UNIT. III. PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS.

BOILING AND CONDENSATION:

The change of phase from liquid to vapour state is known as boiling.

The change of phase from vapour to liquid state is known as condensation.

Applications:

1. Thermal and Nuclear powerplant.
2. Refrigiration system.
3. process of heating and cooling.
4. Heating of metal in furnaces.
5. Air conditioning systems.

BOILING HEAT TRANSFER:

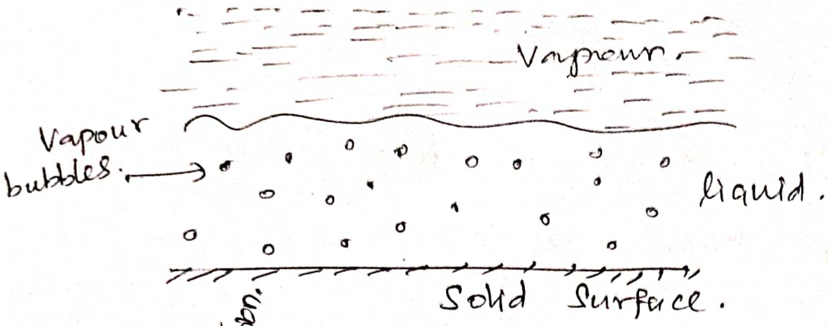
Boiling is a convection process involving a change of phase from liquid to vapour state. This is possible only when the temprature of the surface (T_w) exceeds the saturation temprature of liquid (T_{sat}).

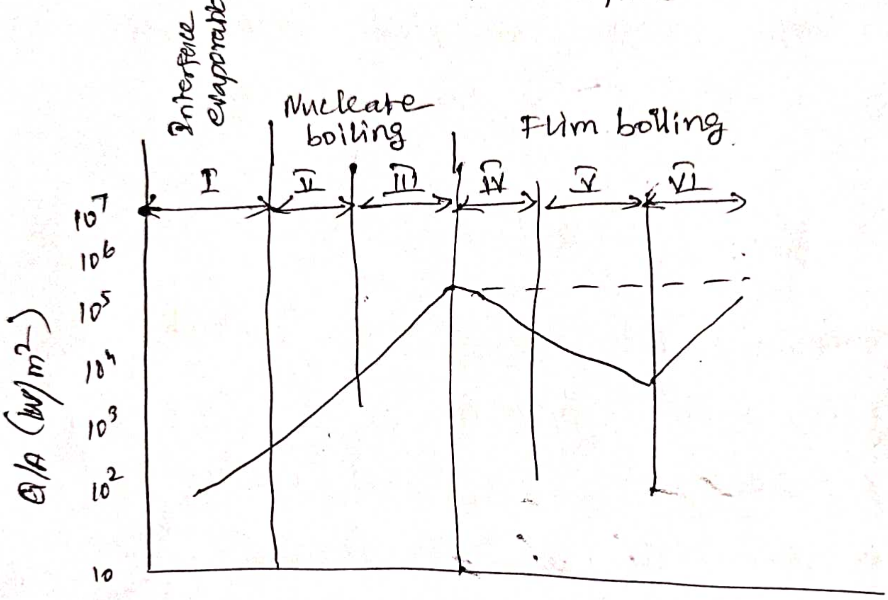
According to convection law,

$$Q = hA\,(T_w - T_{sat})$$

where, $T_w - T_{sat}$ – excess temprature.

POOL BOILING:





I - Free convection

II - Bubble condense in super heated liquid.

III - Bubble raise to surface.

IV - unstable flim.

V - Stable flim.

VI - Radiation coming into play.

1. Interface evaporation:

- ΔT is very small (5°C)
- No bubble formation.

2. Nucleate Boiling :

- II, III regions
- Bubbles formed rapidly
- ΔT is $50^\circ C$
- maximum heat flux occurs at A.

3. Flim boiling :

- IV, V, VI regions
- IV vapour flim is not stable and reforms rapidly.
- VI region radiation occurs.

FLOW BOILING :

Flow boiling (or) forced convection boiling may occur when a fluid is forced through a pipe (or) over surface which is maintained at a temprature ~~of~~ higher than the saturation temprature of fluid.

Formulae:

1. NUCLEATE POOL BOILING..

from [HMT DB 143]

(a) Heat flux, $$Q/A = \mu_L h_{fg} \left[\frac{g \times [\rho_L - \rho_v]}{\sigma}\right]^{0.5} \times \left[\frac{C_{pL} \times \Delta T}{C_{sf} \times h_{fg} P_r^n}\right]^3$$

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(b) critical heat flux,

$$Q/A = 0.18\, h_{fg}\, \rho_v \left[\frac{\sigma \times g\,(\rho_l - \rho_v)}{\rho_v^2}\right]^{0.25}$$

(c) Excess temprature,

$$\Delta T = T_w - T_{sat} < 50^\circ C$$

(d) Heat transfer,

$$Q = m \times h_{fg}$$

2. FILM POOL BOILING:

from [HMT DB 143]

(a) Heat transfer coefficient,

$$h = h_{conv} + 0.75\, h_{rad}.$$

$$h_{conv} = 0.62 \left[\frac{k_v^3 \times \rho_v \times (\rho_l - \rho_v) \times g\, [h_{fg} + 0.4 C_{pv} \Delta T]}{\mu_v\, D\, \Delta T}\right]^{0.25}$$

$$h_{rad} = \sigma \epsilon \left[\frac{T_w^4 - T_{sat}^4}{T_w - T_{sat}}\right]$$

(b) Excess Temprature,

$$\Delta T = T_w - T_{sat} > 50^\circ C$$

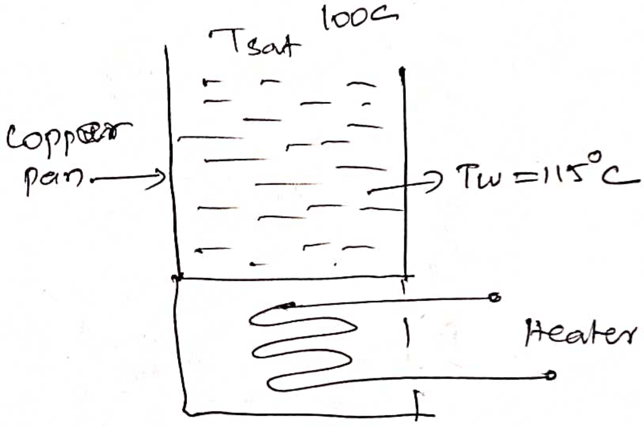
Ex: Water is to be boiled at atmospheric pressure in a polished copper pan by means of an electric heater. The diameter of the pan is 0.38 m and is kept at 115°c. Calculate the following,

1. power required to boil the water.
2. Rate of evaporation.
3. critical heat flux.

