# Two Phase Flows

(Section 16)

SATURATED BOILING HEAT TRANSFER

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# Saturated forced convective boiling in a round tube

$$x(z) = \frac{4f}{DGi_{fg}}\left(z - z_{SC}\right)$$

$$x(z) = \frac{4f}{DGi_{fg}}\frac{1}{1+e}\left(z - z_{d}\right)$$

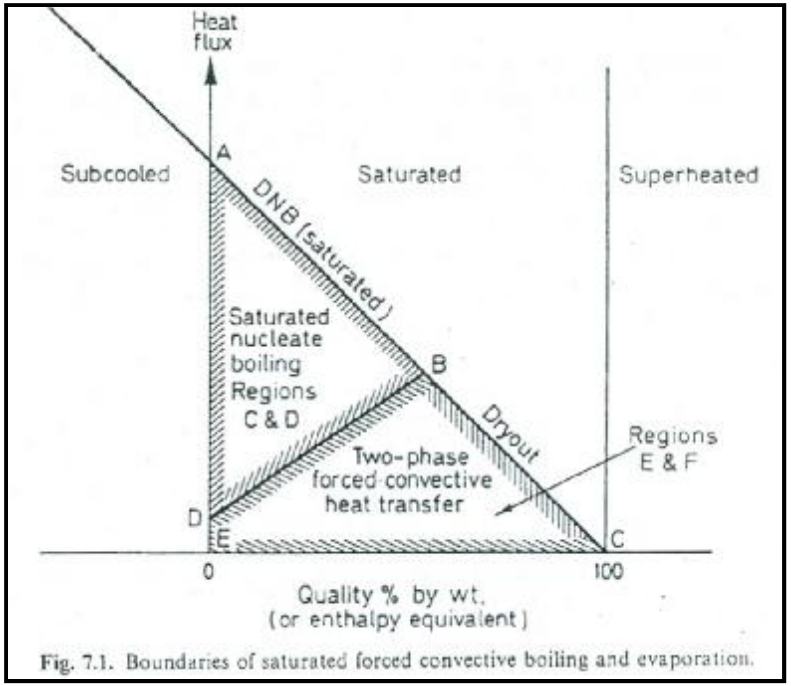


Fig. 7.1. Boundaries of saturated forced convective boiling and evaporation.

