Solution Paper - II

Question1:-

A triple effect forward feed evaporator is used to concentrate a liquid which has marginal elevation in boiling point. The temperature of the stream to the first effect is 105°C, and the boiling point of the solution within third effect is 45°C. The overall heat transfer coefficients are,

2,200 W/m2: in the I-effect,
1,800 W/m2: in the II-effect,
1,500 W/m2: in the III-effect.

Find out at what temperatures the fluid boils in the I and II effects.

Answer:-

Assumptions

1. We may assume that there is no elevation in boiling point in the evaporators.
2. Area of all the three evaporators are same ($A_I = A_{II} = A_{III} = A$)

Total temperature drop = (105-45) °C = 60 °C

Using eq. 9.5, the temperature drop across I-effect,

$$\Delta T_I = \frac{\frac{1}{2200}}{\frac{1}{2200} + \frac{1}{1800} + \frac{1}{1500}} \times 56 = 15.2\ °C$$

Similarly, the temperature drop across II-effect,

$$\Delta T_{II} = \frac{\frac{1}{1800}}{\frac{1}{2200} + \frac{1}{1800} + \frac{1}{1500}} \times 56 = 18.6\ °C$$

And the temperature drop across III-effect,

$$\Delta T_{III} = \frac{\frac{1}{1500}}{\frac{1}{2200} + \frac{1}{1800} + \frac{1}{1500}} \times 56 = 22.3\ °C$$

Therefore, the boiling point in the first effect will be = (105 – 15.2) °C = 89.8 °C
Similarly, the boiling point in the second effect will be = (89.8 – 18.6)°C = 71.2 °C.

Question2:-

What is heat transfer coefficient?

Answer:-

The correlation used in the boiling and condensation may be used here. If the evaporator operates at very high liquid velocity so that the boiling occurs at the top end of the tube, the following correlation (eq. 9.1) may be used,

$$\frac{h_i D}{k} = 0.0278 \mathrm{Re}^{0.8} \mathrm{Pr}^{0.4} \tag{9.1}$$

where, D is the inner diameter of the tube, k is the thermal conductivity of the liquid or solution.