Given data:

$d = 0.38 m$

$T_w = 115°C$



To find:

P,
m, Q/A

Solution:

WKT,

Saturation temp of water 100°c,

$$\boxed{T_{sat} = 100°C}$$

properties of water at 100°c,

From (HMT DB 22)

$\rho_L = 961 \ kg/m^3$

$\nu = 0.293 \times 10^{-6} \ m^2/s$

$P_r = 1.740$

$C_{PL} = 4216 \ J/kg K$

$\mu_L = \rho_L \times \nu = 961 \times 0.293 \times 10^{-6}$

$= 281.57 \times 10^{-6} \ Ns/m^2$

From Steam table [RS Kurmi P.NO 4]

At 100°C

$h_{fg} = 2256.9$ kJ/kg

$h_{fg} = 2256.9 \times 10^3$ J/kg

$V_g = 1.673$ m³/kg

$$\rho_v = \frac{1}{V_g} = \frac{1}{1.673} = 0.597 \text{ kg/m}^3$$

$\Delta T = T_w - T_{sat} = 115 - 100 = 15°C$

$\Delta T = 15°C < 50°C$ Nucleate pool boiling //

1. power required to boil the water,

$$Q/A = \mu_L h_{fg} \left[\frac{g \times (\rho_L - \rho_V)}{\sigma}\right]^{0.5} \times \left[\frac{C_{pL} \times \Delta T}{C_{sf} \times h_{fg} P_r^{n}}\right]^{3} \rightarrow (1)$$

From (HMT DB 143)

σ - Surface tension for liquid vapour surface,

At 100°C,

$\sigma = 0.0588$ N/m From (HMT DB 145)

For water - copper $C_{sf} = 0.013$

$n = 1$ for water (From HMT DB 144)

Subs all value in (1).

$Q/A = 4.83 \times 10^5$ W/m²

$\Rightarrow \quad Q = 4.85 \times 10^5 \times A$

$\left[\because A = \frac{\pi}{4} d^2 \quad d = 0.38 \right]$

$$\boxed{P = Q = 54.7 \times 10^3 \ W}$$

2. Rate of evaporation ($\dot{m}$)

$$Q = \dot{m} \times h_{fg}$$

$$\Rightarrow \boxed{\dot{m} = 0.024 \ kg/s}$$

3. critical heat flux;

$$Q/A = 0.18 \ h_{fg} \times \rho_v \left[\frac{\sigma \times g \times (\rho_l - \rho_v)}{\rho_v^2} \right]^{0.25}$$

$$\boxed{Q/A = 1.52 \times 10^6 \ W/m^2}$$

Result:

$P = 54.7 \times 10^3 \ W$

$\dot{m} = 0.024 \ kg/s$

$Q/A = 1.52 \times 10^6 \ W/m^2$

(AU). It is desired to boil water at atmospheric pressure on a copper surface which is electrically heated. Estimate the heat flux from the surface to the water, if the surface is maintained at 110°c and also the peak heat flux.

Given data:

$T_w = 110^\circ C$

To find:

1. Heat flux Q/A
2. Critical heat flux Q'/A

Solution:

WKT,

$$T_{sat} = 100^\circ c$$

properties of water at $100^\circ C$,

From (HMT DB 22)

$\rho_L = 961 \ kg/m^3$

$\nu = 0.293 \times 10^{-6} m^2/s$

$Pr = 1.740$

$C_{pL} = 4216$.

$\mu_L = \rho_L \times \nu$

$= 961 \times 0.293 \times 10^{-6}$

$\mu_L = 281.57 \times 10^{-6} \ NS/m^2$

From Steam table At $100^\circ c$ (RS kurmi pg.no 4)

$h_{fg} = 2256.9 \times 10^3 \ J/kg$

$V_g = 1.673 \ m^3/kg$

$\rho_v = \frac{1}{V_g} \Rightarrow \rho_v = 0.597 \ kg/m^3$

WKT,

$\Delta T = T_w - T_{sat}$

$= 110 - 100 \Rightarrow \boxed{\Delta T = 10^\circ C}$ ∴ Nucleate boiling

For Nucleate boiling,

$$Q/A = \mu_l \times h_{fg} \left[\frac{g \times (\rho_l - \rho_v)}{\sigma}\right]^{0.5} \times \left[\frac{C_{pl} \times \Delta T}{C_{sf} \times h_{fg} P_r^{n}}\right]^{3} \rightarrow ①$$

from (HMT 143)

where,

$n = 1$ ($\because$ water)

At $100°C$ $\sigma = 0.0588$ N/m

(from HMT DB 145)

For water copper,

$C_{sf} = 0.013$

(from HMT DB 144)

Subs all values in ①,

$$① \Rightarrow \boxed{Q/A = 142.83 \times 10^{3} \ W/m^2}$$

For Nucleate boiling,

Critical heat flux,

$$Q'/A = 0.18\ h_{fg} \times \rho_v \left[\frac{\sigma \times g \times (\rho_l - \rho_v)}{\rho_v^{2}}\right]^{0.25} \rightarrow ②$$

Subs all values in ②

$$\boxed{Q'/A = 1.52 \times 10^{6} \ W/m^2}$$

Ex: A heating element cladded with metal is 8mm diameter and of emissivity 0.92. The element is horizantally immersed in a water bath, The Surface Temprature of the metal is 260°C under steady state boiling conditions. Calculate the power dissipation per unit length of the heater.

Given data:

$D = 8 \times 10^{-3}$ m

$\epsilon = 0.92$

$T_w = 260°C$

To find:

Power dissipation.

Solution:

WKT,

$T_{sat} = 100°C$

$\Delta T = T_w - T_{sat}$

$\Delta T = 160°C > 50°C$

since, film boiling.

