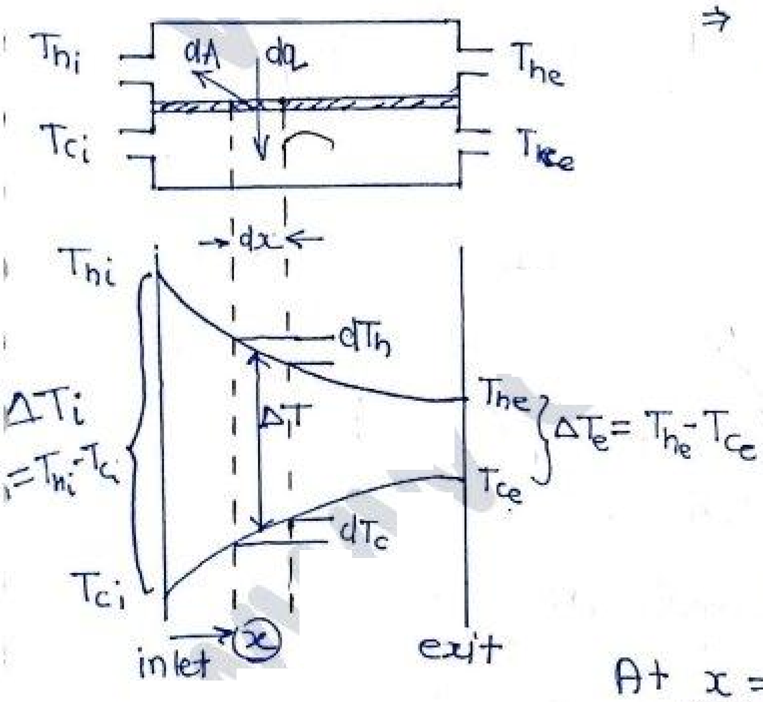
by comparing ① & ② we get

$$U A \Delta T_m = U \int_{Inlet}^{exit} \Delta T \, dA$$

$$\boxed{\Delta T_m = MTD = \frac{1}{A} \int_{Inlet}^{exit} \Delta T \, dA}$$

$\Rightarrow$ valid for any type

To drive expression for parallel flow Heat exchanger:-



$\Rightarrow$ Consider differential H.T area dA of the HE of length dx through which differential H.T. rate between Hot and cold fluid is dq. then

$$dq = U \Delta T \, dA$$

where $dA = B dx$

and $\Delta T = T_h - T_c = f(x)$

At $\underset{(inlet)}{x = 0} \Rightarrow \Delta T = \Delta T_i = (T_{hi} - T_{ci})$

$\underset{(exit)}{x = L} \Rightarrow \Delta T = \Delta T_e = (T_{he} - T_{ce})$

$$dq = -\dot{m}_h C_{ph}\, dT_h = \dot{m}_c C_{pc}\, dT_c$$

$$\Delta T = T_h - T_c$$

$$d(\Delta T) = dT_h - dT_c$$

$$d(\Delta T) = \frac{-dq}{\dot{m}_h C_{ph}} - \frac{dq}{\dot{m}_c C_{pc}}$$

$$d(\Delta T) = -dq\left(\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right)$$

$$d(\Delta T) = -U\Delta T B\,dx\left(\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right)$$

$$\int_{\Delta T_i}^{\Delta T_e} \frac{-d(\Delta T)}{\Delta T} = \int_0^L U B\left(\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right) dx$$

$$\ln\frac{\Delta T_i}{\Delta T_e} = UBL\left(\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right)$$

but BL = total H.T. Area of H.E.
= A

$$\ln\frac{\Delta T_i}{\Delta T_e} = UA\left(\frac{1}{\dot{m}_h C_{ph}} + \frac{1}{\dot{m}_c C_{pc}}\right)$$

total H.T. Rate for entire HE

$$Q = \dot{m}_h C_{ph}(T_{h_i} - T_{h_e}) = \dot{m}_c C_{pc}(T_{c_e} - T_{c_i})$$

$$\ln\left(\frac{\Delta T_i}{\Delta T_e}\right) = UA\left[\frac{T_{hi}-T_{he}}{Q} + \frac{T_{ce}-T_{ci}}{Q}\right]$$

$$\ln\frac{\Delta T_i}{\Delta T_e} = \frac{UA}{Q}\left[\Delta T_i - \Delta T_e\right]$$

$$\therefore \quad Q = UA\left[\frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}\right]$$

Comparing with $Q = UA\,\Delta T_m$

LMTD

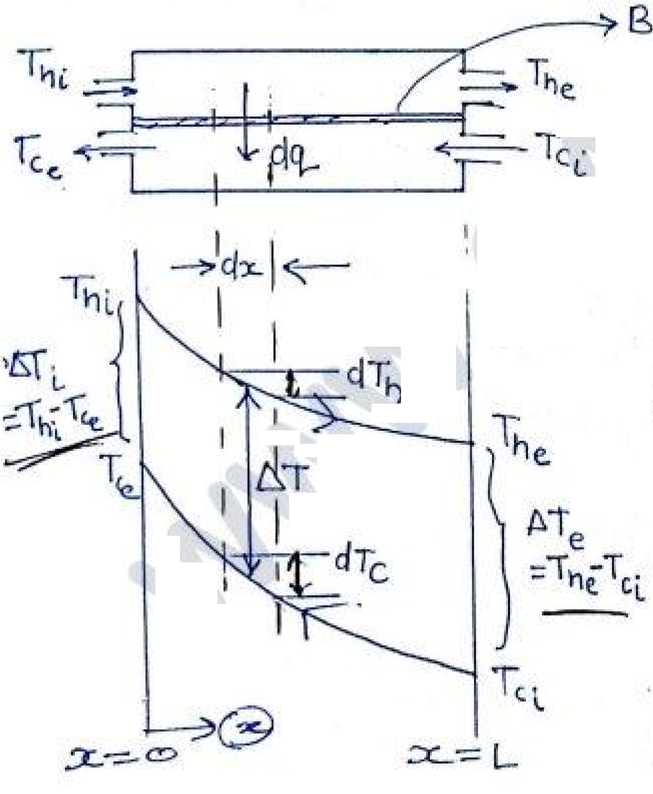
$$\boxed{\Delta T_m = \frac{(\Delta T_i - \Delta T_e)}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}}$$