Boundaries of Saturated forced convective boiling and evaporation

# Suppression of saturated nucleate boiling

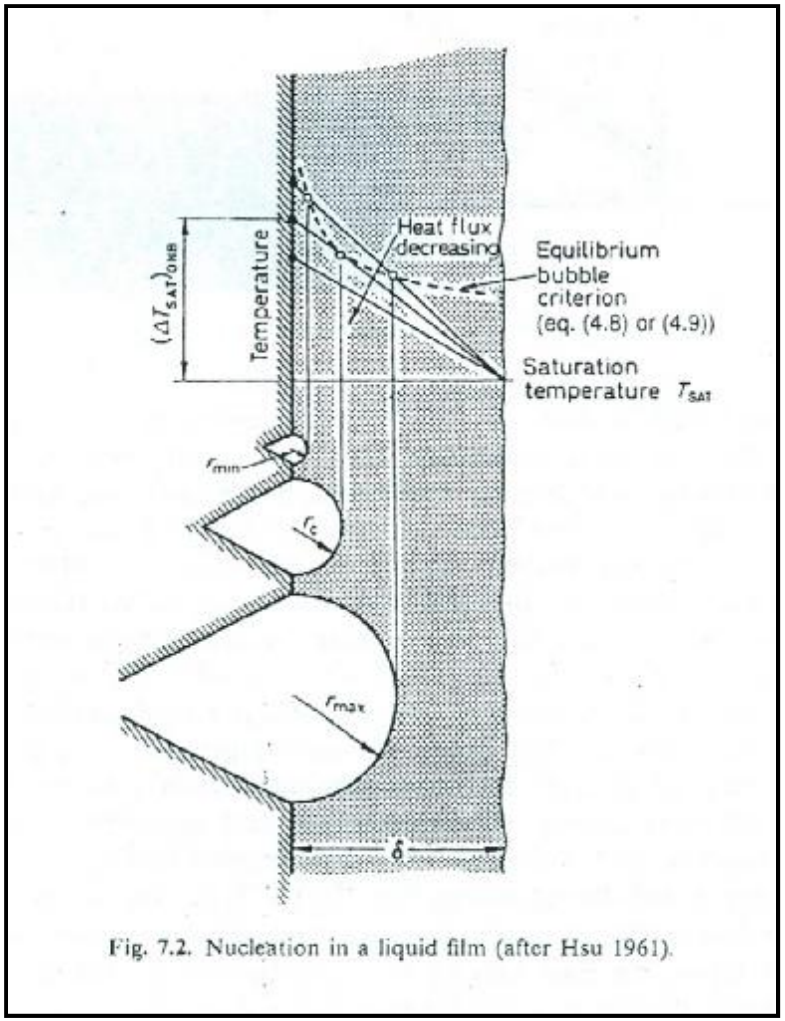



Fig. 7.2. Nucleation in a liquid film (after Hsu 1961).

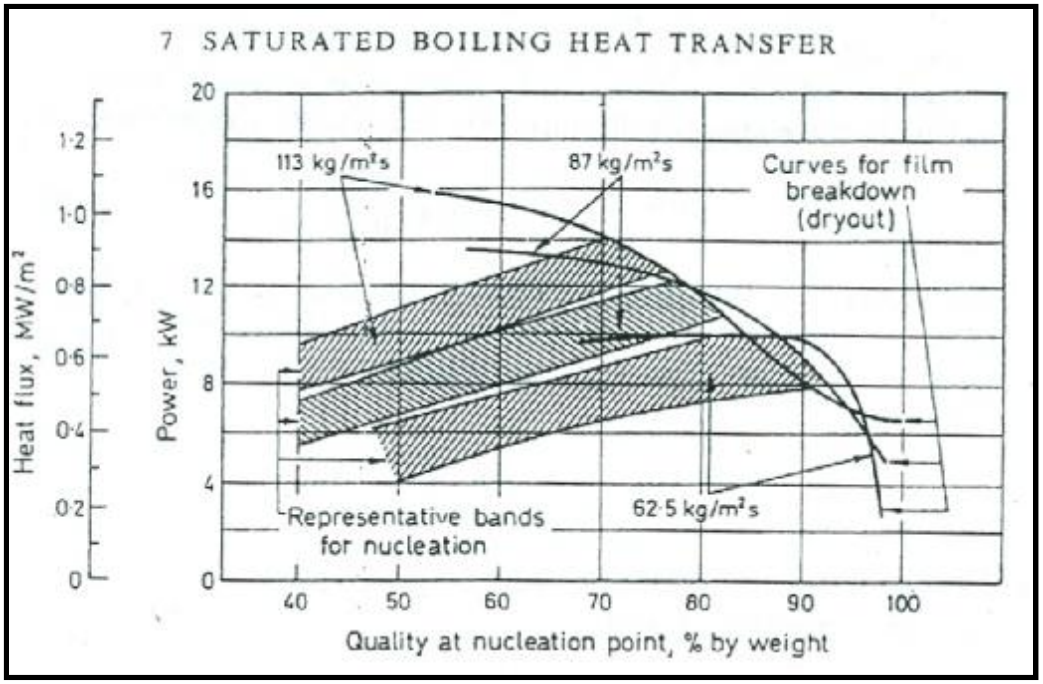
Nucleation in a liquid film

$$\frac{h_{TP}}{h_{fo}} = 3.5\left(\frac{1}{X_{tt}}\right)^{0.5}$$

$$X_{tt} = \sqrt{\frac{(dp/dz)_f}{(dp/dz)_g}} \approx \left(\frac{1-x}{x}\right)^{0.9}\left(\frac{r_g}{r_f}\right)^{0.5}\left(\frac{m_f}{m_g}\right)^{0.1}$$

$$f_{ONB} = \frac{49Bh_{fo}^2}{k_f X_{tt}}$$

$$B = \left[\frac{2s\,T_{SAT}v_{fg}}{Ji_{fg}}\right]$$




Comparison of nucleation bands and film breakdown curves

# Two-phase forced convective region

$$\frac{h_{TP}}{h_f} = \frac{D}{4d}$$

$$1-a = \frac{4d}{D}$$

$$\frac{h_{TP}}{h_f} = \frac{1}{1-a}$$

$$f = -\left(k_f + e_H r_f c_{pf}\right)\frac{dT}{dy}$$

$$1 = \left(\frac{1}{\mathrm{Pr}_f} + \frac{e_H}{m_f / r_f}\right)\frac{dT^+}{dy^+}$$