$T_f = \frac{T_w + T_{sat}}{2}$

$T_f = 180°C$

Properties of Water at 180°C (saturated steam)
from (HMT DB 40)

$\rho_v = 5.16$ kg/m³

$K_v = 0.03268$ W/mK

$C_{pv} = 2709$ J/kgK

$\mu_v = 15.10 \times 10^{-6}$ Ns/m²

properties of saturated water at $100°C$,

from (HMT DB ~~pg~~ 22)

$\rho_L = 961\ kg/m^3$

From steam table at $100°C$ (RS khurmi 4)

$h_{fg} = 2256.9\ kJ/kg$

$h_{fg} = 2256.9 \times 10^3\ J/kg$

WKT,

$h = h_{conv} + 0.75 h_{rad} \rightarrow (1)$

$$h_{conv} = 0.62 \left[\frac{k_v^3 \times \rho_v \times (\rho_L - \rho_v) \times g \left[h_{fg} + 0.68 (C_{pv} \Delta T) \right]}{\mu_v \Delta T D} \right]^{0.25}$$

from (HMT DB 143)

$\Rightarrow \boxed{h_{conv} = 421.02\ W/m^2 K}$

****

WKT, $h_{rad} = \sigma \epsilon \left[\frac{T_w^4 - T_{sat}^4}{T_w - T_{sat}} \right]$ [* Subs T values in K]

from (HMT DB 143)

$\Rightarrow$ (Stefan boltzman constant $\sigma = 5.67 \times 10^{-8}\ W/m^2 K^4$)

$\Rightarrow \boxed{h_{rad} = 20\ W/m^2 K}$

Subs values in (1), $\Rightarrow \boxed{h = 436.02\ W/m^2 K}$

$\Rightarrow Q = hA (T_w - T_{sat})$

$= h \times \pi \times D \times L\ (T_w - T_{sat})$

$\boxed{P = Q = 1753.34\ W/m}$ [$\because L = 1\ m$]

(AU). An aluminium pan of 15cm diameter is used to boil water and the water depth at the time of boiling is 2.5cm. The pan is placed on an electric stove and the heating element rises the temprature of the pan to 110°c. Calculate the power input for boiling and the rate of evaporation. Take $C_{sf} = 0.0132$.

Given:

$d = 0.15m, \quad x = 0.025 m, \quad T_w = 110°c, \quad C_{sf} = 0.0132.$

Solution:

$T_{sat} = 100°c$

properties of water at 100°c from (HMT DB 22)

from steam table (RS kurmi Pg No 4)

ΔT is 10°c ~~&~~ 50°c Nucleate pool boiling

(i) power input for boiling.

$$Q/A = \mu_l \times h_{fg} \left[\frac{g \times (\rho_l - \rho_v)}{\sigma}\right]^{0.5} \times \left[\frac{C_{pl} \times \Delta T}{C_{sf} \times h_{fg} \, P_r^{\,n}}\right]^{3} \rightarrow (1)$$

from (HMT DB 143)

$\sigma = 0.0588 \ N/m$ (from HMT DB 145)

$n = 1$

$$\Rightarrow \quad Q/A = 1.43 \times 10^5 \ W/m^2 \Rightarrow \boxed{P = 2525 \, W}.$$

(ii) Rate of evaporation ($\dot{m}$)

$Q = \dot{m} \times h_{fg}$

$$\Rightarrow \boxed{\dot{m} = 1.11 \times 10^{-3} \ kg/s}$$

HEAT EXCHANGERS.

A heat exchanger is defined as an equipment which transfers the heat from a hot fluid to a cold fluid.

TYPES OF HEAT EXCHANGER;

1. Nature of heat exchange process

(i) Direct Contact HE

Ex: Cooling towers, feed heaters.

(ii) Indirect contact HE

- Sepperate two fluids by wall,

(a) Regenerators.

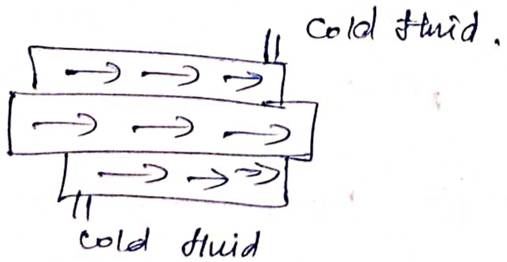
ex: IC engines, gas turbines.

(b) Recuperator:

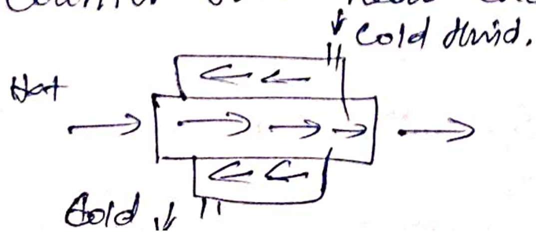
ex; Automobile radiators, economiser.

2. Relative motion Heat Exchangers.

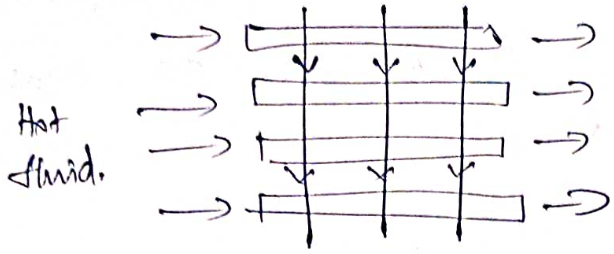
(i) parrallel flow heat exchanger.



(ii) Counter flow heat exchangers.



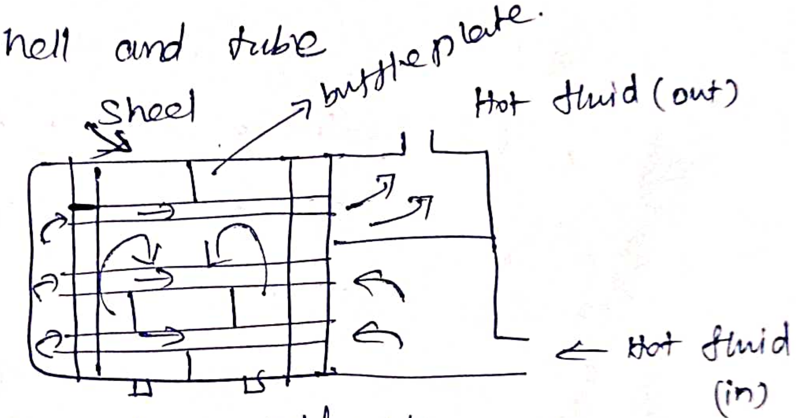
(iii) Cross flow heat exchangers.