LMTD parallel flow

$\Delta T_i = T_{hi} - T_{ci}$

$\Delta T_e = T_{he} - T_{ce}$

MTD for Counter Flow Heat exchanger :-



$$dq = U\Delta T\, B\,dx$$

$$\Delta T = T_h - T_c = f(x)$$

At $x = 0 \Rightarrow \Delta T_i = T_{hi} - T_{ce}$

$x = L \Rightarrow \Delta T_e = T_{he} - T_{ci}$

Also $dq = -\dot{m}_h C_{ph}\, dT_h$

$$dq = -\dot{m}_c C_{ch}\, dT_c$$

$$\boxed{\underset{\text{Counter flow}}{(\Delta T_m)} = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}} = (LMTD)_{\text{counter flow}}$$

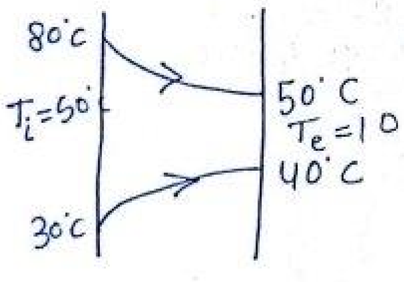
☆ Note:- For same inlet and exit temp. of Hot and Cold fluid employed in parallel and counter flow HE's, the LMTD of Counter flow HE is greater then LMTD of parallel flow HE.

→ This is the reason why counter flow HE occupies lesser H.T. area then parallel flow HE for the same H.T. rate required in both Case.

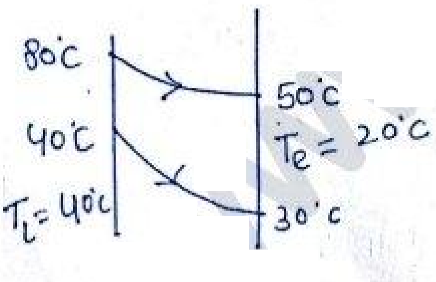
Q.4 Hot oil 80°C — 50°C

~~Cooler~~ Air 30°C — 40°C

Paraller

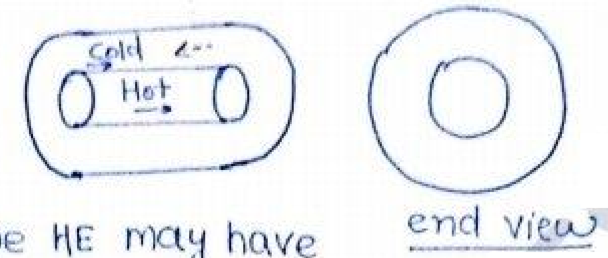


$$(LMTD)_{\text{Paraller}} = \frac{50 - 10}{\ln\left(50/10\right)} = 24.85°C$$



$$(LMTD)_{\text{Countinter}} = \frac{40 - 20}{\ln\left(40/20\right)} = 28.85°C$$

Double Pipe :- concentric tube



→ A double pipe HE may have either ||el mode (or) Counter flow Mode

→ Cross flow is never possible in double pipe

Cross flow :-

$$\left(LMTD\right)_{\substack{\text{cross flow}\\ \text{HE}}} = \left(\Delta T_m\right)_{\substack{\text{Counter}\\ \text{flow}}} \times F$$

where F is correction factor (obtained from HT data book)

$F < 1$

$$\text{Here } F = \frac{26}{28.85} = 0.9$$

when all 4 temp being same

$$\boxed{\left(\Delta T_m\right)_{\text{Counter}} > \left(\Delta T_m\right)_{\text{Cross}} > \left(\Delta T_m\right)_{\text{parallel}}}$$

Q.15

$10^\circ C \longrightarrow 38^\circ C \quad 19\ lit/s$

$46^\circ C \longrightarrow ? \quad 25\ lit/s$

$\dot{m} = \rho \times$ Volume flow rate

$\rho_{\substack{hot\\water}} = \rho_{\substack{cold\\water}}$ $\quad \dot{m} \propto$ Vol. flow rate

$Cp_{\substack{hot\\water}} = Cp_{\substack{cold\\water}}$

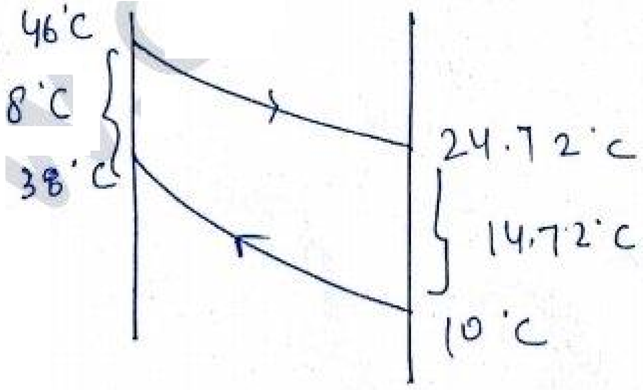
energy balance eqn

$$\dot{m}_h Cp_h (T_{hi} - T_{he}) = \dot{m}_c Cp_c (T_{ce} - T_{ci})$$

$$25(46 - T_{he}) = 19(38 - 10)$$

$$T_{he} = 24.72^\circ C$$

$$(LMTD)_{Counter} = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)} = \frac{8 - 14.72}{\ln(8/14.72)} = 11.02^\circ C$$



