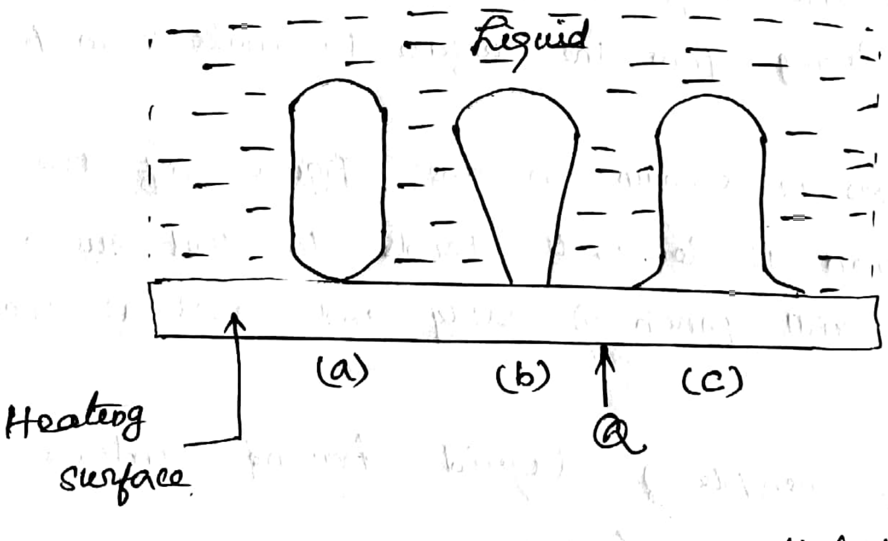
① Explain boiling phenomena in detail

The phenomena of boiling, opposite of Condensation, is commonly encountered in chemical Industries. eg. distillation, evaporation etc. in almost all cases where Condensation is carried out boiling apparatus associated it.

In Chemical Industry usually the boiling takes place either on the submerged surface eg. kettle reboiler or inside a vertical tube eg. vertical tube evaporator.

In boiling practice, initially the vapour is formed in the form of bubbles and after wards as a distinct vapour phase above a liquid interface.



In case of boiling accomplished by a hot submerged, the temp. of the liquid is same as the boiling point of liquid at pressure prevailing in the apparatus.

The bubbles of vapour or formed at the heating surface, rise through the pool of liquid, from the surface of liquid.

Finally the vapour from the vapour space is removed as fast as it is formed through vapour outlet. This type of boiling is referred to as pool boiling of saturated liquid as the vapour leaving is in equilibrium with the liquid at its boiling Temperature.

Heat Transfer by vapourization in absence of mechanical agitation is of course a Combination of free convection and the additional convection generated by the rising stream of bubbles.

If the surface tension of the liquid against heating surface is large, the bubbles tend to spread along the surfaced and blanket the surface rather than living from the surface to make room for other bubbles.

These is shown in the figure if the surface tension is low, it tends to wet surfaces and bubbles will pinch of easily and rises as shown in figure.

An example of liquid having intermediate tension is shown in figure.

② Derive the relationship between heat transfer coefficient 'h' and overall heat transfer coefficient 'U'

Individual heat transfer coefficient (h)

The heat transfer coefficient is used in calculating the heat transfer, typically by convection

$$h = \frac{Q}{A \cdot \Delta T}$$

where

Q - heat flow in input or lost heat flow, J/s = W

h - heat transfer coeff, W/m^2K

A - heat transfer surface area, m^2

ΔT - Temp. diff b/w solid surface & surrounding fluid area

The heat transfer rate can be written as,

$$q_{ry} = h A (T_s - T_a)$$

Overall heat Transfer coefficient (U)

'U' is a measure of the overall ability of a series of Conductive and Convective barrier to transfer heat. It is commonly applied to calculate the heat transfer in Heat Exchangers.

$$q = UA \, \Delta T_{LM}$$

where,

q - heat transfer rate (W)

U - overall heat transfer coeff W/m^2K

A - heat transfer surface area m^2

ΔT_{LM} - Log Mean Temp diff K

It Can be calculated as the reciprocal of sum of series of thermal resistance

$$\frac{1}{UA} = \Sigma \frac{1}{hA} + \Sigma R$$

The relationship b/w the individual heat transfer coeff (h) and overall heat transfer coeff (U) is a simple method for determining an overall heat transfer coefficient that is useful to find the heat transfer between simple elements such as walls in buildings or across heat exchangers.

