TD4 : TWO-PHASE FLOW WITH PHASE CHANGE

VERTICAL EVAPORATOR

In a vertical cylindrical evaporator of diameter D= 5mm, liquid refrigerant R134a is flowing at a pressure of 10 bars. The wall temperature is constant and equal to 58°C.

In the saturation conditions at 10 bars, corresponding to a saturation temperature T_{sat} equal to 40°C, the physical properties of the refrigerant are:

- liquid density ρ_l=1147,6 kg/m^3
- vapour density ρ_v=49.802 kg/m^3
- liquid dynamic viscosity μ_l=1,64.10^{-4} Pa.s
- vapour dynamic viscosity μ_v=1,25.10^{-5} Pa.s
- surface tension σ=0.0061 N/m
- latent heat of vaporisation h_{lv}=255,7 kJ/kg
- liquid thermal conductivity λ=0,07479 W/m/K
- liquid heat capacitance C_P=1497 J/kg/K

1) Liquid enters at the tube bottom z=0 with a mass flow rate $\dot{m}$=15g/s at saturation temperature. Boiling immediately starts. The heat transfer coefficient H will be calculated using Schrock and Grossman correlation, based on a convective heat transfer coefficient H_L and the Martinelli parameter X:

$$H = 7390 H_L \left[\frac{q}{G h_{lv}} + 0{,}00015 \frac{1}{X^{0{,}66}} \right] \qquad \text{avec} \qquad q = H\left(T_P - T_{sat}\right) \quad \text{et} \quad G = \frac{4\dot{m}}{\pi D^2}$$

$$H_L = \frac{\lambda}{D} 0{,}023 \left(\frac{G(1-x)D}{\mu_l} \right)^{0{,}8} Pr^{1/3} \qquad \text{et} \qquad X = \left(\frac{1-x}{x} \right)^{0{,}875} \sqrt{\frac{\rho_v}{\rho_l}} \left(\frac{\mu_l}{\mu_v} \right)^{0{,}125}$$

With the previous equations, estimate the heat transfer coefficient H and the wall heat flux q for the following quality values: x=0.2 x=0.3 x=0.4 x=0.6 and x=0.8. Fit the numerical values of the heat flux with a first order polynomia versus x. Compare to the proposed expression q= -348767x + 316408.

2) Give an analytical expression of the quality x versus z distance from the entrance of the evaporator. Calculate the superficial velocities of liquid and vapour j_L and j_v, and identify the flow pattern from the following flow pattern map.

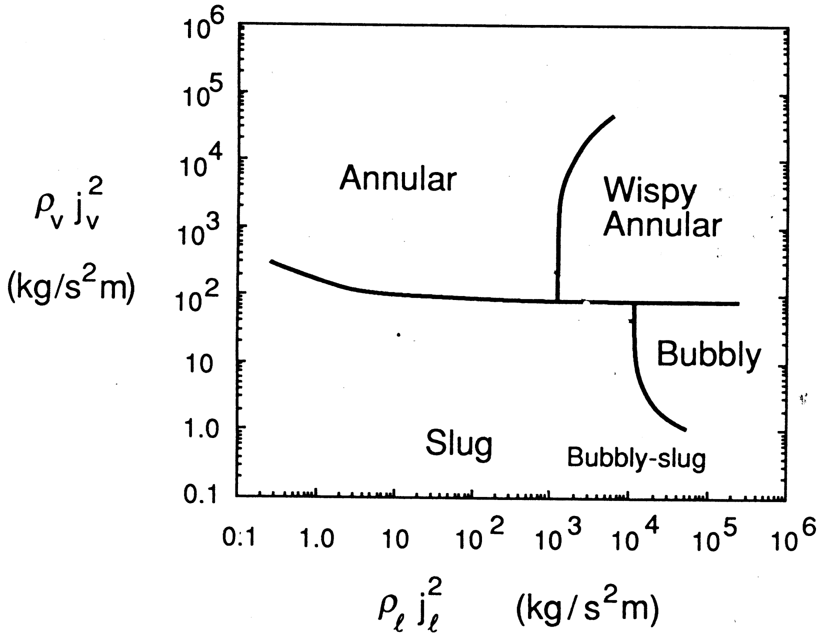

Figure 1 : Flow pattern map of a boiling flow of refrigerant

3) In annular flow regime without droplet entrainment, write an equation to calculate the evolution of the mean void fraction R_{GI} along the tube. The expression obtained in question 2 for x can be used to calculate dx/dz. A value of 0.005 is taken for the wall and interfacial friction factors f_p and f_i. This equation can be solved numerically. The values of R_{GI} versus the quality x are plotted in figure 2. Plot the evolution of the liquid film δ in fonction of z.