Q.6

Hot	Cold
$C_{p_h} = 2\ kJ/kgK$	$C_{p_c} = 4\ kJ/kgK$
$\dot{m}_h = 5\ kg/s$	$\dot{m}_c = 10\ kg/s$
$T_{hi} = 150^\circ$	$T_{ci} = 20^\circ C$
$T_{ho} = 100^\circ C$	$T_{co} = ?$

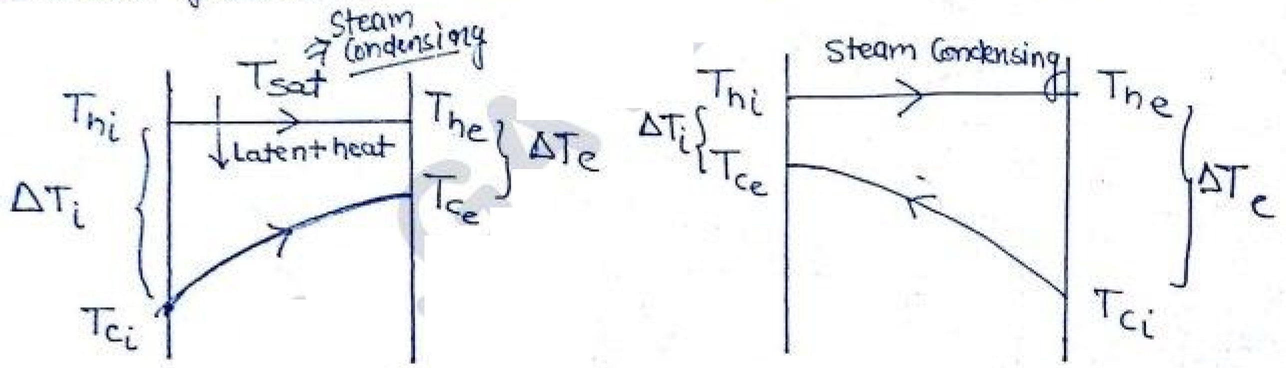
$$\dot{m}_h C_{ph}\left(T_{ho} - T_{hi}\right) = \dot{m}_c C_{pc}\left(T_{ce} - T_{ci}\right)$$

$$5 \times 2 \times 50 = 4 \times 10\left(T_{ce} - 20^\circ\right)$$

$$T_{ce} = 32.5^\circ C$$

Two special Cases Regarding LMTD

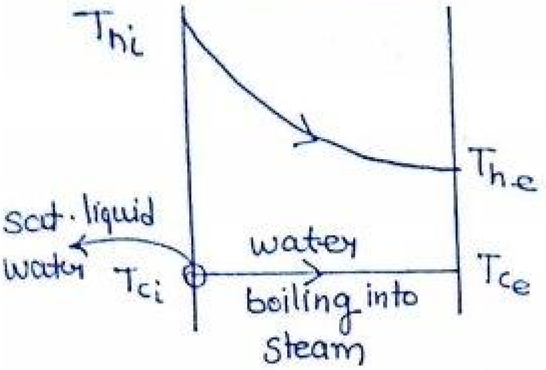
Case (1) when one of the fluid is undergoing phase change (→ steam Condensor) like in steam condenser or evaporator or steam generator then in steam condenser case



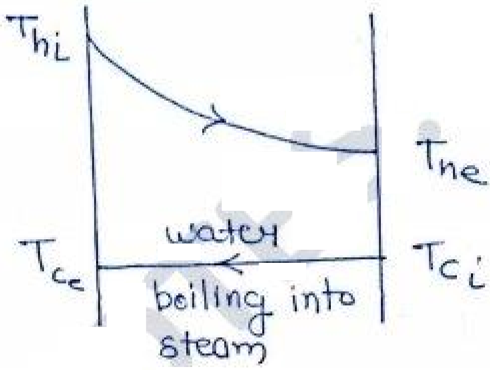
$$\boxed{\left(\Delta T_m\right)_{||el} = \left(\Delta T\right)_{Counter}}$$

Steam Generator

Parallel flow

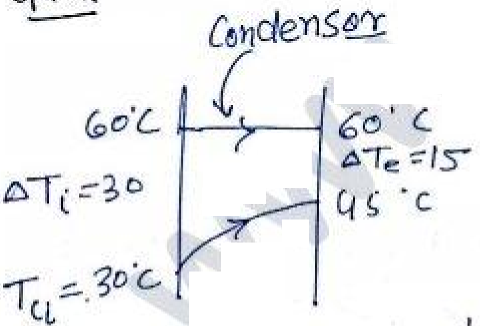


Counter flow



$$\boxed{(\Delta T_m)_{\parallel el} = (\Delta T)_{Counter}}$$

Q.17
G2011

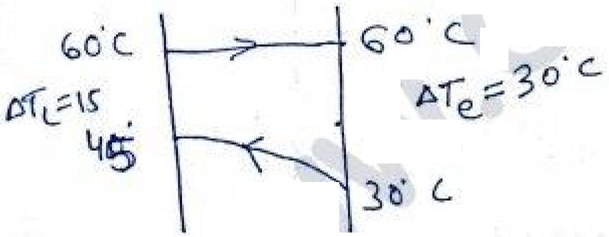


$$\Delta T_i = 30$$

$$\Delta T_e = 15$$

$$LMTD = \frac{15}{\ln\left(\frac{30}{15}\right)} = \frac{15}{\ln(2)}$$

$$(\Delta T_m) = 21.64\ °C$$



$$(\Delta T_m) = \frac{15-30}{\ln\left(15/30\right)}$$

$$\Delta T_f = 21.64°C$$

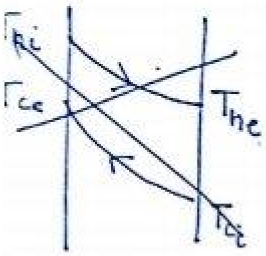
Case-2 When both hot and cold fluid have equal capacity rate in a counter flow H.E.

i.e. when $\dot{m}_h c_{ph} = \dot{m}_c c_{pc}$ in counter flow H.E.