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

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

$$y^+ = \frac{u^* y r_f}{m_f}$$

$$h_{TP} = \frac{c_{pf} r_f u^*}{T^+}$$

$$Nu_f = \frac{h_{TP} d}{k_f}$$

# Chen correlation

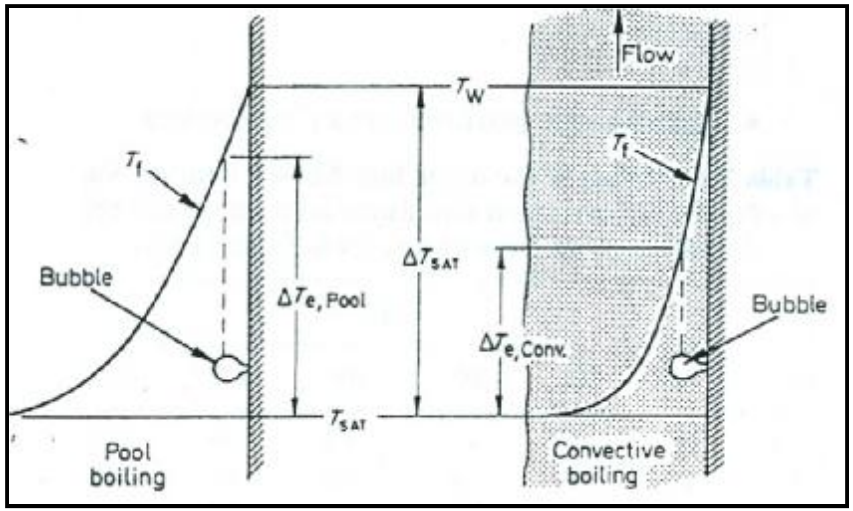
$$h_{TP} = h_{NcB} + h_c$$

$$h_c = 0.023\,\mathrm{Re}_{TP}^{0.8}\,\mathrm{Pr}_{TP}^{0.4}\,\frac{k_{TP}}{D}$$

$$F = \left[\frac{\mathrm{Re}_{TP}}{\mathrm{Re}_f}\right]^{0.8} = \left[\frac{\mathrm{Re}_{TP}}{G(1-x)D/m_f}\right]^{0.8}$$