III Design and constructional features.

(i) concentric tube HE

(ii) Shell and tube



(iii) Mutiple shell and ~~compact~~ tubes. HE

(iv) Compact heat exchangers.

IV physical state of fluids.

(i) Condensers.

(ii) Evaporators.

LOGARITAMIC MEAN TEMPERATURE DIFFERENCE.
(LMTD).

$$Q = UA (\Delta T)_m$$

U - overall heat transfer co-efficient W/m^2K

A - Area, m^2

ΔT_m - Logrithmic Mean Temprature Difference.

ASSUMPTIONS :

(i) Flow is steady.
(ii) The overall heat transfer co-efficient is constant
(iii) The specific heats of both fluids are constant.
(iv) The mass flow rate of both fluids are constant.
(v) Axial conduction along the tube is negligible.
(vi) KE and PE of fluids are negligible.

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FOULING FACTORS :

The surfaces of a heat exchangers do not remain clean after it has been in use for some time. The surfaces become fouled with scaling or deposits. The effect of these deposits affecting the value of overall heat transfer co-efficient (U). This effect is taken care of by introducing an additional thermal resistance called fouling resistance (R_f).

$$U_{outer} = \frac{1}{\frac{1}{h_o} + R_{fo} + \frac{r_o}{k}\ln\left(\frac{r_o}{r_i}\right) + \left(\frac{r_o}{r_i}\right)R_{fi} + \left(\frac{r_o}{r_i}\right)\frac{1}{h_i}}$$

$$U_{inner} = \frac{1}{\frac{1}{h_i} + R_{fi} + \frac{r_i}{k}\ln\left(\frac{r_o}{r_i}\right) + \left(\frac{r_i}{r_o}\right)R_{fo} + \left(\frac{r_i}{r_o}\right)\frac{1}{h_o}}$$

EFFECTIVENESS:

$$\text{Effectiveness } \epsilon = \frac{\text{Actual heat transfer}}{\text{maximum possible heat transfer}} = \frac{Q}{Q_{max}}.$$

FORMULAE (Parallel flow & counter flow).

from (HMT DB 152)

1. Heat transfer $Q = UA(\Delta T)_m$

where,

U - overall heat transfer co-efficient W/m^2K

A - Area m^2

$(\Delta T)_m$ - Logarithmic Mean Temperature Difference (LMTD)

For parallel flow,

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

For counter flow,

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

where,

T_1 - Entry Temp of hot fluid °c

T_2 - Exit Temp of hot fluid °c

t_1 - Entry temp of cold fluid °c

t_2 - Exit temp of cold fluid °c

2. Heat lost by hot fluid = Heat gained by cold fluid.

$$Q_h = Q_c$$

$$\Rightarrow \dot{m}_h C_{ph} (T_1 - T_2) = \dot{m}_c C_{pc} (t_2 - t_1)$$

where,

$\dot{m}_h$ = mass flow rate of hot fluid kg/s

$\dot{m}_c$ = mass flow rate of cold fluid kg/s

C_{ph} = specific heat of hot fluid J/kgK

C_{pc} = specific heat of cold fluid J/kgK

3. Surface area of tube

$$A = \pi D_1 L$$

Here, D_1 - Inner diameter.

4. $Q = \dot{m} \times h_{fg}$

h_{fg} - Enthalpy of evaporation J/kgK

5. Mass flow rate,

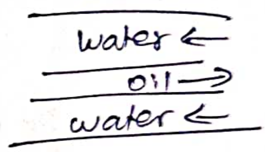
$$\dot{m} = \rho A C$$

Ex:

In a Counter flow double pipe heat exchanger, oil is Cooled from 85°c to 55°c by water entering at 25°c. The mass flow rate of oil is 9800 kg/h and specific heat of oil is 2000 J/kg K. The mass flow rate of water is 8000 kg/h and specific heat of water is 4180 J/kg K. Determine the heat exchanger area and heat transfer rate for an overall heat transfer co-efficient of 280 W/m² K.

Given data:

Hot fluid	Cold fluid.
(T_1, T_2)	(t_1, t_2)
oil	water



$T_1 = 85°c$ $\quad$ $t_1 = 25°c$

$T_2 = 55°c$ $\quad$ $t_2 = ?$

$\dot{m}_h = 9800\ kg/h = \frac{9800}{3600}\ kg/s = 2.72\ kg/s$

$C_{ph} = 2000\ J/kg\,K$

$\dot{m}_c = 8000\ kg/h = \frac{8000}{3600}\ kg/s = 2.22\ kg/s$

$C_{pc} = 4180\ J/kg\,K$

$U = 280\ W/m^2 K$

To find:

1. Heat exchanger Area. A
2. Heat transfer rate Q

Solution:

WKT,

Heat lost by hot fluid (Oil) = Heat gained by water (Cold fluid)

$$Q_h = Q_c$$

$$\dot{m}_h c_{ph} (T_1 - T_2) = \dot{m}_c c_{pc} (t_2 - t_1)$$

$$\Rightarrow \boxed{t_2 = 42.5^\circ C}$$

WKT,

Heat transfer

$$Q = \dot{m}_c c_{pc} (t_2 - t_1)$$

$$\Rightarrow \boxed{Q = 162 \times 10^3 \text{ W}}$$

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WKT,

Heat transfer $Q = UA (\Delta T)_m \rightarrow (13)$

from (HMT DB 152)

$(\Delta T)_m$ for counter flow,

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

$$\Rightarrow \boxed{\Delta T_m = 35.8^\circ C}$$

Subs the values, in (13)

$$\Rightarrow Q = UA (\Delta T_m)$$

$$\Rightarrow \boxed{A = 26.16 \text{ m}^2}$$

Ex: Water flows at the rate of 65 kg/min through a double pipe counter flow heat exchanger. water is heated from 50°c to 75°c by an oil flowing through the tube. The specific heat of 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. Calculate the following.