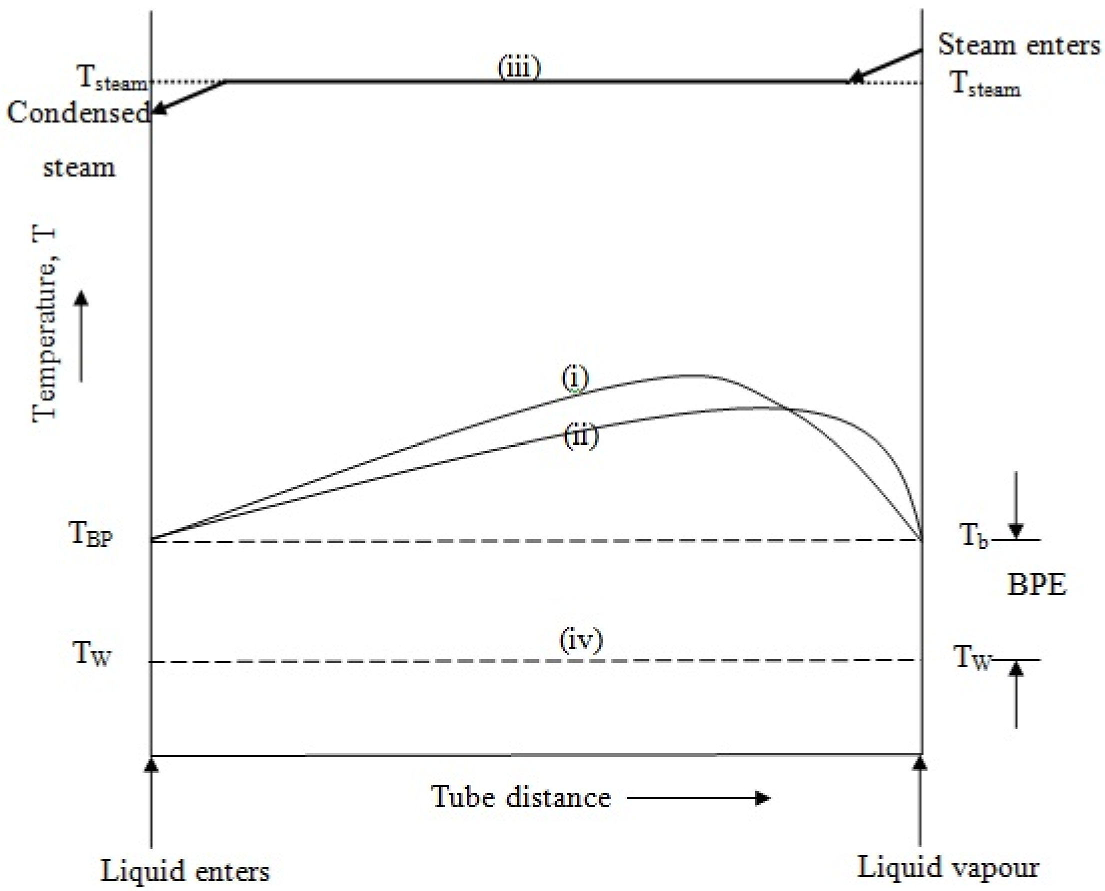


Fig: Temperature profiles in an evaporator

Fouling is a concern in the evaporator; therefore the following equation (eq.9.2) may be used for the overall heat transfer coefficient with time,

$$\frac{1}{U_{dirty}^2} = \frac{1}{U_{clean}^2} + \alpha t \tag{9.2}$$

where, t is the time for where the evaporator is the operation, α is a constant for a particular liquid, U_{dirty} and U_{clean} all the overall heat transfer coefficient of the dirty and clean evaporator.

Question3:-

Discuss the effect of temperature on thermal conductivity.

Answer:-

The atoms and molecules in all substances are moving -- either vibrating in solids or actually moving in liquids and gases. Temperature measures their average kinetic energy or energy of motion. Thermal conductivity changes with temperature.

Effects

Thermal conductivity is relatively constant over a narrow temperature range. As the temperature increases, however, the rate at which particles in the substance are moving increases, and the rate at which heat is transferred typically increases as well.

Question4:-

In the oven door described in illustration 5.1 is subjected to an upward flow of air (that is forced convection). What would be the minimum free stream velocity for which natural convection may be neglected?

Answer:-

The following condition shows the effect of natural convection may be neglected,

$$\frac{Gr_L}{{Re_L}^2} \ll 1$$

The value of *Gr* number calculated in the previous illustration was 1.16 X 10^8

Thus,

$$\frac{1.16 \times 10^8}{(\frac{LU}{v})^2} \ll 1$$

U >> 0.24 m/s

Therefore, the bulk velocity of the air should be far greater that 0.24 m/s.

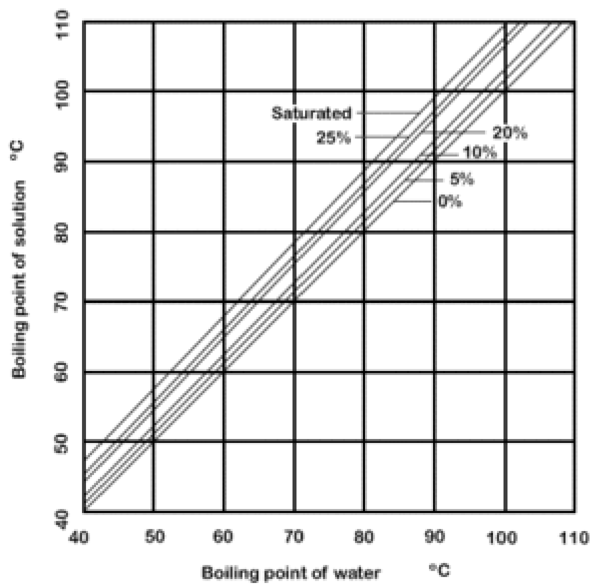
Question5:-

Explain Dühring rule.

Answer:-

Dühring's rule states that a linear relationship exists between the temperatures at which two solutions exert the same vapor pressure The rule is often used to compare a pure liquid and a solution at a given concentration.

Dühring's plot is a graphical representation of such a relationship, typically with the pure liquid's boiling point along the x-axis and the mixture's boiling point along the y-axis; each line of the graph represents a constant concentration.



Question6:-

What is Leidenfrost phenomenon?