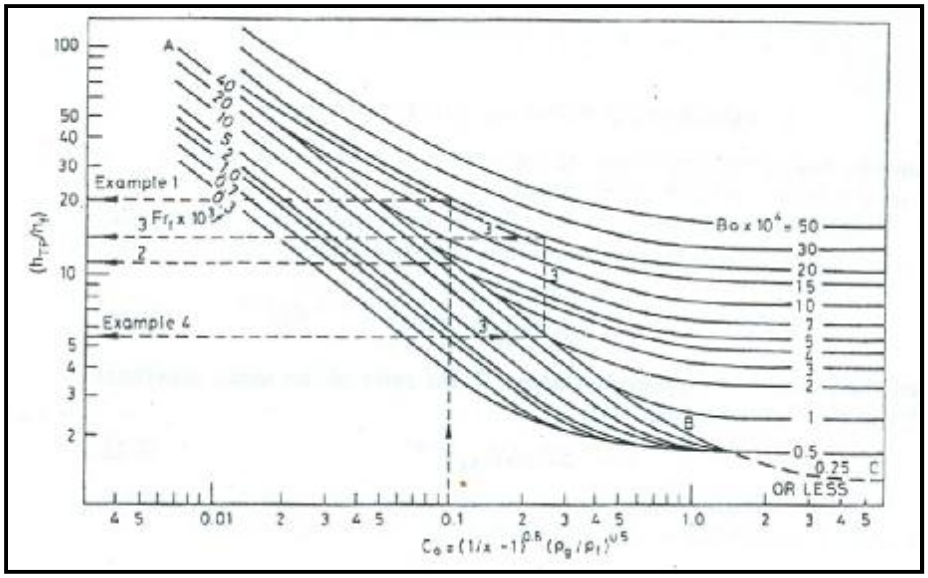
$$F = \left(f_f^2\right)^{0.444}$$

$$F = \left[\left[\frac{\mathrm{Pr}_f + 1}{2}\right] f_f^2\right]^{0.444}$$




Temperature profile for pool boiling and convective boiling with same superheat

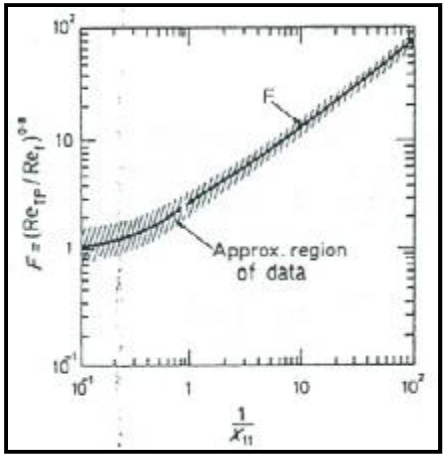
# Chen and Shah correlation




$$f = h_{NcB}\left(T_W - T_{SAT}\right) + h_c\left(T_W - T_f(z)\right)$$

$$f_{TP} = f_c + f_{SCB}\left[1 - \left\{\frac{\left(\Delta T_{SAT}\right)_{ONB}}{\Delta T_{SAT}}\right\}^{1/n}\right]$$

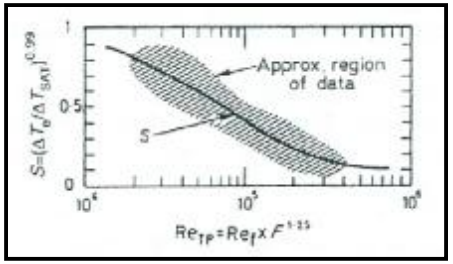
$$h_c = 0.023\left[\frac{G(1-x)D}{m_f}\right]^{0.8}\left[\frac{mc_p}{k}\right]_f^{0.4}\left(\frac{k_f}{D}\right)F$$