1. Heat exchanger area.
2. Rate of heat transfer.

Given data:

Hot fluid - Oil
(T_1, T_2)

Cold fluid - water.
(t_1, t_2)

$\dot{m}_c = 65 \text{ kg/min} = 65/60 \Rightarrow \dot{m}_c = 1.08 \text{ kg/s}$

$t_1 = 50°c$

$t_2 = 75°c$

$C_{ph} = 1.780 \times 10^3 \text{ J/kgK}$

$T_1 = 115°c$

$T_2 = 70°c$

$U = 340 \text{ W/m}^2\text{K}$

Solution:

$Q = \dot{m}_c C_{pc} (t_2 - t_1)$ $[\because C_{pc} = 4186 \text{ J/kgK}]$

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

WKT $Q = UA\Delta T_m \Longrightarrow \boxed{A = 11.54 \text{ m}^2}$

Ex: In a double pipe heat exchanger, hot fluid with a specific heat of 2300 J/kgK enters at 380°C and leaves at 300°C. Cold fluid enters at 25°C and leaves at 210°C. Calculate the heat exchanger area required for counter flow and what would be the percentage of increase in area if fluid flow ~~taken~~ were parallel. Take overall heat transfer co-efficient is 750 W/m²K and mass flow rate of hot fluid is 1 kg/s.

Given data:

$C_{ph} = 2300$ J/kgK

$T_1 = 380°C$

$T_2 = 300°C$

$t_1 = 25°C$

$t_2 = 210°C$

$U = 750$ W/m²K

$m_h = 1$ kg/s

To find:

Heat exchanger area required for,

1. Counter flow.
2. Parallel flow.
3. Percentage of increase in area.

Solution:

$$Q = \dot{m}_h C_{ph} (T_1 - T_2)$$

$$\boxed{Q = 184 \times 10^3 \text{ W}}$$

Case (i) For counter flow,

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

From (HMT DB 152)

$\Rightarrow \quad \Delta T_m = 218.3^\circ C$

WKT,

$Q = UA\,\Delta T_m$

$184 \times 10^3 = 750 \times A \times 218.3$

$\Rightarrow \boxed{A = 1.12\,m^2}$

Case (ii) For parallel flow,

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

From (HMT DB 152)

$\Rightarrow \quad \Delta T_m = 193.1^\circ C$

WKT,

$Q = UA\,\Delta T_m$

$184 \times 10^3 = 750 \times A \times 193.1 \Rightarrow \boxed{A = 1.27\,m^2}$

Case (iii)

percentage increase in Area $= \dfrac{1.27 - 1.12}{1.12}$

$= 13.3\ \%$

Ex: An oil cooler of the form of tubular heat exchanger cools oil from a temprature of 90°C to 35°c by a large pool of stagnant water assumed at constant temprature of 28°c. The tube length is 32 m and diameter is 28 mm. The specific heat and specific gravity of the oil are 2.45 kJ/kgK and 0.8 respectively. The velocity of the oil is 62 cm/s. Calculate the overall heat transfer co-efficient.

Given data:

Hot fluid - oil (T_1, T_2)

Cold fluid - water. (t_1, t_2)

$T_1 = 90°c$

$T_2 = 35°c$

$t_1 = t_2 = 28°c$

$L = 32\ m$

$D = 0.028\ m$

$C_{ph} = 2.45 \times 10^3\ J/kg\ K$

Specific gravity of oil $= 0.8$

Velocity of oil $= 0.62\ m/s$

Solution:

$$\text{Specific gravity of oil} = \frac{\text{Density of oil}}{\text{Density of water}}$$

$$= \frac{\rho_o}{\rho_w}$$

$$0.8 = \frac{\rho_o}{1000}$$

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Density of oil $\rho_o = 800\ kg/m^3$

$$\dot{m}_h = \rho_o \times A \times C$$

$$= 800 \times \frac{\pi}{4} D^2 \times 0.62$$

$$\boxed{\dot{m}_h = 0.305\ kg/s}$$

Heat transfer, $Q = \dot{m}_h \times C_{ph} (T_1 - T_2)$

$$\boxed{Q = 41 \times 10^3\ W}$$

WKT,

$$Q = UA(\Delta T)_m$$

From (HMT DB 152)

For parallel flow,

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

$$(\Delta T)_m = 25.2°C$$

Subs the values,

$$Q = UA\ (\Delta T)_m$$

$$41 \times 10^3 = U \times \pi D L \times 25.2$$

$$\boxed{U = 577.9}\ W/m^2K$$

Result:

$U = 577.9\ W/m^2K$

Ex: In parallel flow heat exchanger, hot water is cooled from 80°c to 40°c by cold water entering at 20°c. The mass flow rate of hot water is 0.2 kg/sec and the mass flow rate of cold water is 0.5 kg/s. If the individual heat transfer co-efficients on both sides are 600 w/m²K, Find the area of the heat exchanger. (13)

Given data:

$T_1 = 80°C$

$T_2 = 40°C$

$t_1 = 20°C$

$\dot{m}_h = 0.2\ kg/s$

$\dot{m}_c = 0.5\ kg/s$

Heat transfer co-efficient on both sides $h_i = h_o = 600\ W/m^2K$

Solution:

WKT,

Heat lost by hot water = Heat gained by cold water.

$$Q_h = Q_c$$

$$\Rightarrow \dot{m}_h\, C_{ph}(T_1 - T_2) = \dot{m}_c\, C_{pc}(t_2 - t_1)$$

(Here, $C_p = 4186\ J/kg\,K$ water)

$$\Rightarrow \boxed{t_2 = 36°C}$$

WKT,

$$Q = UA(\Delta T)_m$$

(From HMT DB 152)

For parallel flow,

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

$$\boxed{(\Delta T)_m = 20.6^\circ C}$$

WKT,

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$$

$$\frac{1}{U} = \frac{h_o + h_i}{h_i h_o}$$

$$\Rightarrow \quad U = \frac{h_i h_o}{h_o + h_i}$$

$$\boxed{U = 300 \ W/m^2K}$$

WKT,

$$Q = UA(\Delta T)_m$$

$$33{,}488 = 300 \times A \times 20.67$$

$$\Rightarrow \boxed{A = 5.40 m^2}$$

<u>Result:</u>

Heat exchanger Area $A = 5.40 \ m^2$

Ex: (AU) In a double pipe counter flow heat exchanger 10,000 kg/hr of an oil having a specific heat of 2095 J/kg K is cooled from 80°C to 50°C by 8000 kg/hr of water entering at 25°C. Determine heat exchanger area for an overall heat transfer co-efficient of 310 W/m²K.

