Department of petroleum Engineering

CH-8591 HEAT TRANSFER

Unit - IV

(1) State stefan - Boltzman law, planck's law and wiens displacement law.

Stefan - Boltzman law:

It states that the total energy emitted by a black body is directly proportional to the fourth power of its absolute Temp.

$$E_b \propto T^4$$

$$E_b = \sigma . T^4 \qquad \text{——— (1)}$$

where T - Temp. 'K'

σ - stefan - Boltzman Const.

$\sigma = 5.67 \times 10^{-8}\ W/m^2 K^4$

For non black body

$$\frac{E}{E_b} = \varepsilon \qquad \text{——— (2)}$$

$$E = \varepsilon . E_b \qquad \text{——— (3)}$$

Combining eqn (1) & (3)

$$\boxed{E = \varepsilon . \sigma . T^4}$$

'ε' emissivity of non-black body.

planck's law:

$$E_{b\lambda} = \frac{2\pi h c^2 \lambda^{-5}}{\exp(hc/\lambda K_B T)^{-1}}$$

$$= \frac{K_1 \lambda^{-5}}{\exp(K_2/\lambda T)^{-1}}$$

where,

$E_{b\lambda}$ - Emissive power

T - Absolute Temp

h - planck's Const

K_B - Boltzman const.

c - velocity of light

$K_1 = 2\pi c^2 h$ & $K_2 = hc/K_B$.

Monochromatic emissive power $E_{b\lambda}$ can be defined as the "Amount of radiant energy emitted by a surface per unit area per unit time & per unit wavelength". This is known as planck's law or planck's Distribution.

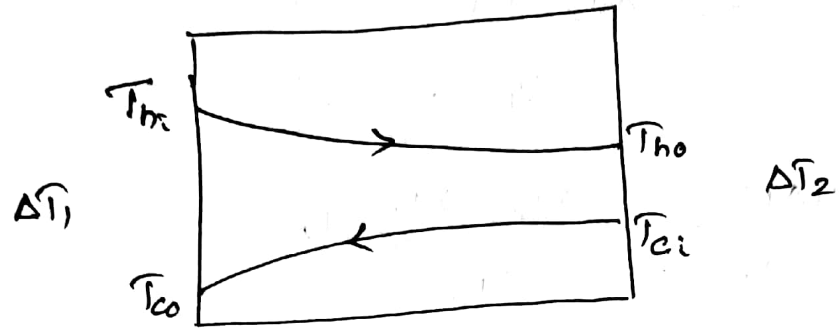
Wein's Displacement Law:

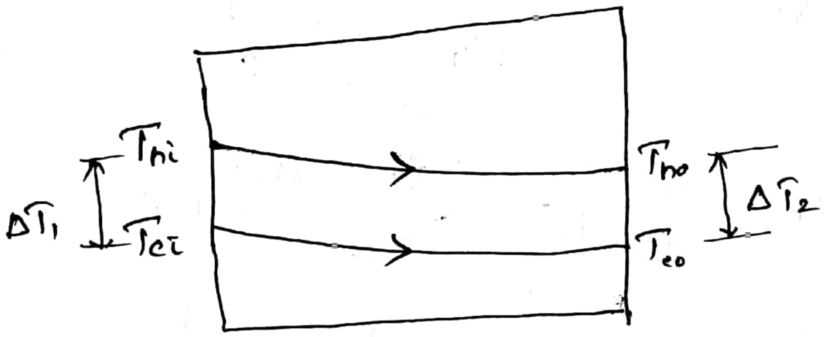
Wein's displacement law can be deduced from planck's law that the max wavelength λ_{max} corresponding to the peak of the λ Vs $E_{b\lambda}$ plot is inversely proportional to the Temp of black body.

$\lambda_{max} T = \text{Const} = 2898\ \mu m\ K$

This is called Wein's Displacement law.

Derive an expression for LMTD





where.

T_{hi} - Temp of hot fluid in (K)

T_{ci} - Temp of cold fluid in (K)

T_{ho} - Temp of hot leaving (K)

T_{co} - Temp of cold leaving (K).

$$\frac{dQ}{dA} = U(\Delta T)$$

$$= U(T_h - T_c)$$

U - overall HT coeff.

$$\text{Slope} = \frac{d(\Delta T)}{dQ}$$

$$= \frac{\Delta T_2 - \Delta T_1}{Q_T}$$

$$\frac{d(\Delta T)}{U \Delta T} = \frac{\Delta T_2 - \Delta T_1}{Q_T} \cdot dA$$

$$\int_{\Delta T_1}^{\Delta T_2} \frac{d(\Delta T)}{\Delta T} = \frac{(\Delta T_2 - \Delta T_1)\, U}{Q_T} \int_0^A dA$$

$$\ln\left[\frac{\Delta T_2}{\Delta T_1}\right] = \frac{(\Delta T_2 - \Delta T_1)}{Q_T} UA$$

For parallel flow/ cocurrent flow.