Shah correlation

Reynolds number factor, F

Suppression factor, S



# Gungor – Winterton correlation

$$h_{TP} = Eh_f + Sh_{NcB}$$

$$E = 1 + 24000\,Bo^{1.16} + 1.37\left(1/X_{tt}\right)^{0.86}$$

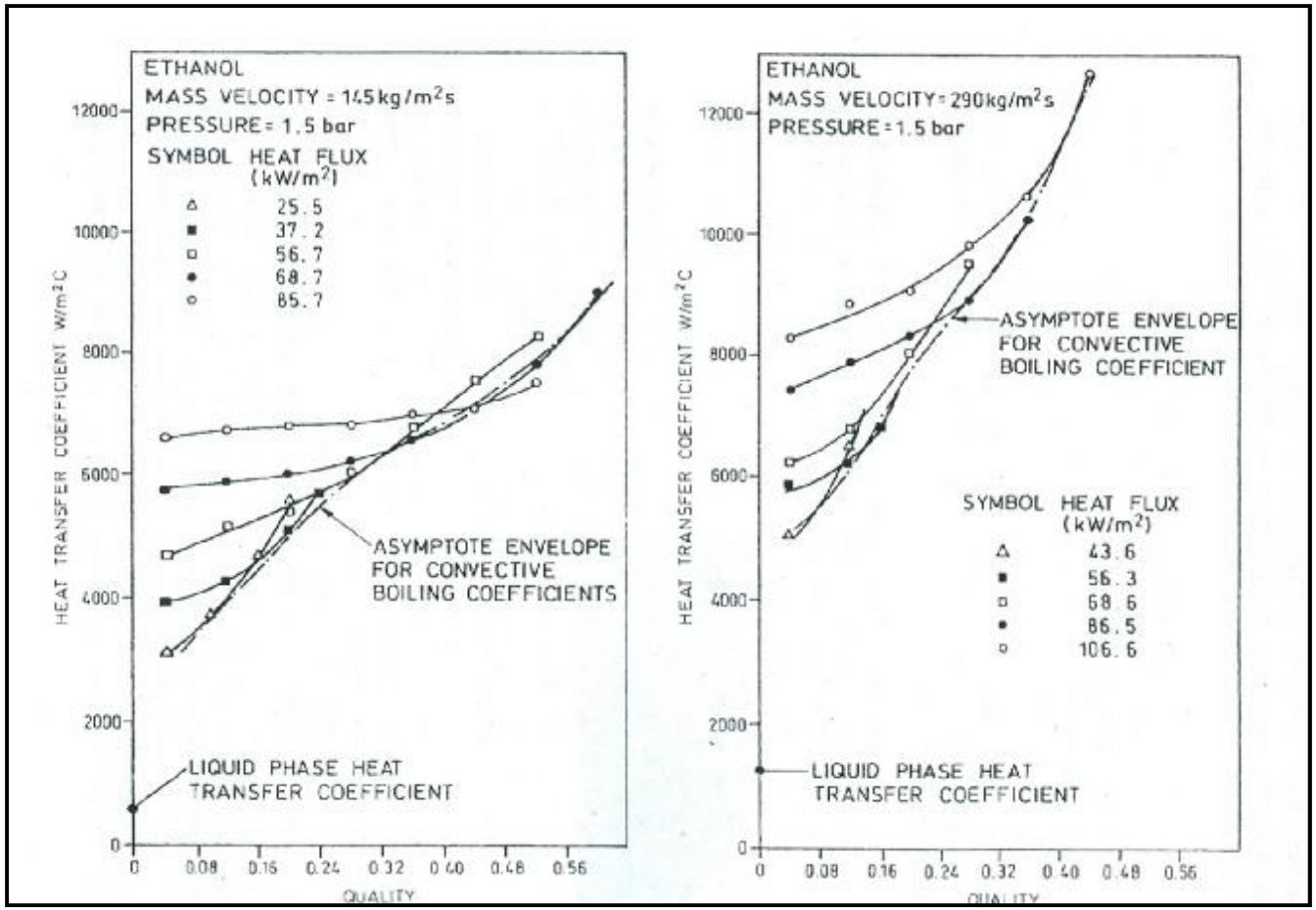
$$S = \left[1 + 1.15\times10^{-6}\,E^2\,\mathrm{Re}_f^{1.17}\right]^{-1}$$

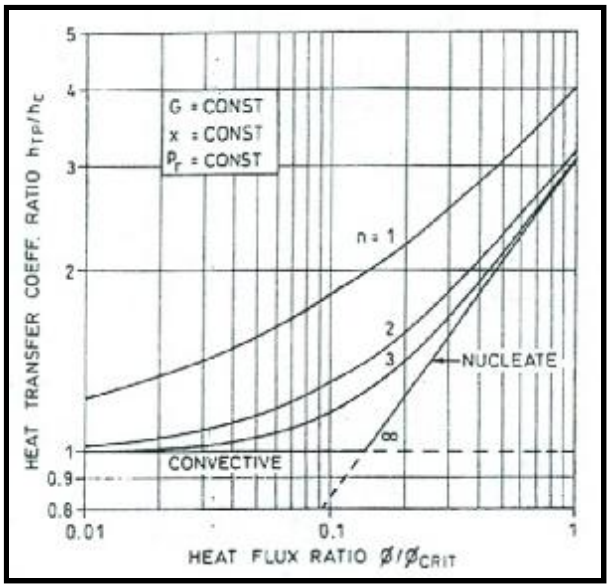
$$h_{NcB} = 55P_r^{0.12}\left(-0.4343\ln \mathrm{P}_r\right)^{-0.55} M^{-0.5} f^{0.67}$$

$$h_{TP} = \left[\left(h_{NcB}\right)^3 + \left(h_c\right)^3\right]^{1/3}$$

$$Nu = \frac{\left(f/8\right)\left(\mathrm{Re}-1000\right)\mathrm{Pr}}{1 + 12.7\left(f/8\right)^{1/2}\left(\mathrm{Pr}^{2/3}-1\right)}$$

# Boiling Ethanol in a vertical tube at two mass fluxes






Power law based boiling model

Steiner-Taborek schematic representation of the vertical flow boiling process