Ex: (AU) In a counter flow double pipe heat exchanger, water is heated from 25°C to 65°C by an oil with a specific heat of 1.45 kJ/kg K and mass flow rate is 0.9 kg/s. The oil is cooled from 230°C to 160°C. If the overall heat transfer co-efficient is 420 W/m²°C, calculate the following

1) The rate of heat transfer.
2) The mass flow rate of water.
3) The surface area of heat exchanger.

Ans:

$$Q = 91.35 \times 10^3 \ W$$

$$A = 1.455 m^2$$

$$\dot{m}_c = 0.545 \ kg/s$$

(UA) Hot oil with a capacity rate of 2500 W/K flows through a double pipe heat exchanger. It enters at 360°C and leaves at 300°C. Cold fluid enters at 30°C and leaves at 200°C. If the overall heat transfer coefficient is 800 W/m²K, determine heat exchanger area for (i) Parallel flow (ii) Counter flow.

CROSS FLOW HE (or) Shell and Tube HE.

Formulae;

1. $Q = FUA (\Delta T)_m$

From (HMT DB 152)

F- correction factor (from HMT DB)

$$(\Delta T)_m = \frac{[(T_1 - t_2) - (T_2 - t_1)]}{\ln\left[\frac{T_1 - T_2}{T_2 - t_1}\right]} \quad \text{(counter flow)}$$

2. Heat lost by Hot fluid = Heat gained by Cold fluid.

$$Q_h = Q_c$$

$$\dot{m}_h C_{ph} (T_1 - T_2) = \dot{m}_c C_{pc} (t_2 - t_1)$$

Ex: In a Cross flow heat exchangers, both fluids unmixed, hot fluid with a specific heat of 2300 J/kg. enters at 380°C and leaves at 300°C. cold fluid enters at 25°C and leaves at 210°C. Calculate the required surface area of heat exchanger. The overall heat transfer co-efficient is 750 W/m²K. mass flow rate of hot fluid is 1 kg/s.

Given data:

$C_{ph} = 2300 \text{ J/kg K}$

$T_1 = 380°C$

$T_2 = 300°C$

$t_1 = 25°C$

$t_2 = 210°C$

$U = 750 \text{ W/m}^2\text{K}$

$\dot{m}_h = 1 \text{ kg/s}$

To find:

HE (A)

Solution:

Cross flow, unmixed type HE

$$Q = F\,UA\,(\Delta T)_m \longrightarrow (13)$$

From (HMT DB 152)

F - Correction factor

$$(\Delta T)_m = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left[\frac{380 - 210}{300 - 25}\right]} \quad (\because \text{counter flow})$$

$$\boxed{(\Delta T)_m = 218.3°C}$$

WKT,

$$Q = \dot{m}_h C_{ph} (T_1 - T_2)$$

$$\boxed{Q = 184 \times 10^3 \text{ W}}$$

For correction factor (F),

From (HMT DB 162)

From graph,

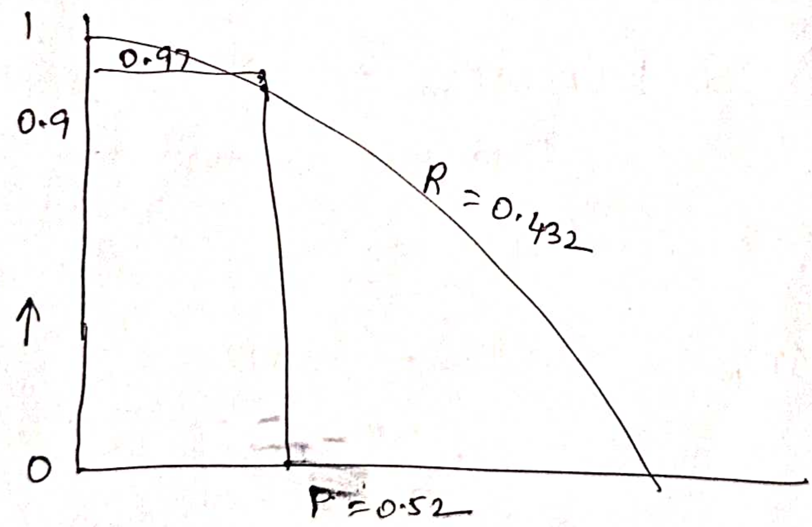
$$X_{axis} \text{ Value } P = \frac{t_2 - t_1}{T_1 - t_1} = 0.52$$

$$\text{Curve value } R = \frac{T_1 - T_2}{t_2 - t_1} = 0.432$$

For X_{axis} and R value,

Corresponding y value 0.97

$$\boxed{F = 0.97}$$



Subs all values in (1)

$$Q = FUA\,(\Delta T)_m$$

$$184 \times 10^3 = 0.97 \times 750 \times A \times 218.3$$

$$\Rightarrow \boxed{A = 1.15\ m^2}$$

Ex: In a refrigerating plant water is cooled from 20°C to 7°C by brine solution entering at −2°C and leaving at 3°C. The design heat load is 5500 W and the overall heat transfer is 800 W/m²K. what Area required when using a shell and tube heat exchanger with the water making one shell pass and brine making two tube passes.

Given data:

Hot fluid water
cold fluid brine solution.

$T_1 = 20°C$

$T_2 = 7°C$

$t_1 = -2°C$

$t_2 = 3°C$

$Q = 5500\,W$

$U = 800\,W/m^2K$

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AP / Mech.

To find:

A

Solution:

Shell and tube Heat exchanger
(One shell pass _ Two tube pass)

$Q = F U A (\Delta T)_m \longrightarrow (1)$

from (HMT DB 152)

F - correction factor

For Counter flow,

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

$$\boxed{(\Delta T)_m = 12.57^\circ C}$$

For F (correction factor),

From (HMT DB 159)

(one shell pass and two tube passes)

From graph,

X value $P = \frac{t_2 - t_1}{T_1 - t_1} = 0.22$

Curve $R = \frac{T_1 - T_2}{t_2 - t_1} = 2.6$

Corresponding y value,

$$\boxed{F = 0.94}$$

Subs all values in (B),

$$Q = FUA\,(\Delta T)_m$$

$$\Rightarrow \boxed{A = 0.58\ m^2}$$

NUMBER OF TRANSFER UNITS METHOD:

NTU method is used to determine the inlet and exit temprature of the heat exchanger.