$(\dot{m} c_p) \rightarrow$ product is called heat capacity Rate

From enery balance equation

$$\dot{m}_h c_{ph}(T_{hi} - T_{he}) = \dot{m}_c c_{pc}(T_{ce} - T_{ci})$$



$$(T_{hi} - T_{he}) = (T_{ce} - T_{ci})$$

$$T_{hi} - T_{ce} = T_{he} - T_{ci}$$

$$\Rightarrow \Delta T_i = \Delta T_e$$

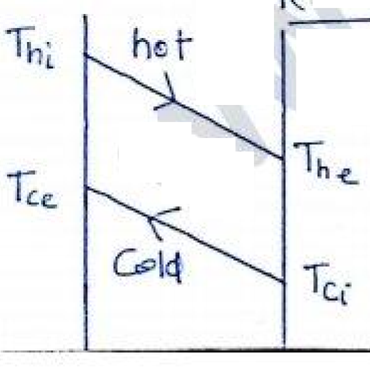
$$LMTD = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)} = \frac{0}{0} \text{ (underdefined)}$$

Then from L' hospital Rule

$$(LMDT)_{counter} = \text{Either } (\Delta T_i \text{ or } \Delta T_e)$$

$$\boxed{(\Delta T_m)_{counter} = \Delta T_i = \Delta T_e}$$

linear and parallel line obtained



$$\dot{m}_h c_{ph} = m_c c_{pc}$$

it is known as balanced counter flow HE

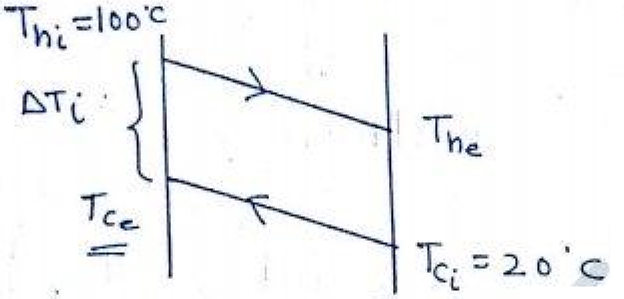
Q.5 $(\Delta T_m) = 20^\circ C$

$\dot{m}_h = 2\,\dot{m}_c$

$C_{ph} = \frac{1}{2}\, C_{pc}$ $\Rightarrow$ $\dot{m}_h C_{ph} = \dot{m}_c C_{pc}$

& HE is Counter H.E.

(Balanced Counter flow H.E.)



$(\Delta T_m) = (\Delta T_i) = 20^\circ C$

$T_{h_i} - T_{ce} = 20$

$T_{ce} = 100 - 20 = \underline{80^\circ C}$

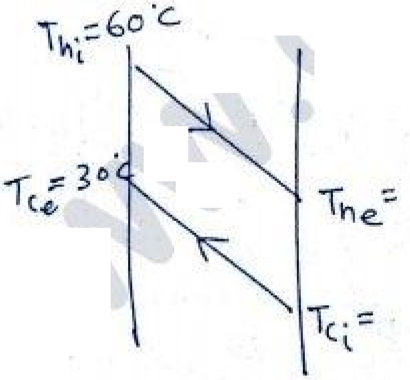
Q.3

$\dot{m}_h = 1$ kg/s $\quad C_{ph} = 10$ kJ/kgK

$\dot{m}_c = 2$ kg/s $\quad C_{pc} = 5$ kJ/kgK

$\Rightarrow \dot{m}_h C_{ph} = \dot{m}_c C_{pc} = 10$ kJ/sK

balanced Counter flow H E



LMTD $= \Delta T_i = 60 - 30$

$(\Delta T_m) = 30^\circ C$

Design of Heat exchanger (LMTD Method)

In any design of HE it is required to obtained the area of heat transfer needed for a given H.T. rate between hot and cold fluid and hence to obtain the dimension of tube i.e. d, L, n, P

where d = diameter of each tube

L = length of HE

n = No. of tubes ~~or pipes~~ per pass

p = No. of pass.

Given data :-

① Both the mass flow rate of Hot and Cold fluid ($\dot{m}_h$) ($\dot{m}_c$)

② Both the specific heats of Fluids (C_{ph} & C_{pc})

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

$$C_{P_{air}} = 1.005 \text{ kJ/kgK}$$

③ Overall H.T. Coefficient (U) in watt/m^2K

④ 3 tempratures among 4 temp.

for ex. T_{hi}, T_{ci}, T_{ce}

To find - Area (A) of HE.

Solution :-

Step ① Calculate the 4th unknown temp. from energy balance equation

i.e. $$\dot{m}_h C_{ph}(T_{hi} - T_{he}) = \dot{m}_c C_{ph}(T_{ce} - T_{ci})$$

Step 2 Draw the temp profile of Hot and Cold Fluid based on the type of H.E. to be designed and hence obtain LMTD of HE.

Step ③ Calculate the heat transfer rate between hot and cold fluids from the rate of enthapy change of either of the Fluid.

$$Q = \dot{m}_h \underset{\downarrow\ J/kg\,K}{C_{ph}}(T_{hi} - T_{he}) = \dot{m}_c \underset{\downarrow\ J/kg\,K}{C_{pc}}(T_{ce} - T_{ci}) \ J/sec$$

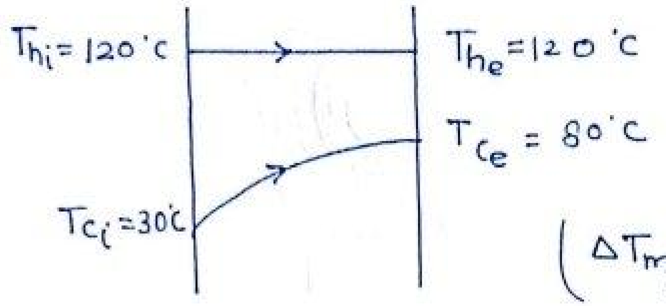
Step ④ obtain area from

$$Q = UA\,\Delta T_m$$

Que steam is condensing at a temp of 120°c in a condensor cooling water enters in condensor at a temp. 30°c and while flowing through the condensor at mass flow rate 1500 kg/hr leaves the condensor at 80°c. If overall H.T. Coefficient is 2000 $\frac{watt}{m^2 k}$. The heat tranfer area of the condensor is ?