This method only accounts for conduction within materials, it does not take into account heat transfer through methods such as radiation.

$$\frac{1}{UA} = \frac{1}{h_1 * A_1} + \frac{dx_w}{k * A} + \frac{1}{h_2 * A_2}$$

where,

U - overall HT coeff W/m^2K

A - Contact area m^2

k - Thermal conductivity of material W/m^2K (W/mK)

h - Individual HT coeff W/m^2K

dx_w - wall thickness (m)

As the areas for each surface approach being equal as the equation. It can be written as the transfer coeff per unit area. dx_w is the difference of two radii where the inner and outer radii are used to define the thickness of a pipe carrying a fluid.

~~The thermal~~ $$\frac{1}{U} = \frac{1}{h_1} + \frac{dx_w}{k} + \frac{1}{h_2}$$

or

$$U = \frac{1}{\frac{1}{h_1} + \frac{dx_w}{k} + \frac{1}{h_2}}$$

The thermal resistance due to pipe wall is calculated by the following relationship

$$R = \frac{x}{k \cdot A}$$

@

Where,

x - wall thickness (m)

k - thermal conductivity W/mK

A - Total area of heat transfer m^2

This represents the heat transfer by conduction in pipe.

The Convective heat transfer coeff for each stream depends on the type of fluid.

Some typical heat transfer coeff include

Air → $h = 10$ to 100 W/m²K

Water → $h = 500$ to $10{,}000$ W/m²K

Thermal resistance due to fouling deposits:

Surface coatings can build on HT surface during heat exchanger operation due to fouling.

The additional thermal resistance due to foulers can be found by comparing the overall heat transfer coeff (lab) with calculations based on theoritical calculation

$$\frac{1}{U_{exp}} = \frac{1}{U_{pre}} + R_f$$

U_{exp} - overall HT coeff on experimental W/m²K

U_{pre} - overall HT coeff based on calculated or measured W/m²K

R_f - Thermal resistance m^2K/W.

(1) Dry steam at 100°c condenses on the outside surface of a horizontal pipe of OD 2.5cm. The pipe surface is maintained at 84°c by circulating water through it. determine the rate of formation of condensate per meter length of pipe.

The properties of condensate at film temperature are; ρ_f = ~~958~~ 936 kg/m³, $\mu_f = 306 \times 10^{-6}$ Ns/m², $k_f = 677 \times 10^{-3}$ W/mK, λ = 2257 kJ/kg.

Given data:

$T_s = 100°C + 273$

$= 373 K$

$D = 2.5 cm = 2.5 \times 10^{-2} m$

$T_w = 84°C \Rightarrow 357 K$

$\rho_f = 963 \; kg/m^3$

$\mu_f = 306 \times 10^{-6} \; Ns/m^2$

$k_f = 677 \times 10^{-3} \; W/mK$

$\lambda = 2257 \; kJ/kg$

$= 2257 \times 10^3 \; J/kg$

To find $Q = ?$

formula

$Q = \dot{m} \lambda$

Soln:

$$h = 0.725 \left[\frac{\rho^2 g \lambda k^3}{\mu D_o \Delta T}\right]^{0.25}$$

$$= 0.725 \left[\frac{963^2 \times 9.81 \times 2257 \times 10^3 \times (677 \times 10^{-3})^3}{306 \times 10^{-6} \times 2.5 \times 10^{-2} \times (373 - 357)}\right]^{0.25}$$

$$= 0.725 \left[\frac{6.371 \times 10^{-2}}{1.22 \times 10^{-4}}\right]$$

$$\boxed{h = 10959.73 \ W/m^2 K}$$

$$Q = h \pi D_o (T_s - T_a)$$

$$= 10959.73 \times \pi \times 2.5 \times 10^{-2} (373 - 357)$$

$$\boxed{Q = 13772.4 \ W}$$

$$\dot{m} = Q/\lambda$$

$$= \frac{13772.4}{2257 \times 10^3}$$

$$\boxed{\dot{m} = 6.10 \times 10^{-3} \ kg/s}$$

⑤ A vertical square plate 30 by 30 cm is exposed to steam at atmospheric pressure. The plate temp is 98°C. Calculate the heat transfer and the mass of steam condensed per hour.

Data: $\rho = 960\ kg/m^3$, $\mu = 2.82 \times 10^{-4}\ kg/m\,s$

$k = 0.68\ W/mK$, $\lambda = 2255\ kJ/kg$, saturation temp of steam $= 373K\ (100°C)$

Assume that the flow of condensate is laminar.

Solution:

Given: $\rho = 160\ kg/m^3$ $\lambda = 2255 \times 10^3\ J/kg$,

$L = 0.3\ m$, $\Delta T = 373 - 376 = 2K$,

$g = 9.81\ m/s^2$, $\mu = 2.82 \times 10^{-4}\ kg/m.s$

$k = 0.68\ W/m.k$.