Ex: A parallel flow heat exchanger is used to cool 4.2 kg/min of hot liquid of specific heat 3.5 KJ/kgK at 130°c. A cooling ~~tower of~~ water of specific heat 4.18 KJ/kgK is used for cooling purpose at a temprature of 15°c. The mass flow rate of cooling water is 17 kg/min. Calculate the following,

1. outlet temp of liquid 2. outlet temp of water 3. Effectiveness of heat exchanger. Take overall heat transfer co-efficient is 1100 W/m²K. Heat exchanger area is 0.30 m².

Given data:

$\dot{m}_h = 0.07$ kg/s

$C_{ph} = 3.5 \times 10^3$ J/kgK

$T_1 = 130°C$

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

$t_1 = 15°C$

$\dot{m}_c = 0.28$ kg/s

$U = 1100$ W/m²K

$A = 0.30$ m²

To find:

T_2, t_2, ϵ

Solution:

capacity rate of hot liquid $C = \dot{m}_h \times C_{ph}$

$C = 245 \ W/K \rightarrow (1)$

capacity rate of water $C = \dot{m}_c \times C_{pc}$

$C = 1170.4 \ W/K \rightarrow (2)$

from (1) & (2)

$C_{min} = 245 \ W/K$

$C_{max} = 1170.4 \ W/K$

$$\frac{C_{min}}{C_{max}} = 0.209 \rightarrow (3)$$

Number of Transfer units,

$$NTU = \frac{UA}{C_{min}}$$

from (HMT DB 152)

$\Rightarrow NTU = 1.34$

For effectiveness ϵ

(from HMT DB 163)
parallel flow HE

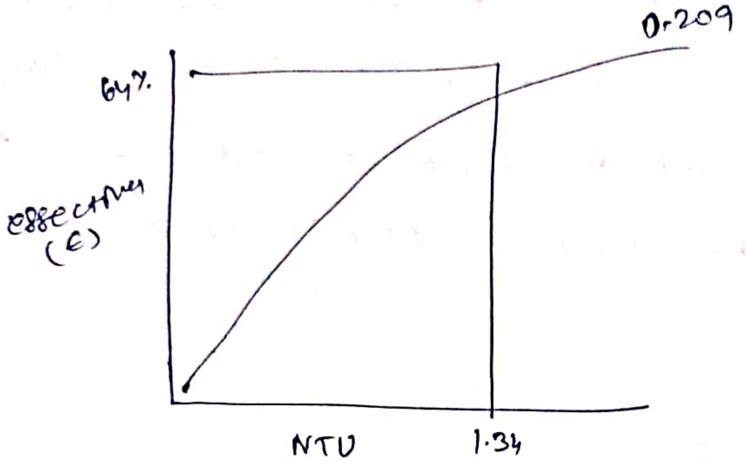
from Graph,

X axis $\rightarrow$ $NTU = 1.34$

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

Corresponding Y axis value, is 64%.

$\therefore \boxed{\epsilon = 0.64}$



Maximum possible heat transfer

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

$$\boxed{Q_{max} = 28,175 \, W}$$

From data book. 16
$Q = \epsilon \, C_{min}(T_1 - t_1)$
$\Rightarrow Q = 18,032 \, W$

Actual heat transfer rate,

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

$$Q = 18,032 \, W$$

WKT,

$$Q = \dot{m}_c \, C_{ph} (t_2 - t_1)$$

$$\Rightarrow \boxed{t_2 = 30.40^\circ C}$$

WKT, $Q = \dot{m}_h \, C_{ph} (T_1 - T_2)$

$$\Rightarrow \boxed{T_2 = 56.4^\circ C}$$

Result:

$T_2 = 56.4^\circ C$, $t_2 = 30.40^\circ C$, $\epsilon = 0.64$

(AU). It is desired to use double pipe counter flow heat exchanger to cool 3 kg/s of oil ($c_p = 2.1$ kJ/kgK) from 120°C. Cooling water at 20°C enters the heat exchanger at a rate of 10 kg/s. The overall heat transfer co-efficient of the heat exchanger is 600 W/m²K and the heat transfer area is 6 m². Calculate the exit temperatures of oil and water.

Given data:

$\dot{m}_h = 3\ kg/s$

$C_{ph} = 2.1 \times 10^3\ J/kgK$

$T_1 = 120°C$

$t_1 = 20°C$

$\dot{m}_c = 10\ kg/s$

$U = 600\ W/m^2K$

$A = 6\ m^2$

To find:

T_2, t_2

Solution:

Capacity rate of hot oil

$$C = \dot{m}_h \times C_{ph}$$

$$C = 6300\ W/K \longrightarrow (1)$$

Capacity rate of water,

$$C = \dot{m}_c \times C_{pc}$$

$$C = 41860\ W/K \longrightarrow (2)$$

From 1 & 2,

$$C_{min} = 6300 \text{ W/K}$$

$$C_{max} = 41860 \text{ W/K}$$

$$\Rightarrow \frac{C_{min}}{C_{max}} = 0.15$$

$$NTU = \frac{UA}{C_{min}}$$ from (HMT DB 152)

$$NTU = 0.571$$

For effectiveness ϵ,
from (HMT DB 164) (counter flow)

