EVALUATION ON THE COURSE "TWO-PHASE FLOWS WITH PHASE CHANGE"

WEDNESDAY FEBRUARY 1ST, 2023

Vertical evaporator for cooling electronic devices

Refrigerant R134a at a pressure of 10 Bars enters a tube of 4mm diameter at a temperature of 30°C and a pressure of 10 bars. The tube is heated by the thermal dissipation of electronic component with a constant heat flux of $1 W/cm^2$.
The mass flux G is equal to 200 $kg/m^2/s$.
The physical properties of R134a at saturation temperature Tsat=39.4°C at 10 bars are:
- densities of liquid and vapour : ρ_l=1147.6 kg/m^3, ρ_v=48.8 kg/m^3
- dynamic viscosities of liquid and vapour : μ_l=1.64 10^{-4} Pa.s, μ_v=12.5 10^{-6} Pa.s,
- latent heat of vaporisation h_{LV}=163230 J/kg,
- heat capacity at constant pressure for liquid C_{pl}=1497 J/kg/K,
- surface tension σ=6.1 10^{-3} N/m,
- thermal conductivity for liquid λ=0.074 W/m/K,
- Prandtl number Pr=3.28.

1°/ The flow enters in single-phase liquid regime at T_{le}=30°C in the evaporator. Calculate the evolution of the liquid temperature $T_L(z)$ and the wall temperature $T_P(z)$ as a function of the vertical position z (z=0 at the entrance) by using Dittus-Boelter correlation for the heat transfer coefficient in single-phase flow H_l:

$$Nu = \frac{H_l D}{\lambda} = 0,023\left(\frac{GD}{\mu_l}\right)^{0,8} Pr^{1/3}$$

2°/ Calculate the value of $z=z_{sat}$ at which the mean liquid temperature will be equal to the saturation temperature $T_L(z_{sat})=T_{sat}$. Justify that for $z=z_{sat}$, the onset of nucleate boiling is reached by using Frost and Dzakowic correlation :

$$T_p - T_{sat} > \left[\frac{8\sigma T_{sat} q}{\lambda \varrho_v h_{lv}}\right]^{1/2} \frac{1}{Pr}$$

3°/ For $z > z_{sat}$, express the quality x versus z. Calculate the values of the superficial velocities of liquid j_L and gas j_V for z=0.3 m, z=0.6 m. By using the flow pattern map (Figure 1) determine the flow pattern at the different locations. At which z value, the flow becomes pure vapor.

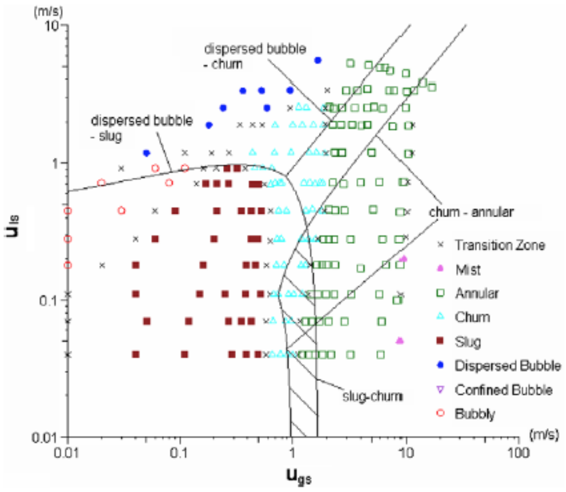

Figure 1 : Flow pattern map for R134a at 10bar in a 4 mm diameter tube according to Chen and Karayannis (2006)

4°/ At z=0.3m and z=0.6 m, determine the wall temperature using Gunger et Winterton correlation :

$$H = H_l\left[1 + 3000\left(\frac{q}{Gh_{lv}}\right)^{0.86} + \left(\frac{x}{1-x}\right)^{3/4}\left(\frac{\rho_l}{\rho_v}\right)^{0.41}\right] \text{ with } H_l = \frac{\lambda}{D}0.023\left(\frac{G(1-x)D}{\mu_l}\right)^{0.8} Pr^{1/3}$$

Plot the evolution of the wall temperature and the liquid temperature. Comment the result.

5°/ Evaluate the void fraction at z=0.3m and z=0.6m using relevant drift flux models, that will be justified:

$$U_v = \frac{j_V}{R_V} = C_0(j_V + j_L) + U_\infty$$

6°/ Using the momentum balance equation for the mixture, evaluate the pressure difference between z=0 and z=0.6 m. Explain the physical meaning of the different terms.

$$\frac{d}{dz}\left[\frac{G^2x^2}{\rho_v R_v} + \frac{G^2(1-x)^2}{\rho_l R_l}\right] = -\frac{dp}{dz} + \frac{\tau_p 4}{D} - \left(\rho_l R_l + \rho_v R_v\right)g$$

The terms will be first calculated for $z<z_{sat}$ in single-phase flow. For $z>z_{sat}$, the hydrostatic pressure gradient will be evaluated using an average value of the void fraction between z=0.3m and z=0.6m. The frictional pressure gradient will be calculated either at z=0.3m or z=0.6m, using Lockhart and Martinelli model.