Answer:-

Leidenfrost phenomenon was observed by Leidenfrost in 1756. When water droplets fall on a very hot surface they dance and jump on the hot surface and reduces in size and eventually the droplets disappear. The mechanism is related to the film boiling of the water droplets. When water droplet drops on to the very hot surface, a film of vapour forms immediately between the droplet and the hot surface. The vapour film generated provide and up-thrust to the droplet. Therefore, the droplet moves up and when again the droplet comes in the contact of the hot surface, the vapour generated out of the water droplet and the phenomenon continues till it disappears.

The effectiveness of nucleate boiling depends primarily on the ease with which bubbles form and free themselves from the heating surface. The important factor in controlling the rate of bubble detachment is the interfacial tension between the liquid and the heating surface. If this interfacial tension is large the bubbles tends to spread along the surface and blocked the heat transfer area, rather than leaving the surface, to make room for other bubbles. The heat transfer coefficient obtained during the nucleation boiling is sensitive to the nature of the liquid, the type and condition of the heating surface, the composition and purity of the liquid, agitation, temperature and pressure.

Question7:-

Define Grashof number?

Answer:-

The **Grashof number** Gr is a dimensionless number in fluid dynamics and heat transfer which approximates the ratio of the buoyancyto viscous force acting on a fluid. It frequently arises in the study of situations involving natural convection. It is named after the German engineer Franz Grashof.

$$\mathrm{Gr}_L = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}$$ for vertical flat plates

$$\mathrm{Gr}_D = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2}$$ for pipes

$$\mathrm{Gr}_D = \frac{g\beta(T_s - T_\infty)D^3}{\nu^2}$$ for bluff bodies

where the L and D subscripts indicates the length scale basis for the Grashof Number.

g = acceleration due to Earth's gravity

β = volumetric thermal expansion coefficient (equal to approximately 1/T, for ideal fluids, where T is absolute temperature)

T_s = surface temperature

T_∞ = bulk temperature

L = length

D = diameter

ν = kinematic viscosity

The transition to turbulent flow occurs in the range $10^8 < \mathrm{Gr}_L < 10^9$ for natural convection from vertical flat plates. At higher Grashof numbers, the boundary layer is turbulent; at lower Grashof numbers, the boundary layer is laminar.

The product of the Grashof number and the Prandtl number gives the Rayleigh number, a dimensionless number that characterizes convection problems in heat transfer.

There is an analogous form of the **Grashof number** used in cases of natural convection mass transfer problems.

$$\mathrm{Gr}_c = \frac{g\beta^*(C_{a,s} - C_{a,a})L^3}{\nu^2}$$

where

$$\beta^* = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial C_a}\right)_{T,p}$$

and

g = acceleration due to Earth's gravity

$C_{a,s}$ = concentration of species *a* at surface

$C_{a,a}$ = concentration of species *a* in ambient medium

L = characteristic length

v = kinematic viscosity

ρ = fluid density

C_a = concentration of species *a*

T = constant temperature

p = constant pressure

Question8:-

A pipe having 10 cm of diameter is carrying saturated steam at 8 bar of absolute pressure. The pipe runs through a room. The wall of the room is at 300 ^oK. A portion around 1 m of the pipe insulation is damaged and exposed to the room atmosphere. Calculate the net rate of heat loss from the pipe by radiation.

Answer:-

The emissivity of the pipe surface is not given so it may be considered black. Moreover, since the room may be big compared to the surface area of the pipe, the room may also be considered to be a blackbody.
We can write $F_{11} + F_{12} = 1$.
The value of $F_{11} = 0$, as the pipe cannot see itself.
Thus F_{12}, the view factor (1-pipe, 2-room) will be 1.
The net rate heat loss due to radiation,

$$Q_{12} = A_{pipe}\epsilon_{pIpe}F_{12}\sigma\,(T_{pipe}^4 - T_{room}^4)$$

T_{pipe} can be obtained by the temperature of the steam at the prevailing pressure with the help of steam table = 450 K.
σ (= 5.67 X 10^{-8} W/m^2/K^4)
On putting the value,
$Q_{12} = \{\pi(0.1)(1)\}(1)(1)(5.67 \times 10^{-8})\{450^4 - 300^4\}$
$Q_{12} = 586\ W$