Sol^n

ΔT



$\Delta T_i = 90^\circ C$

$\Delta T_e = 40^\circ C$

$$(\Delta T_m) = \frac{90 - 40}{\ln\left(\frac{90}{40}\right)} = 61.65^\circ C$$

$$Q = \dot{m}_c C_{P_c} (T_{c_e} - T_{c_i})$$

$$Q = \frac{1500}{3600} \times 4.186 \times 10^3 (80 - 30)$$

$$Q = 87208.33 \text{ J/s}$$

$U = 2000 \text{ W/m}^2\text{K}$

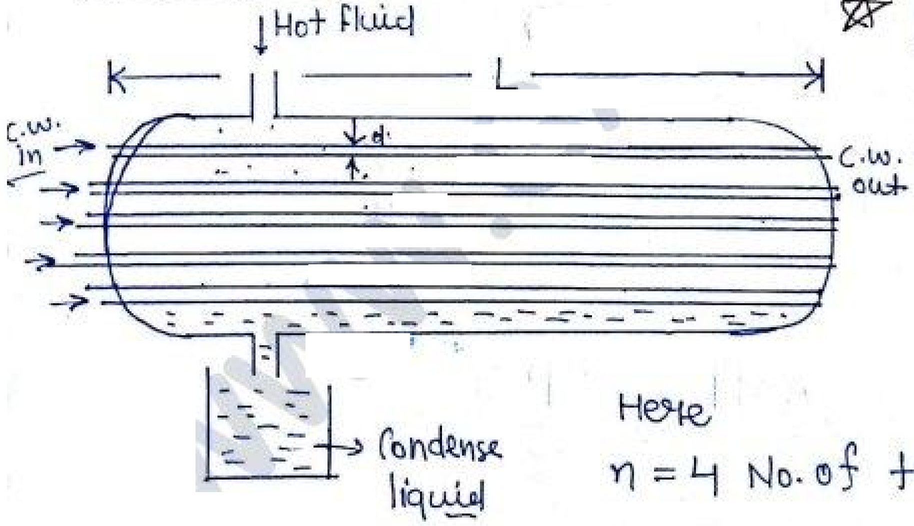
$$Q = UA\Delta T_m$$

$$A = \frac{87208.33}{2000 \times 61.65}$$

$$A = 0.707 \text{ m}^2$$

To Get the dimensions from Area.

$$\boxed{A = \pi d L n \times p}$$

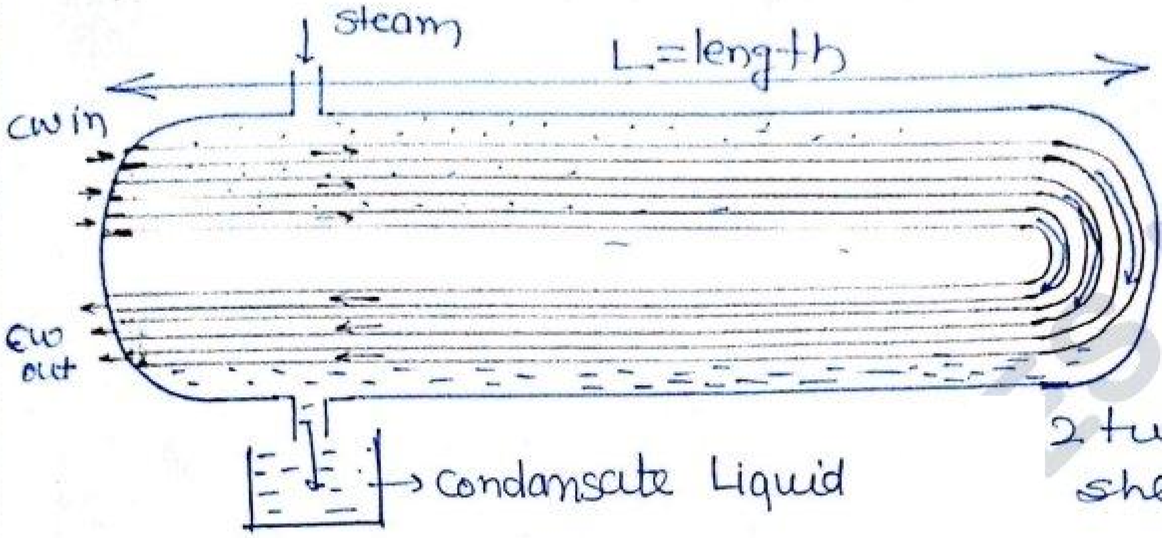


Single tube pass shell & tube HE

Here

$n = 4$ No. of tube per pass

$p = 1$ No. of pass.



2 tube pass
shell & tube HE

Here $\eta = 3$ (No. of tuper per pass)

$p = 2$ (No. of pass)

Note:- Passes are provided only when the H.E. area required is very large. By providing pass we can reduce the length of the HE needed for a given HT area so that the HE can be aceomodated in the available ~~freesp~~. Flow space.

