Ex-3 Standard Vertical Short Tube Evaporator

35,000 kg/hr of an aqueous feed containing 1% dissolved solids is to be concentrated to 20% solids, in a single effect evaporator. The feed enters at 25^{o}C. The steam chest is fed with saturated steam at 110^{o}C. The absolute pressure maintained in the evaporator is such that the water will boil at 55^{o}C. The boiling point elevation for the boiling solution (20% solids) is 15^{o}C over that of water. Specific heat of feed solution can be taken as that of water.

From steam tables, the following data were taken:

Latent heat of vaporization of water at 55^{o}C is 2370.8 kJ/kg. Specific heat of water vapor in the temperature range of 55 to 90^{o}C can be assumed to be constant at 1.871 kJ/kg.^{o}C. Latent heat of steam at 110^{o}C is 2230 kJ/kg.

The overall heat transfer coefficient, under normal operating conditions would be 2500 W/m^{2}.^{o}C.

A vertical short-tube evaporator with the following specifications is available. Check whether it is suitable for the above duty.

Tubes:
OD: 100 mm, thickness: 1.5 mm
pitch: triangular, 125 mm
length: 1220 mm
number of tubes: 626

Downtake:
Inner diameter: 1500 mm
Outer diameter: 1520 mm

Tubesheet: Diameter: 3710 mm; Thickness: 36 mm

Vapor drum: Height: 3000 mm; ID of shell: 3400 mm; Thickness: 12 mm; Dished end closure;

Calandria: Thickness: 12 mm; ID of shell: 3400 mm

Draw to scale the sectional elevation and tube layout of **Standard vertical short tube evaporator (Calandria Evaporator)** with the above specifications:

Calculations:

Let us have the following notations:

Feed: F

Concentrated product: P

Water vapor: V

Steam: S

Mass balance:

Solid balance:

F x 0.01 = P x 0.2

P = 35000 x 0.01 / 0.2 = 1750 kg/hr

V = F - P = 35000 - 1750 = 33250 kg/hr

Energy balance:

Temperature of Water vapor, leaving from the evaporator

= 55^{o}C + Boiling point elevation = 55^{o}C + 15^{o}C = 70^{o}C

Enthalpy balance:

Reference temperature = Boiling point of solution (70^{o}C)

Enthalpy of feed + Latent heat of steam = Enthalpy of vapor + Enthalpy of product solution

$F\,H_F + S\,\lambda_S = V\,(\lambda_v + C_p(70\text{-}55)) + P\,H_P$

35000 x 4.184 x (25-70) + S x 2230 = 33250 x (2370.8 + 1.871 x (70-55)) + 0

-6,589,800 + 2230 S = 79,762,261

S = 38722.9 kg/hr

Steam requirement = 38722.9 kg/hr = 10.756 kg/sec

Heat transfer area estimation:

Q = Rate of heat transfer through heating surface from steam = U A ΔT

i.e.,

$S \lambda_S = U A \Delta T$

$10.756 \times 2230 = 2.5 \times A \times (110 - 70)$

$A = 239.8\ m^2$

Heat transfer area required = 239.8m²

Available heat transfer area = $n \pi d L = 626 \times \pi \times 0.1 \times 1.22$ = **$239.9\ m^2$**.

Hence the design is satisfactory.