Two Phase Flows

(Section 14)

VOID FRACTION AND PRESSURE DROP IN SUBCOOLED BOILING

By: Prof. M. H. Saidi

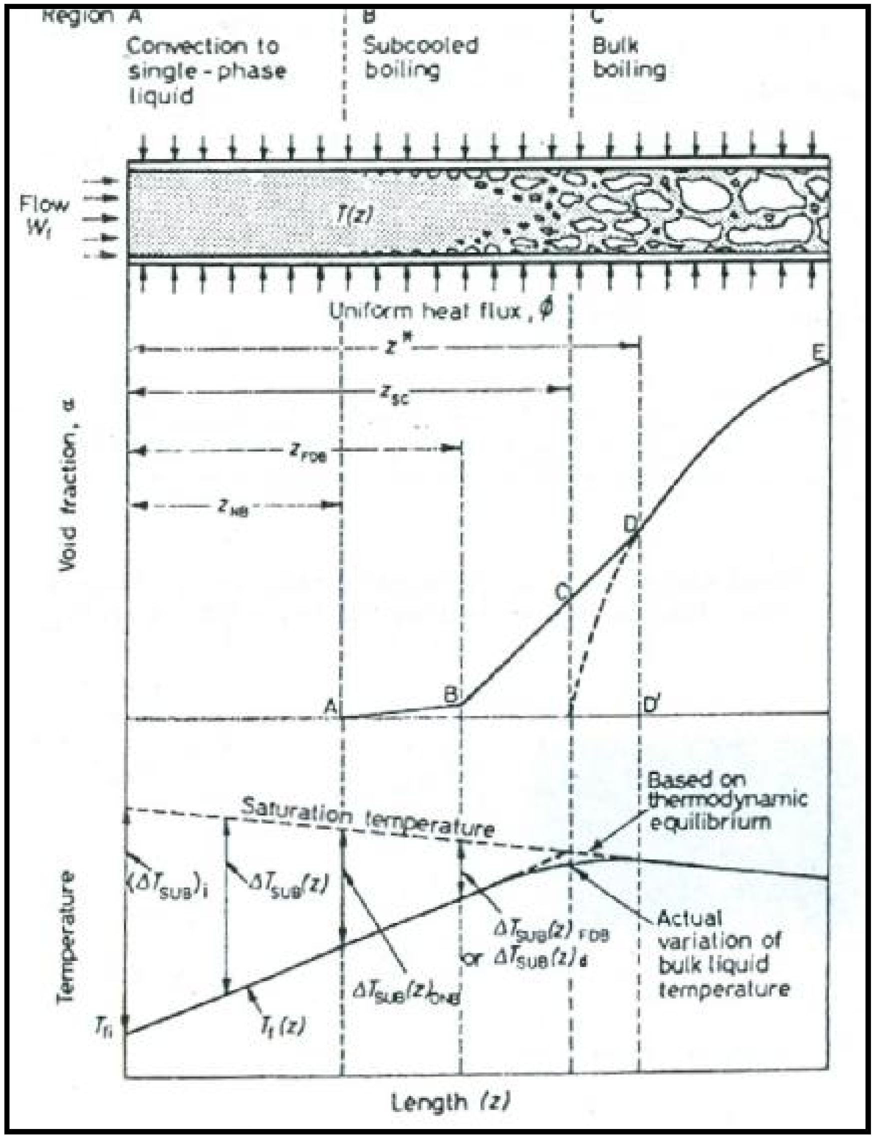
Center of Excellence in Energy Conversion

School of Mechanical Engineering

Sharif University of Technology

Sharif University of Technology

Void fraction in subcooled boiling



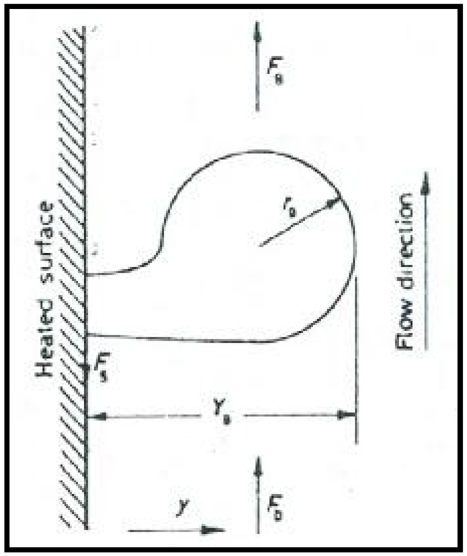
Highly subcooled region:

$$a_W = \left(\frac{P_h}{S}\right)\left(\frac{4}{3}p\,r^3\right)\left(\frac{1}{AS}\right) = \frac{16}{3}p\,\frac{r}{D_h}\left(\frac{r}{S}\right)^2$$

$$a_W \approx \left(\frac{p}{3}\right)\frac{r}{D_h} \approx \left(\frac{p}{6}\right)\frac{Y_B}{D_h}$$

$$Y_B = 0.015\left[\frac{s\,D_e}{t_W}\right]$$

Point of departure of vapor bubbles



$$\Delta T_{SUB}(z)_d = h\,\frac{f}{Gu_f}$$

$$C_B g\left(r_f - r_g\right) r_B^3 + C_F \frac{t_W}{D_e} r_B^3 - C_S r_B s = 0$$

$$Y_B = C\left[\frac{s\,D_e}{t_W}\right]^{1/2}\left[1 + C'\left(\frac{g\left(r_f - r_g\right)D_e}{t_W}\right)\right]^{-1/2}$$

$$u^* = \sqrt{\frac{t_W}{r_f}}$$

$$Y_B^+ = \left[\frac{Y_B u^* r_f}{m_f}\right] = C\frac{\left(s\,D_e r_f\right)^{1/2}}{m_f}\left[1 + C'\left(\frac{g\left(r_f - r_g\right)D_e}{t_W}\right)\right]^{-1/2}$$

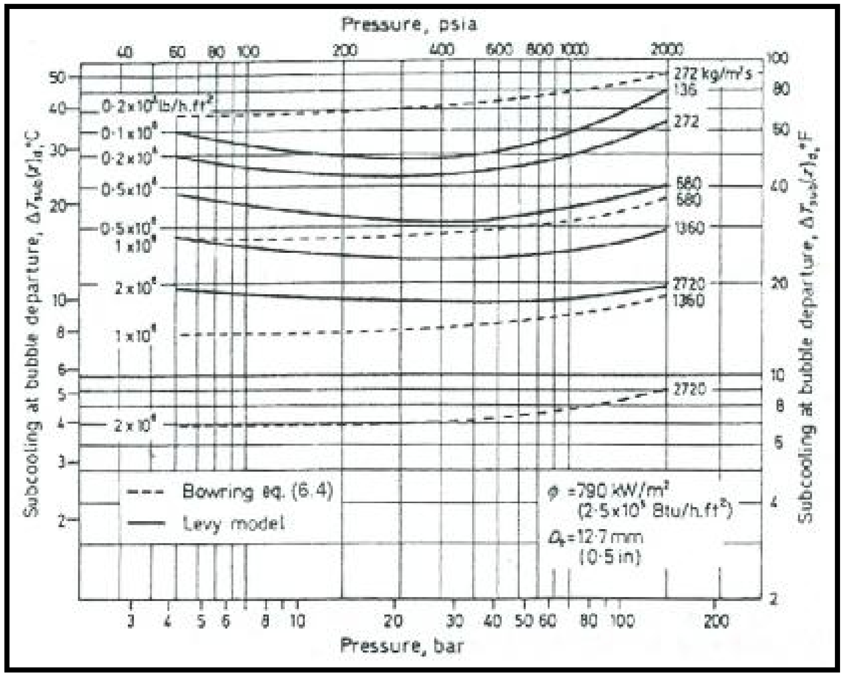
$$T_B^+ = \frac{c_{pf}\, r_f u^*}{f}\left(T_W - T_B\right)$$

Point of departure of vapor bubbles

$$
\begin{cases}
T_B^+ = \Pr_f \, Y_B^+ & 0 \le Y_B^+ \le 5 \\
T_B^+ = 5\left[\Pr_f + \ln\left(1 + \Pr_f \left\{ \dfrac{Y_B^+}{5} - 1 \right\} \right) \right] & 5 \le Y_B^+ \le 30 \\
T_B^+ = 5\left[\Pr_f + \ln\left(1 + 5\Pr_f \right) + 0.5 \ln\left\{ \dfrac{Y_B^+}{30} \right\} \right] & Y_B^+ \ge 30
\end{cases}
$$