The average heat transfer coeff (h) for condensation on a vertical plate is given by

$$h = 0.943 \left[\frac{\rho^2 g \lambda k^3}{L\ \mu\ (\Delta T)}\right]^{1/4}$$

$$= 0.943 \left[\frac{(960)^2 \times 9.81 \times 2255 \times 10^3 \times (0.68)^3}{(0.3)(2.82 \times 10^{-4})(2)}\right]^{1/4}$$

$$\boxed{h = 13150\ W/m^2 k}$$

The heat transfer rate is

$$Q = hA(T_s - T_w)$$

$= 13150 \times 0.3 \times 0.3\ (373 - 371)$

$= 2367\ W$

$= 2367\ J/s$.

mass flow of condensate (condensate rate) $= Q/\lambda = \dfrac{2367}{2255 \times 10^3}$

$= 1.05 \times 10^{-3}\ kg/s$

$= 3.78\ kg/h$.

⑧ with the help of q/A Vs T, explain the various stages involved in the boiling of saturated liquid and briefly discuss about the influence of boundary layer on heat transfer.

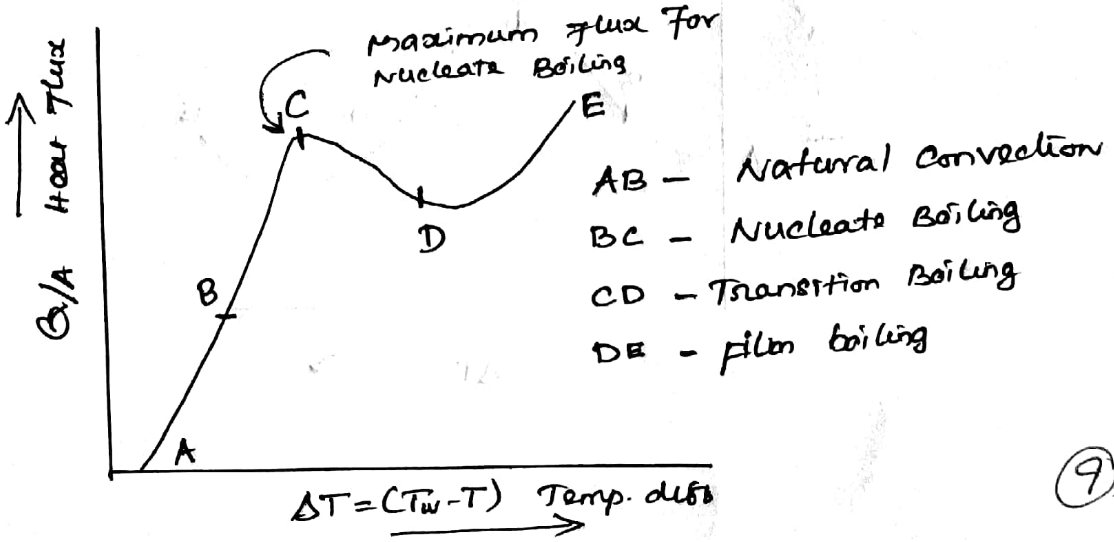
Consider a heating element e.g. tube bundle is submerged in a pool of boiling liquid. The steam is condensing inside the tubes.

Let Q/A be the heat flux and $\Delta T = (T_w - T)$ be the difference in temperature between tube wall and boiling liquid.

Start with very small temperature drop and go on increasing ΔT (by increasing T_w & keeping T constant) in step wise manner.

Measure for each step the value of Q/A and ΔT till high values of ΔT are obtained.

When we plot Q/A Vs ΔT on logarithmic coordinates, we will get a curve as shown in figure.



The curve is divided into four segments AB, BC, CD & DE.

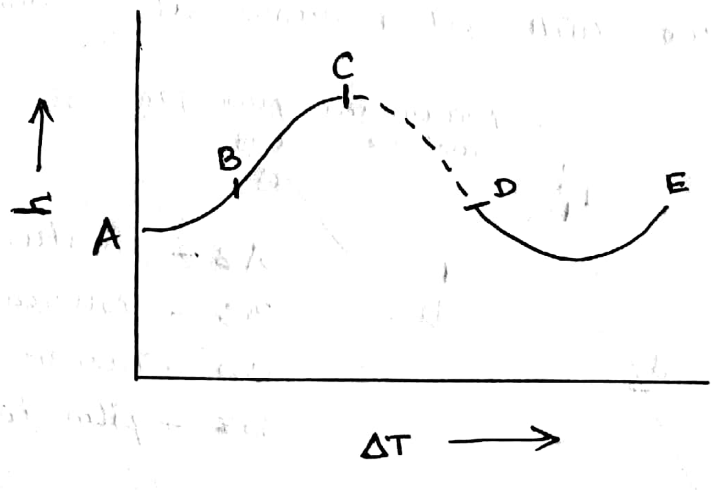
under very small temp. drop, the rate of production of bubbles proceeds slowly & the mechanism is that of transfer of heat by free convection.

