22.313J, 2.59J, 10.536J THERMAL-HYDRAULICS IN POWER TECHNOLOGY

Homework Set 4

Pool Boiling in a Stainless Steel Kettle

You are to analyze the pool boiling characteristics of water at atmospheric pressure in a kettle for making coffee or tea. The heated surface is horizontal and made of stainless steel. The contact angle for water on stainless steel, θ, is 60 degrees in the temperature range of interest. The saturation properties of water at 0.1 MPa are reported in Table 1.

Bubble nucleation at a small re-entrant cavity

Consider the active cylindrical re-entrant cavity ($r_c = 1$ μm) shown in Figure 1.

    i)   First assume that the system is at room temperature, i.e., 20°C. This is the situation in Figure 1(A). Calculate the distance x from the edge of the cavity neck. (The vapor pressure and the surface tension at 20°C are 2.34 kPa and 0.073 N/m, respectively)

    ii)   Calculate the superheat required for the bubble to rise to the cavity mouth (Figure 1(B)).

    iii)   Calculate the critical superheat for the cavity, i.e., the minimum superheat needed for the bubble to grow out of the cavity.

    iv)   Estimate the bubble diameter at departure.

    v)   Estimate the growth period. (*Hint*: use the solution to the bubble growth equation)
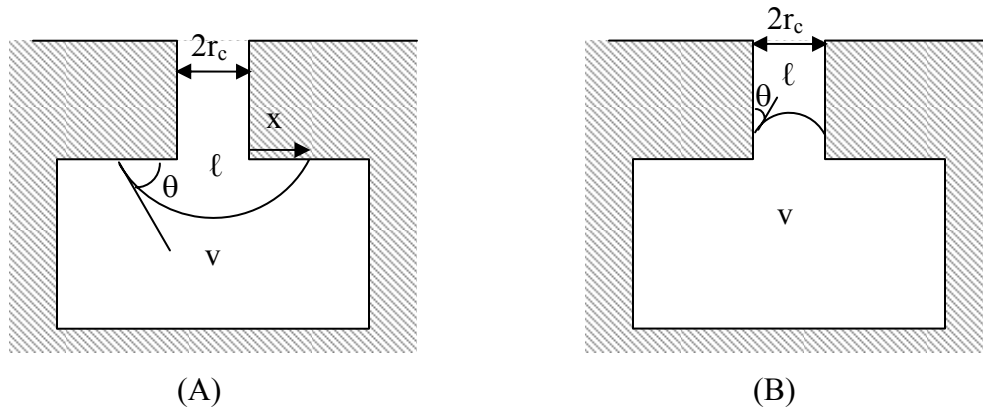
    vi)   Estimate the departure frequency.

(A)   (B)

Figure 1. Re-entrant cavity

Construction of the boiling curve

vii)   Draw the boiling curve for the kettle. Include all regimes discussed in class, i.e., natural convection, nucleate boiling, transition boiling and film boiling. (*Simplifying assumption:* in calculating the film boiling heat transfer coefficient, use saturation properties for both liquid and vapor, and a value of 0.8 for the thermal emissivity of the heated surface)

viii) Find the wall superheat at the onset of nucleate boiling (i.e., the intersection of the natural convection and nucleate boiling curves), and compare it with the result in 'iii' above. Is there a significant discrepancy? If so, explain why.

Table 1. Properties of saturated water at 0.1 MPa.

Parameter	Value
T_{sat}	373 K (100°C)
ρ_f	958 kg/m^3
ρ_g	0.6 kg/m^3
β	7.8×10^{-4} 1/K
h_f	419 kJ/kg
h_g	2,676 kJ/kg
$C_{p,f}$	4.2 kJ/(kg°C)
$C_{p,g}$	2.0 kJ/(kg°C)
μ_f	2.8×10^{-4} Pa·s
μ_g	1.2×10^{-5} Pa·s
k_f	0.681 W/(m°C)
k_g	0.025 W/(m°C)
σ	0.059 N/m
Molecular weight	0.018 kg/mol

Stefan-Boltzmann constant for radiative heat transfer: $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4