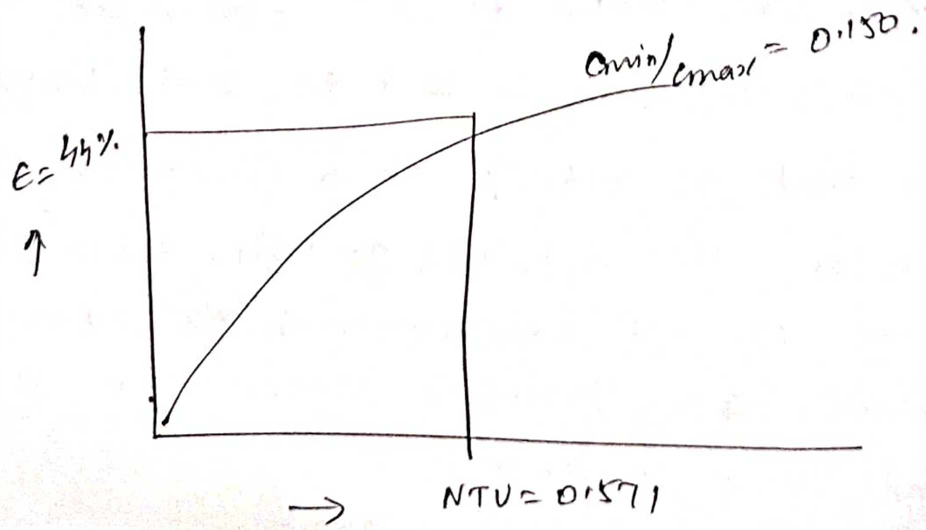
From graph,

X axis $NTU = 0.571$

Curve $C_{min}/C_{max} = 0.150$

Corresponding Y axis value is 42 %.

$$\boxed{\epsilon = 0.42}$$



maximum possible heat transfer,

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

$$\boxed{Q_{max} = 63 \times 10^4 \ W}$$

Actual heat transfer rate

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

$$\boxed{\dot{Q} = 2,64,000 \ W}$$

WKT,

$$Q = \dot{m}_c C_{pc} (t_2 - t_1)$$

$$\Rightarrow \boxed{t_2 = 26.23^\circ C}$$

$$Q = \dot{m}_h C_{ph} (T_1 - T_2)$$

$$\Rightarrow \boxed{T_2 = 78^\circ C}$$

Ex: In a cross flow both fluids unmixed heat exchanger, water at 6°C flowing at the rate of 1.25 kg/s. It is used to cool 1.2 kg/s of air that is initially at a temprature of 50°C. Calculate the following, ① Exit temprature of water ② Exit temprature of air. Assume overall heat transfer coefficient is 130 W/m^2K and area is 23 m^2.

Ans: $T_2 = 12.6^\circ C$, $t_2 = 14.6^\circ C$

Ex: In a counter flow heat exchanger, water is heated from 20°c to 80°c by an oil with a specific heat of 2.5 kJ/kgK and mass flow rate of 0.5 kg/s. The oil is cooled from 110°c to 40°c. If the overall heat transfer co-efficient is 1400 W/m²K, find the following by using NTU method. 1. mass flow rate of water, 2. Effectiveness of heat exchanger 3. Surface Area. (20)

Given data:

$t_1 = 20°c$

$t_2 = 80°c$

$C_{ph} = 2.5 \times 10^3 \ J/kgK$

$\dot{m}_h = 0.5 kg/s$

$T_1 = 110°c$

$T_2 = 40°c$

$U = 1400 \ W/m^2K$

To find:

$\dot{m}_c, \epsilon, A$

Solution:

WKT,

$$Q_h = Q_c$$

$$\dot{m}_h C_{ph} (T_1 - T_2) = \dot{m}_c C_{pc} (t_2 - t_1)$$

$$\Rightarrow \boxed{\dot{m}_c = 0.348 \ kg/s}$$

Capacity rate of oil $C = \dot{m}_h C_{ph}$

$$C = 1250 \ W/K \rightarrow (1)$$

Capacity rate of water $C = \dot{m}_c C_{pc}$

$$C = 1456.7 \ W/K \rightarrow (2)$$

From ① & ②,

$$C_{min} = 1250 \text{ W/K}$$

$$C_{max} = 1456.73 \text{ W/K}$$

$$\frac{C_{min}}{C_{max}} = 0.858 \longrightarrow ③$$

WKT,

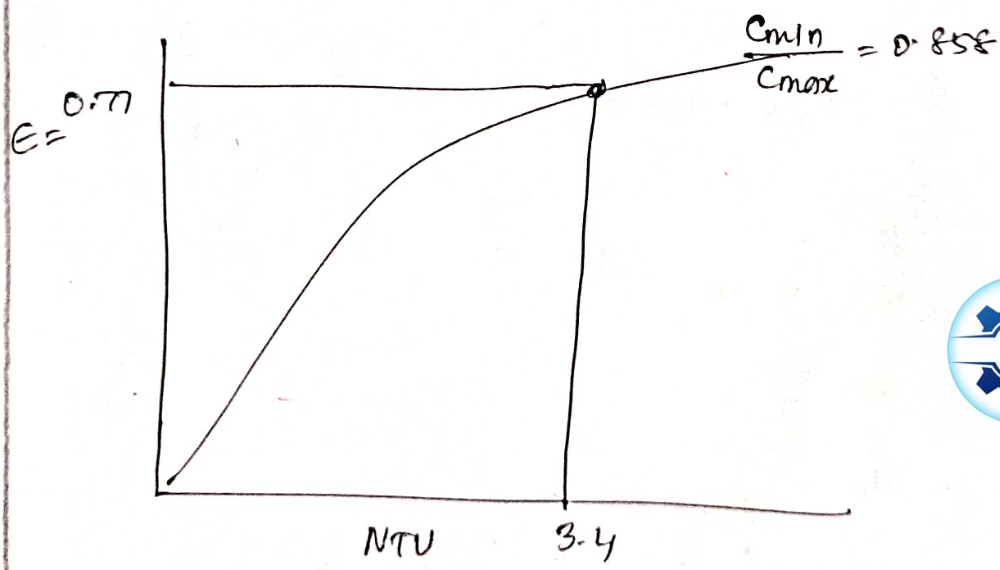
$$\epsilon = \frac{T_1 - T_2}{T_1 - t_1} \quad \text{From (HMT DB 152)}$$

$$\boxed{\epsilon = 0.77}$$

For Area, From (HMT DB 164) (Counter flow)

Y axis $\Longrightarrow$ $\epsilon = 0.77$

Curve $\longrightarrow$ $\frac{C_{min}}{C_{max}} = 0.858$



Corresponding X axis value, NTU = 3.4

$$NTU = \frac{UA}{C_{min}} \quad \text{From (HMT DB 152)}$$

$$\Longrightarrow \boxed{A = 3.03 \text{ m}^2}$$

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