$$\boxed{Q_T = UA \frac{(\Delta T_2 - \Delta T_1)}{\ln(\Delta T_2/\Delta T_1)}}$$

$$\Delta T_1 = T_{hb} - T_{ca} \; ; \; \Delta T_2 = T_{ha} - T_{cb}$$

After rearranging

Finally

For counter current flow

$$\boxed{U_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}}$$

For cocurrent

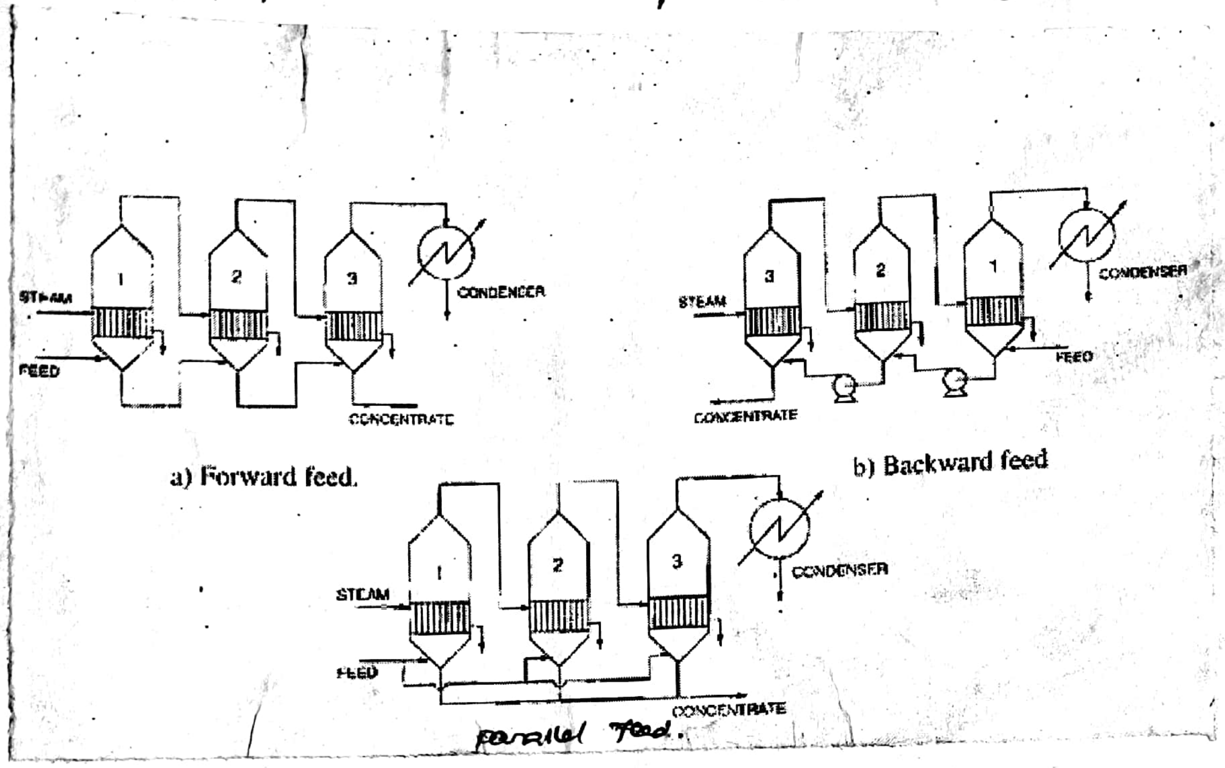
for parallel flow

$Q = U$

④

Forward & Backward Feed

Multiple effect evaporator arrangement.



a) Forward feed.

b) Backward feed

Parallel feed.

Forward feed:

* Operation is simple
* It does not require intermediate pumps for transfer from one effect to the next, the liquid flows automatically because the pressure difference in the next effect is lower
* It is suitable, if the feed solution is hot
* Low steam economy.

Backward feed.

* The backward feed technique offers some advantages over the forward feed arrangement, although at higher capital & capital operating cost because of intermediate pumping

* This is suitable, if the final thick liquor is highly viscous but not very heat sensitive.

* This method is suitable, if the feed solution is cold.

✓ Inter effect pumps are necessary

✓ Higher risk of damage of the viscous product subjected to a higher temperature.

✓ Risk of fouling.

Advantages of circulation evaporator

- They are simple, easy and cheap to construct
- They are easy to use and clean
- stirring of the evaporating liquids can be done easily
- Relatively inexpensive
- As scaling occurs inside the tubes, it can be easily removed by mechanical or chemical means.
- provides moderately good heat transfer at a reasonable cost.
- High heat transfer coefficients
- Requires low head room.
- Can be put into more rigorous services than horizontal tube evaporator.

② A Tripple-effect evaporator is concentrating a solution that has no appreciable boiling point elevation. The temp. of steam to the first effect is 381.1 K (108.3°C) and the boiling points of the solution in the last effect is 324.7 K (51.7°C). The overall heat transfer coeff in the first, second and third effect are 2800, 2200 and 1100 W/m²K respectively. At what temperature will the solution boil in the first and second effects.

