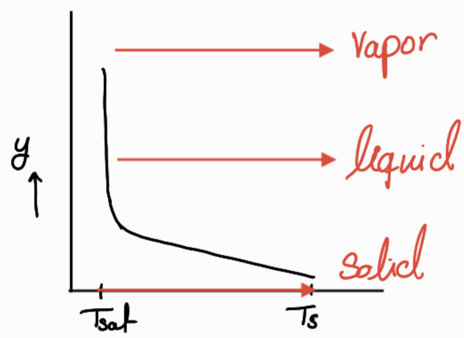
Chapter 10: Boiling

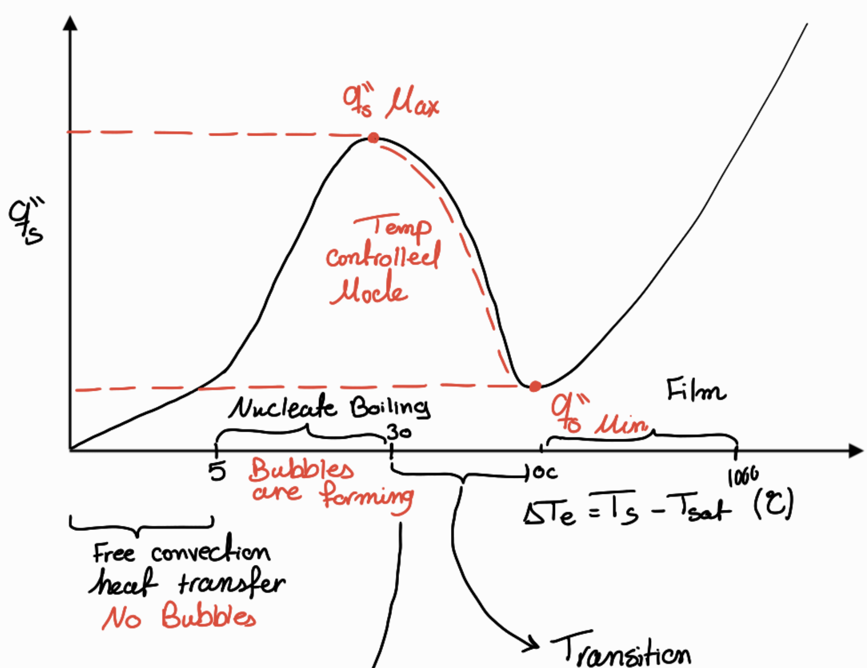
- Boiling is considered to be a convention mode of heat transfer
- Boiling occurs when $T_s > T_{sat}$ where T_s: surface temperature
  T_{sat}: saturation temperature
- Heat transfer $q_s'' = h \Delta T_e$
- Boiling types : Pool Boiling or Forced convection boiling

Saturated pool Boiling

T in liquid remains above T_{sat}



Boiling curve (No forced boiling → Pool Boiling)



- Power controlled mode : current passing in wire is controlled
- Temp controlled mode: water temp is controlled

5→10: Isolated Bubbles

10-30: Jets and columns

Free convection boiling

- Exists at $\Delta T_e \leq 5°C$
- Surface temp $> T_{sat}$
- For turbulent or laminar flow

$$\overline{Nu}_L = \frac{\overline{h} L}{K} = C(Ra_L)^n \quad : \quad Ra_L = Gr_L Pr = \frac{g \beta (T_s - T_\infty) L^3}{\upsilon \alpha}$$

Nucleate boiling

- Exists at $5 \leq \Delta T_e \leq 30$

Transition boiling

- Exists at $30 \leq \Delta T_e \leq 120$

Film boiling

- Exists at $\Delta T_e > 120$

Pool Boiling correlations

Nucleate boiling

$$q_s'' = \mu_l h_{fg} \left(\frac{g(\rho_l - \rho_v)}{\sigma} \right)^{1/2} \left(\frac{C_{p,l} \Delta T_e}{C_{s,f} h_{fg} Pr_l^n} \right)^3$$

σ: surface tension

l, v: saturated liquid, saturated vapor properties evaluated at T_{sat}

$C_{s,f}$ & n from Table 10.1

Critical heat flux (q_{max})

$$q''_{max} = C h_{fg} \rho_v \left(\frac{\sigma g (\rho_l - \rho_v)}{\rho_v^2} \right)^{1/4}$$

$C = 0.131$ for large horizontal cylinders, spheres and large finite heated surface