Mass flow rate of the Coolent

$$\boxed{\dot{m}_c = \rho \times \frac{\pi}{4} d^2 \times V \times \eta}$$

η = no. of tubes per pass

V = Velocity

$$\boxed{A = \pi d L (\eta \times p)}$$

Q.19

wet steam − ~~120~~ °C 115 °C

65 − 100 °C

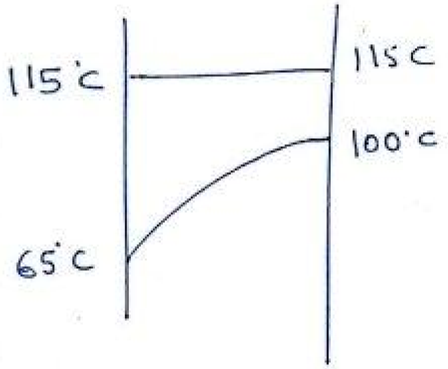
$C_p = 4.6\ kJ/kgK$

$\rho = 1100\ kg/m^3$ $\quad m_c =$

$V = 1.2\ m/s$ $\qquad h_i = 5\ kW/m^2K$

$d = 25\ mm$ $\qquad h_o = 10\ kW/m^2K$

$L = 3.5\ m$



$$\frac{1}{U} = \frac{1}{5} + \frac{1}{10} = \frac{10+5}{50}$$

$$U = \frac{50}{15} = \frac{10}{3}\ kW/m^2K$$

$\Delta T_i = 50\ °C \qquad \Delta T_e = 15\ °C$

$$\Delta T_m = \frac{50-15}{\ln\left(\frac{50}{15}\right)} =$$

$$\Delta T_m = 29.07\ °C$$

$$Q = m_c C_{p_c} (\Delta T_c) = U A \Delta T_m$$

$$A = \frac{m_c C_{p_c} \Delta T_c}{U \Delta T_m}$$

$$A = \frac{11.8 \times 4.6 \times (100-65) \times 10^3}{\frac{10}{3} \times 10^3 \times 29.07}$$

$$A = 19.60\ m^2$$

$$\dot{m} = \rho \times \frac{\pi}{4} \times d^2 \times L \times n \Rightarrow 11.8 = 1100 \times \frac{\pi}{4} \times \frac{(25)^2}{10^6} \times 3.5 \times n$$

$$n = 18.22$$

$n \simeq 19$ tubes

$$A = \pi d L \times n \times P = 19.62$$

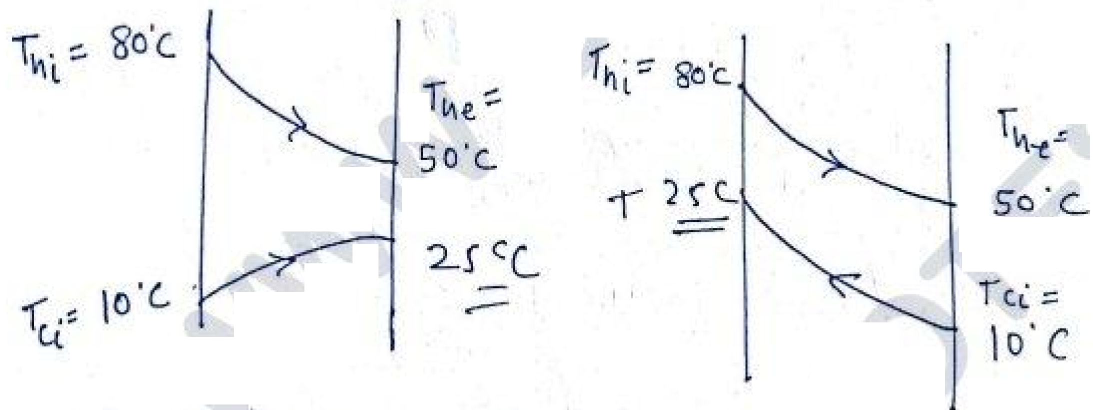
$$\Rightarrow \pi \times \frac{25}{100} \times 19 \times 3.5 \times P = 19.62$$

$$P = 3.75 \simeq 4 \text{ pass}$$

$$\Rightarrow \quad n = 19 \text{ tubes}$$

$$P = 4 \text{ pass.}$$

Q.21



$$\Rightarrow \dot{m}_h C_{ph}(T_{hi} - T_{he}) = m_c C_{pc}(T_{ce} - T_{ci})$$

$m_h = 1 \text{ kg/sec.}$

$$1 \times (80 - 50) = 2(T_{ce} - 10)$$

$C_{ph} = C_{pc}$ (one flud)

$$\boxed{T_{ce} = 25^\circ C} \text{ Same both}$$

$$Q = U A_p (\Delta T_m)_p = m C_{ph}(T_{hi} - T_{he}) = U A_c (\Delta T_m)_c$$

$$\frac{A_c}{A_p} = \frac{(\Delta T_m)_p}{(\Delta T_m)_c} = \frac{\dfrac{90 - 25}{\ln(90/25)}}{\dfrac{55 - 40}{\ln(55/40)}}$$

$$A_c / A_p = 0.92$$

Effectiveness of Heat Exchanger :- (ϵ)

It is defined as the ratio between actual heat transfer rate taking place between Hot and Cold fluid and the max possible heat transfor rate that can occur between them.

$$\boxed{\epsilon_{HE} = \frac{q_{act}}{q_{max.possible}}}$$

$$q_{act} = \dot{m}_h c_{ph} \left(T_{hi} - T_{he}\right) = \dot{m}_c c_{pc} \left(T_{ce} - T_{ci}\right)$$

$$q_{max} = \left(\dot{m} c_p\right)_{small} \times \left(T_{hi} - T_{ci}\right),$$

where $(\dot{m} c_p)_{small}$ is the smaller capacity Rate between $\dot{m}_h c_{ph}$ & $\dot{m}_c c_{pc}$

Why $(\dot{m} c_p)_{small}$?

