ME-446 Liquid-Gas Interfacial Heat and Mass Transfer

Homework 8

Presentation by Group 8 on Thursday 13th November

Problem 1: Maxima of number of isolated bubbles

In *International Journal of Heat and Mass Transfer 182 (2022) 121904*, Zhang et al gave an expression for the number of isolated bubbles on a surface:

$$N_{iso} = \sum_{N=1}^{\infty} \frac{N_0^N}{(N-1)!} e^{-\left(N_0 + \frac{\pi N D_b^2}{A}\right)}$$

where N_0 is the expectation value of the number of active nucleation sites on the surface, A is the surface area, and D_b is the diameter when departing from the surface. Assume the critical heat flux (CHF) is reached when $\frac{\partial N_{iso}}{\partial T} = 0$ and N_0 is the only parameter on the right-hand side that is a function of temperature T.

A) Prove that the following is true at CHF,

$$n_0 \pi D_b^2 = 1$$

where n_0 is the expected active nucleation site density at CHF or $n_0 = N_0/A$ at CHF.

B) Show that at CHF,

$$N_{iso} = \frac{N_0}{e}$$

Problem 2: Kandlikar Model

Kandlikar expression for the critical heat flux of pool boiling at an upward-facing horizontal heated large surface is given by:

$$q_c'' = h_{fg} \rho_g^{\frac{1}{2}} \left(\frac{1 + \cos\beta}{16} \right) \left[\frac{2}{\pi} + \frac{\pi}{4}(1 + \cos\beta) \right]^{\frac{1}{2}} \left[\sigma g (\rho_l - \rho_v) \right]^{\frac{1}{4}}$$

Plot the CHF prediction for contact angles β between 5° and 50° using water properties at atmospheric pressure.

Problem 3: Bubble coalescence

Consider two bubbles, both with radius r, initially isolated, with contact angle = 0°. If they merge into a bigger spherical bubble while conserving the volume (also with contact angle = 0°). Calculate the surface energy change of the system, assuming the liquid-bubble interface has a surface tension of γ.

Problem 4: Monte-Carlo simulation of spatial distribution of nucleation sites

Write a Monte Carlo code to simulate the spatial distribution of nucleation sites.

1. Define a 1 cm $\times$ 1 cm plate.
2. Randomly select 100 points on this plate as active nucleation sites.

A) Plot the histogram for the probability density distribution of the nearest-neighbor distance among active nucleation sites.

B) What functional form do you expect for this distribution? How well does the expected form align with your simulation data, and why?

C) Repeat the same analysis for a cylindrical surface with radius 0.5 cm and height 1 cm instead of the flat plate. Answer the same questions (a) and (b) for this configuration.