$C = 0.149$ for large horizontal plates

Minimum heat flux (Min)

$$q''_{min} = C\, h_{fg}\, \rho_v \left(\frac{\sigma g (\rho_l - \rho_v)}{(\rho_l + \rho_v)^2} \right)^{1/4}$$

properties at saturation temp

$C = 0.09$

Film pool Boiling

$$\overline{Nu}_D = \frac{\bar{h}_{conv} D}{k_v} = C \left(\frac{g(\rho_l - \rho_v)\, h'_{fg} D^3}{\nu_v k_v (T_s - T_{sat})} \right)^{1/4}$$

D: diameter of cylinder or sphere

$$\bar{h}_{conv} = C \left(\frac{k_v^3 \rho_v (\rho_l - \rho_v)\, g\, (h_{fg} + 0.8\, C_{p,v} \Delta T_e)}{\mu_v D \Delta T_e} \right)^{\frac{1}{4}}$$

$C = 0.62$ for horizontal cylinders → Area is $\pi D L$

$C = 0.67$ for Spheres

$h'_{fg} = h_{fg} + 0.8\, C_{p,v} (T_s - T_{sat})$

Vapor properties are evaluated at system pressure and film temp : $T_f = \frac{T_s + T_{sat}}{2}$

ρ_l, h_{fg} evaluated at T_{sat}

But at film:- Radiation + Convection so use:

$$\bar{h}^{4/3} = \bar{h}_{conv}^{4/3} + h_{rad} (\bar{h})^{1/3}$$

If $\bar{h}_{rad} < \bar{h}_{conv}$ use:

$$\bar{h} = \bar{h}_{conv} + \frac{3}{4} \bar{h}_{rad}$$

where:

$$h_{rad} = \varepsilon \sigma \frac{(T_s^4 - T_{sat}^4)}{T_s - T_{sat}}$$

→ IN KELVIN

$\sigma = 5.67 \times 10^{-8}$

Condensation rate

$$\dot{m} = \frac{q_s}{h_{fg}} = \frac{q_s'' A}{h_{fg}}$$ For steady state

Cylinder $D = 1mm$

$q/L = 3150$

$T_s = 126$ $T_{sat} = 100$ $\Delta T_e = 26$ $\rightarrow 5 < 26$

$h = ?$

$C_{sf} = ?$ $q_s'' = \frac{q}{A} = \frac{q}{\pi D L}$ q'

$$q_s'' = \mu_l h_{fg} \left(\frac{g(\rho_l - \rho_v)}{\sigma}\right)^{1/2} \left(\frac{c_{p,l} \Delta T_e}{C_{s,f} h_{fg} Pr_l^n}\right)^3$$

$$q_s = 279 \times 10^{-6} \times 2257 \times 10^3 \times \left(\frac{9.81 \times (957.9 - 0.5955)}{58.9 \times 10^{-3}}\right)^{\frac{1}{2}} \left(\frac{4217 \times 26}{C_{sf} \times 2257 \times 10^3 \times (1.76)^1}\right)^3$$

$$= \frac{(629.7)\ (399.3)\ \left(\frac{0.0276}{C_{sf}}\right)^3}{(\pi)(1 \times 10^{-3})}$$

$$q_s' = \frac{1683.6}{(C_{sf})^3}$$

$C_{s,f} = 0.8$

$D = 20\ mm$

$L = 200\ mm$

$\varepsilon = 0.9$

$T_s = 455$, horiz

initial heat tran

$\Delta T = 455 - 100 = 355$

$$\bar{h}_{conv} = C\left(\frac{K_v^3 \rho_v (\rho_l - \rho_v) g (h_{fg} + 0.8 C_{p,v} \Delta T_e)}{\mu_v D \Delta T_e}\right)^{\frac{1}{4}}$$

$$= 0.62 \times \left(\left(\frac{0.0379 \times 0.4005 \times (957.9 - 0.4005) \times 9.81 (2257 \times 1000 + 0.8 \times 1997 \times 355)}{0.4005 \times 47.04 \times 10^{-6} \times 0.02 \times 355}\right)\right)^{\frac{1}{4}}$$

$= 163.05$

$$= \varepsilon \sigma \frac{(T_s^4 - T_{sat}^4)}{T_s - T_{sat}} \qquad \sigma = 5.67 \times 10^{-8}$$

$$= 0.9 \times 5.67 \times 10^{-8} \times \left(\frac{(455 + 273)^4 - (100 + 273)^4}{355}\right)$$

$= 37.59$

$$\bar{h} = \bar{h}_{conv} + \frac{3}{4} \bar{h}_{rad}$$