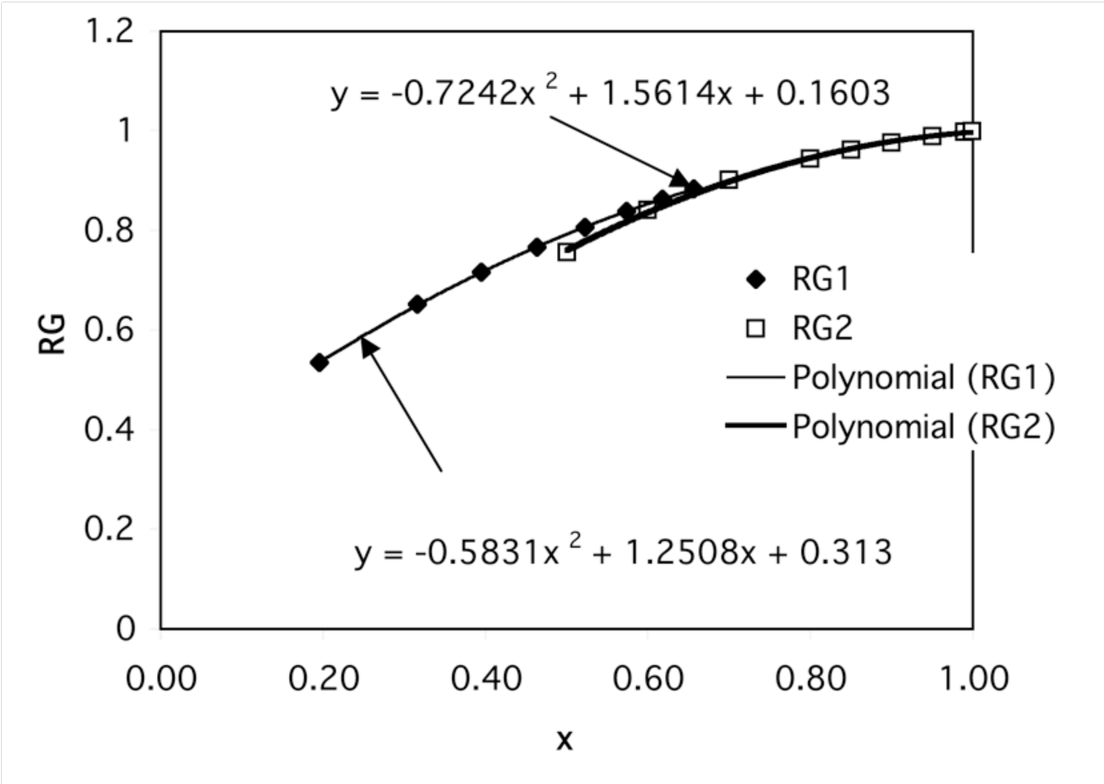

Figure 2 : Numerical resolution of the equations $f(R_G,x)=0$

4) When the liquid film becomes thin enough, the flow in the film is laminar ($Re_L=U_l\delta\rho_l/\mu_l < 2000$). Write an equation to calculate the evolution of the quality x versus δ, D, λ, T_p-T_{sat}, G and h_{lv}. Consider heat transfer by conduction only through the liquid film. As in the previous question, write an equation to calculate the void fraction R_{G2} versus x. Propose an algorithm to calculate R_{G2} versus z. Figure 2 gives the evoluation of R_{G2} versus x. Thanks to this figure, plot an evolution of the liquid film thickness versus z. At which value of z is it reasonnable to use this model?

5) Determine the value of z for which a pure vapour flow is observed.

6) Express the pressure difference between the tube inlet (z=0) and the tube outlet (z=4m). Calculate its value and the contribution of the different terms.