Bubbles from on the surface, release from it, rise to the surface of liquid and then disengaged into the vapour space and they are very few to disturb natural convection current set up in liquid.

This occurs over the segment AB where in Q/A is proportional to $\Delta T^{1.25}$. The segments BC of the curve is also as a straight line with slope greater than that of segment AB.

The temperature drop corresponding to point 'C' is called critical temperature drop and corresponding flux is called peak flux.

The action occuring below critical temperature drop over segment BC is called Nucleate boiling. where vaporisations take place directly from the surface.



③

Over the segment CD as the temperature drop increases the flux decreases and reaches a minimum at point D. The point D is known as the Leidenfrost point.

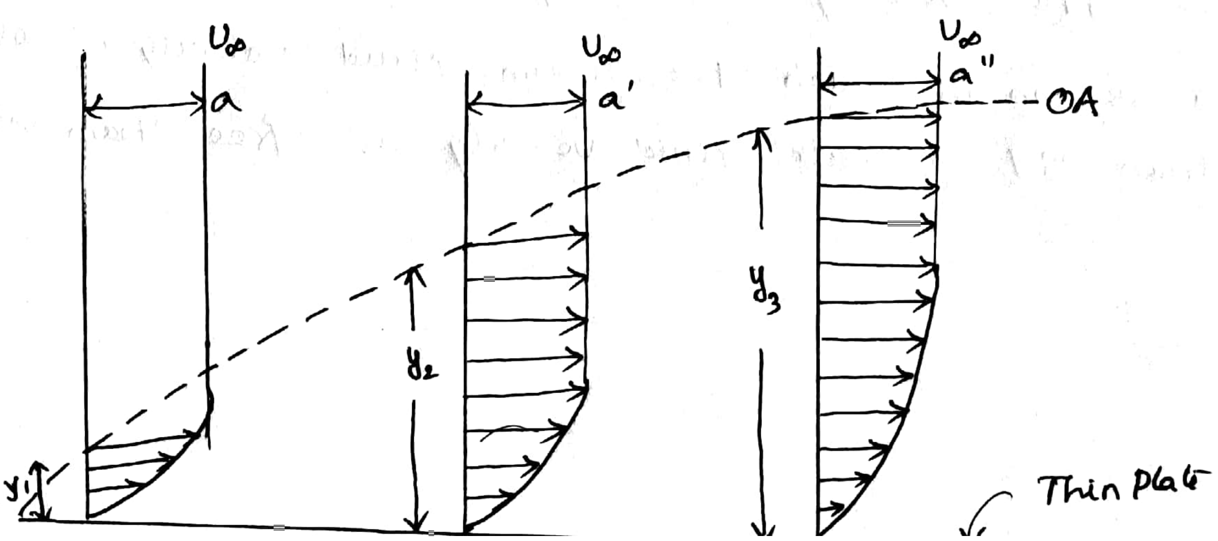
The boiling action over the segment CD is known as transition boiling.

Influence of boundary layer on heat Transfer:

When a fluid flows over a solid surface the fluid velocity in the neighbourhood of the surface will change in a direction at right angles to the stream flow because of the viscous forces acting within the fluid

Consider the flow of fluid parallel within a thin plate as shown in figure.

The velocity of the fluid approaching the thin plate is uniform across the entire fluid stream.



As the fluid reaches the leading edge of the plate, a velocity gradient is set up at right angles to the plane with the velocity at the surface of thin plate still zero.

The fluid velocity increases with distance from the plate as shown in figure.

In the above figure, the velocity distribution are shown for three different distances from the leading edge of the plate.

The curves shows that the local velocity approaches asymptotically the bulk fluid velocity.

The line OA which is a outer limit of boundary layer separates the fluid stream into two parts.

- One in which the fluid velocity is constant
- The other in which the velocity is increasing from zero to approximately that of undisturbed flow.

The velocity boundary layer is defined as a region in which the ~~stream~~ fluid velocity is less than 99% of bulk fluid velocity or free stream velocity.