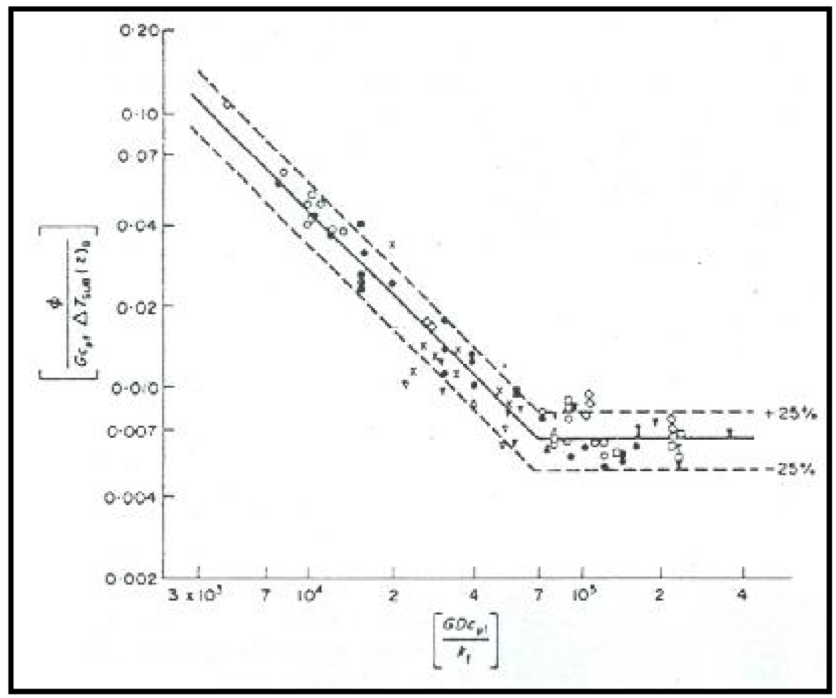
$$
\Delta T_{SUB}(z)_d = f\left[\frac{1}{h_{fo}} - \frac{T_B^+}{c_{pf}\, r_f\, u^*} \right]
$$

Void fraction in subcooled boiling



$$\Delta T_{SUB}(z)_B = 153.8\left[\frac{f}{Gc_{pf}}\right]$$

$$\Delta T_{SUB}(z)_B = 0.0022\left[\frac{fD}{k_f}\right]$$



Low subcooling region

$$z_d = \frac{G c_{pf} D}{4}\left[\frac{\left(\Delta T_{SUB}\right)_i}{f} - \frac{h}{G u_f}\right]$$

$$f = f_e + f_a + f_{SPL}$$

$$f_{SCB} = f_e + f_a$$

$$e = \frac{f_a}{f_e} = \left(\frac{r_f}{r_g}\right)\left(\frac{c_{pf}}{i_{fg}}\right)t$$

$$e = \left[1 + \frac{v_g}{v_f}\frac{c_{pf}\Delta T_{SUB}(z)}{i_{fg}}\right]$$

$$x'(z) = \frac{4}{DGi_{fg}}\left[\frac{f - f_{SPL}}{1-e}\right](z - z_d)$$

$$\left(\frac{a_B}{1-a_B}\right) = \left(\frac{r_f}{r_g}\right)\left(\frac{4}{DGi_{fg}}\right)\left(\frac{u_f}{u_g}\right)\left(\frac{f}{1+e}\right)(z_{SC} - z_d)$$

$$\left(\frac{a_B}{1-a_B}\right) \approx \left(\frac{r_f}{r_g}\right)\left(\frac{c_{pf} h f}{Gi_{fg}\left(u_g / u_f\right)(1+e)v_f}\right)$$

Void fraction in subcooled boiling

Empirical method of Thome et al.

$$a = \frac{Mx'}{1 + x'(M-1)}$$

$$x' = \frac{i(z) - i_B'}{i_g - i_B'}$$

$$i_B' = i_f \left[1 - 0.0645 \frac{f}{G}\right]$$

$$T^* = \frac{\Delta T_{SUB}(z_0) - \Delta T_{SUB}(z)}{\Delta T_{SUB}(z_0)}$$

$$T^* = 1 - \exp(-Z^+)$$

$$T^* = \tanh Z^+$$

$$Z^+ = \frac{z - z_0}{z_{SC} - z_0}$$

$$x'(z) = \frac{c_{pf} \Delta T_{SUB}(z_0)}{i_{fg} + c_{pf} \Delta T_{SUB}(z_0)(1 - T^*)} (Z^+ - T^*)$$

$$a(z) = x'(z) \Big/ \left\{ \frac{C_0 (r_f - r_g)}{r_f} x'(z) + \left[C_0 + \frac{\overline{u}_{gj}}{u_{f0}} \right] \left(\frac{r_f}{r_g} \right)^{-1} \right\}$$