when steam is condensing in a Condensor

$$(\dot{m} c_p)_{steam} \longrightarrow \infty$$

because when steam is condensing

$(\Delta T)_{steam} = 0$ ($\because$ phase change)

$$Q = mc_p \Delta T$$

$$(\dot{m} c_p)_{steam} = \frac{Q}{\Delta T} \to \infty$$

$(mc_p)_{max}$ can be ∞
So we take $(mc_p)_{min}$ for any type of HE

if $\dot{m}_h C_{ph} < \dot{m}_c C_{pc}$

Then

$$\epsilon_{H.E} = \frac{\dot{m}_h C_{ph}(T_{hi} - T_{he})}{\dot{m}_h C_{ph}(T_{hi} - T_{ci})}$$

$$\boxed{\epsilon_{H.E.} = \frac{T_{hi} - T_{he}}{T_{hi} - T_{ci}}}$$

on the other hand if $\dot{m}_c C_{pc} < \dot{m}_h C_{pc}$

then

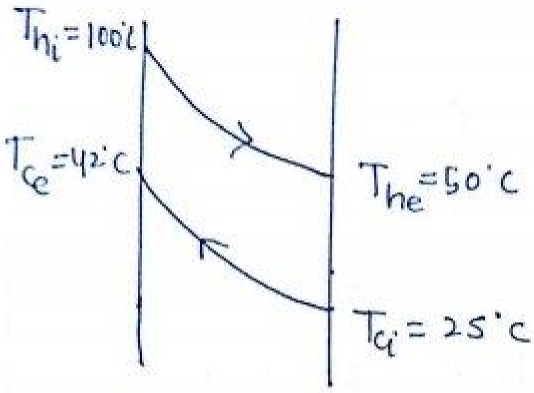
$$\epsilon_{H.E.} = \frac{m_c C_{pc}(T_{ce} - T_{ci})}{\dot{m}_c C_{pc}(T_{hi} - T_{ci})}$$

$$\boxed{\epsilon_{H.E.} = \frac{(T_{ce} - T_{ci})}{(T_{hi} - T_{ci})}}$$

* only one of the ~~two~~ above two formule given for ϵ ~~is~~ given is valid at a time only under the special case of both the capacity rate being equal on both hot & cold side i.e. $(mC_p)_h = (mC_p)_c$ then only any formula of ϵ given used.

* Practically $\epsilon = 0.5$ to 0.8

Q. 14



$(\dot{m}C_p)_{water} = 1.5 \times 4178$

$(\dot{m}C_p)_{oil} = 1 \times 2130$

so $(\dot{m}C_p)_{oil}$ ~~water~~ is small

so $\epsilon = \dfrac{(mC_p)_{oil}(T_{h_i} - T_{he})}{(mC_p)_{oil}(T_{h_i} - T_{ci})}$

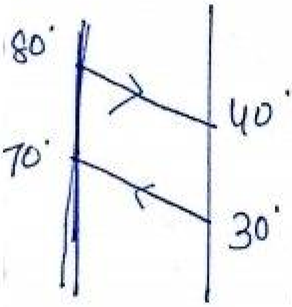
$\epsilon = \dfrac{50}{75} = \dfrac{2}{3}$

~~Q. 16~~ Q. 12

$(mC_p)_{water} = 4.18 \times 0.5 = 2.09 \ kJ/sK$

$(mC_p)_{air} = 1 \times 2.09 = 2.09 \ kJ/sK$

Counter



$(mC_p)_{water} = (mC_p)_{air}$ Counter balanced

$\dfrac{T_{h_i} - T_{he}}{T_{h_i} - T_{ci}} = 0.8 = \dfrac{80 - T_{he}}{80 - 50}$

$T_{he} = 40°C$

so $\Delta T_m = 10°C$ $(\Delta T)_c$ ~~$(\Delta T_m)_h = 40° = (\Delta T)_m$~~

~~$(\Delta T_m) = 40°C$~~

Number of Transfer Unit (NTU): —

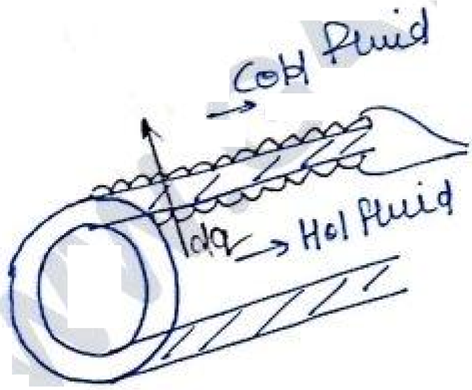
$$\boxed{NTU = \frac{UA}{(\dot{m}C_p)_{small}}}$$

UA → W/m^2K

$\dot{m}$ → kg/sec

C_p → J/kg K

NTU being directly proportional to the area of HE. It indicates overall size of HE. ~~Also~~ and with the uses of HE, NTU ↓, bcoz U↓



Fouling factor (F) → $m^2K/watt$

Fouling factor is the factor which takes into account the thermal resistance offered by any chemical scaling or deposits, that are formed on the H.T. surfaces on both hot side and cold side.

F → 0.0005 $m^2K/watt$
(OR)
0.0006 $m^2K/watt$
(OR)
0.0004 $m^2K/watt$

with fouling on both hot side & cold side of HE 'U' can be calculated as

with fouling $\boxed{\frac{1}{U} = \frac{1}{h_1} + f_1 + \frac{1}{h_2} + f_2}$

f_1 on HOT side

f_2 on Cold side

As a Result of fouling

① $U \downarrow$

② NTU $\downarrow$

③ $\epsilon_{HE} \downarrow$

④ Q (H.T. Rate) $\downarrow$

overall performance of HE is reduced.