Solution

Total Temp drop = ΔT

$= 381.3 - 324.7$

$= 56.6\ K$

$$\Delta T = \Delta T_1 \left[1 + U_1/U_2 + U_1/U_3\right]$$

$$56.6 = \Delta T_1 \left[1 + (2800/2200)(2800/1100)\right]$$

$$\boxed{\Delta T_1 = 11.75 K}$$

$$\Delta T = \Delta T_2 \left[1 + U_2/U_1 + U_2/U_3\right]$$

$$56.6 = \Delta T_2 \left[1 + (2200/2800) + (2200/1100)\right]$$

$$\boxed{\Delta T_2 = 14.95 K}$$

$\therefore \quad \Delta T_3 = 56.6 - [11.75 + 14.95]$

$\boxed{\Delta T_3 = 29.9 \text{ K}}$

$\Delta T_1 = T_s - T_1$

$T_1 = 381.3 - 11.75$

$\boxed{T_1 = 369.55 \text{ K}}$

$= 96.55°C$

$\Delta T_2 = T_1 - T_2$

$T_2 = 369.55 - 14.95$

$= 354.6 - 14.95$

$T_2 = 354.6 \quad [81.6°C]$

Bp in the first effect 369.5 K 96.55°C

Bp in the second effect 354.6 K 81.6°C

(5) An aqueous solution of a high molecular weight is concentrated from 5% to 40% at the rate of 100 m^3/day. The feed temperature is 25°C and the concentrated product leaves as its boiling point. Calculate the rate at which heat must be supplied if evaporation occurs at

1. 1 atmospheric pressure
2. A vaccum of 650 mm Hg. What advantage of this operation under vaccum is apparent from the answers?

Given: Density of feed = 1020 kg/m^3
Specific heat of feed = 4.1 kJ/kg°C
and the sp. heat of the product = 3.9 kJ/kg°C.

Given Data:

$$x_f = 5\% = 0.05$$

$$x_p = 40\% = 0.4$$

$$F = 100\ m^3/day$$

$$T_f = 25°C$$

$$\rho_f = 1020\ kg/m^3$$

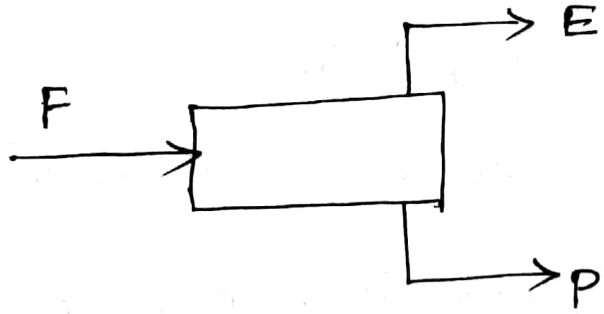
$$C_{pf} = 4.1\ kJ/kg°C$$

$$C_{pp} = 3.9\ kJ/kg°C$$

To find:

$Q = ?$ @ $p =$ Atm. pressure

$Q = ?$ @ $p = 650$ mm Hg.



Overall material Balance

$F = E + P$

$F = 100\ m^3/day$

$F = 100\ m^3/day \times \rho_f$

$= 100\ m^3/day \times 1020\ kg/m^3$

$= \frac{102000}{24}$

$= 4250\ kg/hr$

Solute Balance

$F x_F = P \cdot x_P$

$4250 \times 0.05 = P \times 0.4$

$P = 531.25\ kg/hr$

$E = F - P$

$= 4250 - 531.25$

$E = 3718.75\ kg/hr$

$Q = F C_{pf} (T - T_f) + E \lambda_v$

T_f - Boiling of water @ atm. pr. = 373 K

Latent heat of vaporization @ atm. pr. 2257

$$Q = \frac{4250}{3600} \times 4.1 \times 10^{-3} [373 - 298] + \frac{3718.75}{3600} \times 2257$$

$$= 1.18 \times 4.1 \times 10^{-3} (75) + 1.03 \times 2257 \times 10^{3}$$

$Q = 2687560$ W

③ An evaporator operating at atmospheric pressure (101.325 kPa) is fed at the rate of 10000 kg/h of weak liquor containing 4% caustic soda. Thick liquor leaving the evaporator contains 25% caustic soda. Find the capacity of the evaporator.

<u>Solution</u>

<u>Basis</u>

10,000 kg/h of weak liquor entering

Let 'm' be the kg/h of thick liquor leaving.

Material Balance of caustic soda.

Caustic soda in the Feed = Caustic soda in the thick liquor

$$0.04 \times 10000 = 0.25 \times m$$

$$\boxed{m = 1600 \text{ kg/h}}$$

Overall Material Balance

kg/h of Feed = kg/h water evaporated + kg/h of thick liquor

10000 = kg/h water evaporated + 1600

Water evaporated = 10000 − 1600

= 8400 kg/h

capacity of the evaporator = 8400 kg/h.