INDIAN INSTITUTE of TECHNOLOGY PATNA

Department of Mechanical Engineering

ME546: Multiphase Flow and Heat Transfer

Quiz 03 **Date: 15th of February, 2017**

Problem statement: Estimate the critical heat flux for pool boiling from a 13 mm square stainless steel surface facing upward in a pool of saturated liquid water at atmospheric pressure. Assuming that the nucleate boiling correlation applies up to the critical heat flux condition, estimate the temperature of the heated surface at the maximum heat flux ($C_{sf} = 0.013$). How are the results compare with different correlations.

Useful data

$$\frac{q''_{max}}{q''_{max,Z}} = f(L/L_b)$$

$$q''_{\mathrm{max,Z}} = 0.131 h_{lv} \rho_v \left[\frac{\sigma(\rho_l - \rho_v) g}{\rho_v^2}\right]^{1/4}$$

$$L_b \sim \left[\frac{\sigma}{g(\rho_l - \rho_v)}\right]^{\frac{1}{2}} = \frac{\lambda_D}{2\pi\sqrt{3}}$$

Table 1 Correlations for the critical heat flux

Geometry	Correlation	Range of applicability	R
Infinite heated flat plate	$\frac{q''_{\max}}{q''_{\max,Z}} = 1.14$	$\frac{L}{L_b} > 30$	
Small heater of width or diameter L with vertical side walls	$\frac{q''_{\max}}{q''_{\max,Z}} = \frac{1.14\lambda_D^2}{A_{\text{heater}}}$	$9 < \frac{L}{L_b} < 20$	
Horizontal cylinder of radius R	$\frac{q''_{\max}}{q''_{\max,Z}} = 0.89 + 2.27\exp\left\{-3.44\sqrt{\frac{R}{L_b}}\right\}$	$\frac{R}{L_b} \geq 0.15$	
Large horizontal cylinder of radius R	$\frac{q''_{\max}}{q''_{\max,Z}} = 0.90$	$\frac{R}{L_b} > 1.2$	
Small horizontal cylinder of radius R	$\frac{q''_{\max}}{q''_{\max,Z}} = 0.94\left(\frac{R}{L_b}\right)^{-1/4}$	$0.15 \leq \frac{R}{L_b} \leq 1.2$	
Small bluff body with characteristic dimension L	$\frac{q''_{\max}}{q''_{\max,Z}} = C_0\left(\frac{L}{L_b}\right)^{-1/2}$	Large $\frac{L}{L_b}$	

The Forster-Zuber correlation for nucleation boiling heat transfer is given as:

$$q'' = 0.00122\left(\frac{k_l^{0.79} C_{Pl}^{0.45} \rho_l^{0.49}}{\sigma^{0.5} \mu_l^{0.29} h_{lv}^{0.24} \rho_v^{0.24}}\right)\left[T_w - T_{sat}(P_l)\right]^{1.24} \Delta P_{sat}^{0.75}$$

where ΔP_{sat} is the difference in saturation pressure corresponding to a difference in saturation temperature equal to the wall superheat $T_w - T_{sat}(P_l)$. The combination of property units that work is $k_l \sim$ W/m K, $C_{Pl} \sim$ kJ/kg K, $\rho \sim$ kg/m^3, $P \sim$ Pa, $\sigma \sim$ N/m, $\mu \sim$ Ns/m^2, $h_{lv} \sim$ kJ/kg.

Saturated water properties at 101.3 kPa: $T_{sat} = 100$°C, $\rho_l = 958.63$ kg/m^3, $\rho_v = 0.597$ kg/m^3, $h_{lv} = 2256.7$ kJ/kg, $C_{Pl} = 4.22$ kJ/kg K, $\mu_l = 277.53 \times 10^{-6}$ Pa s, $k_l = 0.679$ W/m K, $\sigma = 0.05891$ N/m.

The Rohsenow's correlation for nucleation boiling heat transfer is given as:

$$\frac{C_{Pl}\Delta T_{sat}}{h_{lv}} = C_{sf}\left[\frac{q''}{\mu_l\, h_{lv}}\sqrt{\frac{\sigma}{g(\rho_l - \rho_v)}}\right]^m \left[\frac{\mu_l\, C_{Pl}}{k_l}\right]^{1+n}$$

$m = 0.33$ and $1 + n = 1$ for water.

End