Pratcically NTU

$NTU \simeq 1.5, 1.15, 2, 2.5, 4$

$NTU \not> 18$ $\boxed{NTU \geqq 1}$

Capacity Rate Ratio (C)

$$\boxed{C = \frac{(\dot{m}C_p)_{small}}{(\dot{m}C_p)_{big}}} \qquad 0 \le C \le 1$$

$C = 0$, if one of the fluid is undergoes phase change (like steam condensation)

Since $(\dot{m}C_p)_{big} \to \infty$

For any Heat exchanger:-

$$\epsilon = f(NTU, c)$$

For parallel flow

$$\boxed{\epsilon = \frac{1 - e^{-(1+c)NTU}}{1+c}}$$

For counter flow

$$\boxed{\epsilon = \frac{1 - e^{-(1+c)NTU}}{1 - c\, e^{-(1+c)NTU}}}$$

Case ①:- when one of the fluids in HE is undergoing phase change like in steam Condensor or evaporator

i.e. $c = 0$ (one fluid has phase Change

then $\epsilon_{\parallel el\ flow} = 1 - e^{-NTU}$

$\epsilon_{counter} = 1 - e^{-NTU}$

$$\boxed{\epsilon_{parallel} = \epsilon_{counter}}$$

Case ② when hot & cold fluids have equil capacity rate i.e.

when $\dot{m}_h C_{p_h} = \dot{m} C_{p_c}$

$\Rightarrow \quad C = 1$

Then $$\boxed{\epsilon_{\|el\ flow} = \frac{1 - e^{-2NTU}}{2}}$$

and $\epsilon_{counter} = \frac{0}{0}$ (underdefined)

from L' hospital Rule

$$\boxed{\epsilon_{counter} = \frac{NTU}{1+NTU}}$$ balance counter HE.

Any HE Problem

LMTD method → Design (A)

ϵ NTU method → To get $T_{ce} = ?$ & $T_{he} = ?$

ϵ - NTU Method :- The main objective of ϵ - NTU method is to obtain both the exit temp. of Hot and Cold fluid for a Given H.E. Area 'A'.

Given data:-

1. Both the mass flow rate of Hot & Cold fluids ($\dot{m}_h$ & $\dot{m}_c$)
2. Both the specific heats C_{ph} & C_{pc}
3. overall H.T. coefficient 'U' watt/m²K
4. Only two inlet temp. of fluids (T_{hi} & T_{ci})
5. Area 'A' of H.E.

To get $T_{he} = ?$ $T_{ce} = ?$

Solutions

Step ①:- calculate both the capacity rate of fluids i.e. $(\dot{m}C_p)_h$ & $(\dot{m}C_p)_c$ and Hence obtain capacity rate ratio 'c'

$$c = \frac{(\dot{m}C_p)_{small}}{(\dot{m}C_p)_{big}}$$

Step ② Calculate $NTU = \dfrac{UA}{(\dot{m}C_p)_{small}}$

step ③ Calculate $\epsilon = f(NTU, c)$

ϵ is a function of NTU, & c

Step (4)

$$\epsilon \rightarrow \left(\frac{T_{hi} - T_{he}}{T_{hi} - T_{ci}}\right) \qquad \left(\frac{T_{ce} - T_{ci}}{T_{hi} - T_{ci}}\right)$$

⇒ If $m_h c_{ph}$ is small ⇒ if $\dot{m}_c c_{pc}$ is small

Select only one formula of 'ϵ' based on which fluid has smaller capacity rate and hence obtain only one exit temp.

Step (5) obtain other exit temp. from energy balance eqn.

$$\dot{m}_h c_{ph}(T_{hi} - T_{he}) = \dot{m}_c c_{pc}(T_{ce} - T_{ci})$$

Q.22

$m_c = 7500$ kg/h $\qquad m_h = 8000$ kg/h

$T_{ci} = 15^\circ C \qquad T_{hi} = 105^\circ C$

$$C = \frac{(m_h c_{ph})_{air\,hot}}{(m_c c_{pc})_{cold}} = 0.256$$

$$NTU = \frac{UA}{(mc_p)_{small}} = \frac{145 \times 20}{2233.33} = 1.2985 \qquad \epsilon = \frac{1 - e^{-(1-C)NTU}}{1 - C \cdot e^{-(1-C)NTU}}$$

$$\epsilon = 0.6863$$

So $0.6863 = \dfrac{105 - T_{he}}{105 - 15}$

$$T_{he} = 43.23^\circ C$$

Q.18 Here $\dot{m}_h C_{p_h} = \dot{m}_c C_{p_c}$

$$C = 1$$

$$\epsilon_{\parallel el} = \frac{1 - e^{-2NTU}}{2} \qquad NTU = \frac{UA}{(\dot{m}C_p)_{small}}$$

$$\epsilon = 0.4589 \qquad = \frac{1000 \times 5}{1 \times 4000}$$

any formula can use $\qquad NTU = 1.25$

$$\epsilon = \frac{T_{ce} - T_{ci}}{T_{hi} - T_{ci}}$$

$$0.4589 = \frac{T_{ce} - 15}{102 - 15} \Rightarrow T_{ce} = 54.92^\circ C$$

Q.9 $A = 60\, m^2$ $\qquad \dot{m}_h C_{p_h} = \dot{m}_c P_c$

$U = 25\ W/m^2K$ $\qquad \Rightarrow C = 1$

$C_p = 1\ kJ/kg\,K$

$\dot{m} = 1\ kg/sec.$

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

$$NTU = \frac{25 \times 60}{1000} = 1.5$$

$$\epsilon = \frac{1.5}{1 + 1.5} = 3/5 = 0.6$$

Q.8 $\epsilon = 0.8$

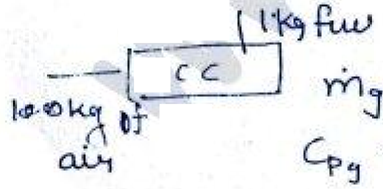
Counter flow $\qquad \epsilon = \frac{NTU}{1+NTU} \qquad NTU = 4$

$C = 1$

$$0.8 = \frac{NTU}{1 + NTU}$$

In Gas turbine power plant

High A/F Ratio are used
(100 : 1)



$\dot{m}_g \simeq \dot{m}_{air}$

$C_{p_g} \simeq C_{p_{air}}$

$\dot{m}_g C_{p_g} \simeq \dot{m}_{air} C_{p_{air}}$ & Counter flow

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