BOILING

boiling = evaporation at a solid-liquid interface when $T_s > T_{sat}$ also *boiling = convection process with phase change and latent heat effect h_{fg}*

Heat Flux

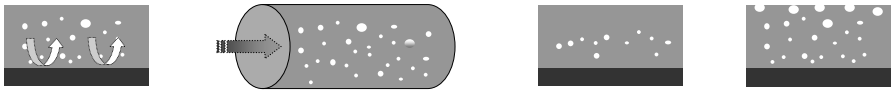
$$q_s'' = h(T_s - T_{sat})$$

$$\Delta T_e = T_s - T_{sat}$$ excess temperature

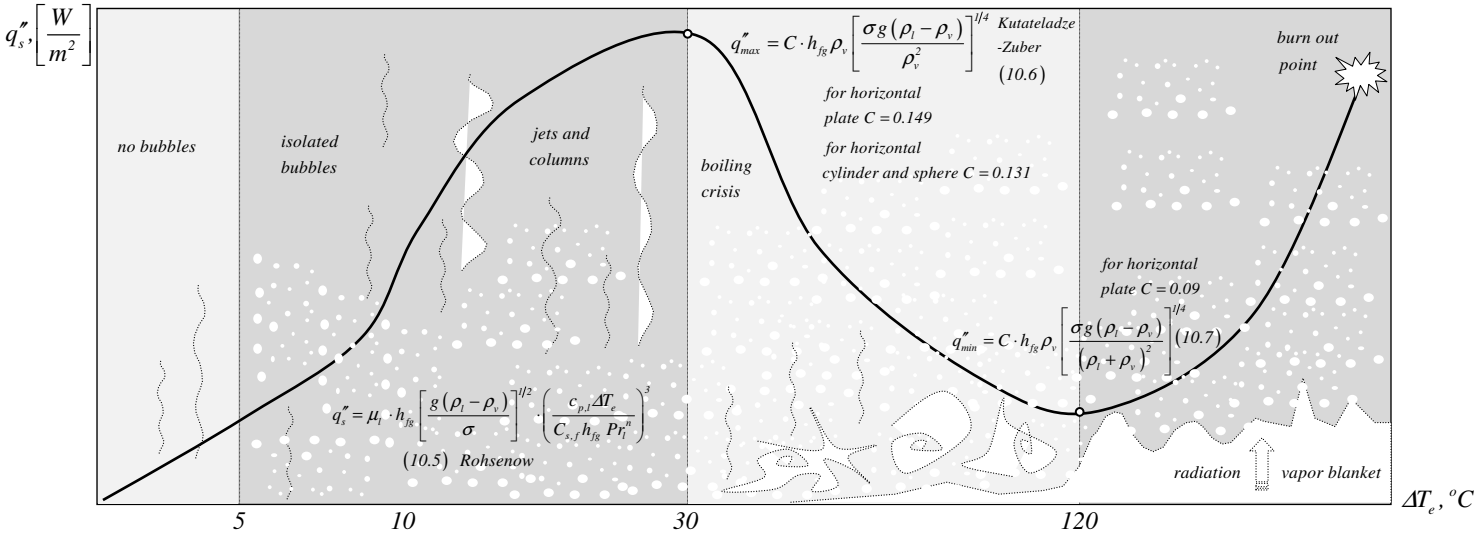
Properties : v vapor at $T_f = \frac{T_s + T_{sat}}{2}$; l liquid at T_{sat}

Modes of Boiling

pool boiling	forced boiling	subcooled boiling	saturated boiling
liquid is quiescent, free convection production of bubbles			



Saturated Pool Boiling Curve



Nucleate Boiling

$$q_s'' = \mu_l \cdot h_{fg} \left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2} \cdot \left(\frac{c_{p,l}\Delta T_e}{C_{s,f} h_{fg} Pr_l^n}\right)^3 \quad (10.5)\ \text{Rohsenow}$$

convection coefficient

$$h = \frac{q_s''}{\Delta T}$$

indeces :
l = liquid
v = vapor

σ = *surface tension for liquid-vapor interface (for water A-6)*

Surface–Fluid Combination	$C_{s,f}$	n
Water–copper		
Scored	0.0068	1.0
Polished	0.0128	1.0
Water–stainless steel		
Chemically etched	0.0133	1.0
Mechanically polished	0.0132	1.0
Ground and polished	0.0080	1.0
Water–brass	0.0060	1.0
Water–nickel	0.006	1.0
Water–platinum	0.0130	1.0
n-Pentane–copper		
Polished	0.0154	1.7
Lapped	0.0049	1.7
Benzene–chromium	0.0101	1.7
Ethyl alcohol–chromium	0.0027	1.7

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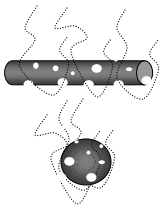
$q = q_s'' A$ — *rate of heat transfer*

$\dot{m} = \frac{q}{h_{fg}}$ — *mass rate of evaporation*

$M = \dot{m} \cdot time$ — *mass evaporated*

Film Boiling

$$\overline{Nu}_D = \frac{\bar{h}_{conv} D}{k_v} = C \left[\frac{g(\rho_l - \rho_v) h'_{fg} D^3}{\nu_v k_v (T_s - T_{sat})}\right]^{1/4} \quad (10.8)$$



$C = 0.62$ *for horizontal cylinders*

$C = 0.67$ *for spheres*

$h'_{fg} = h_{fg} + 0.80 c_{p,v}(T_s - T_{sat})$ *correlated latent heat*

Influence of radiation for $T_s > 300\,^oC$:

effective radiation coefficient

$$\bar{h}_{rad} = \frac{\varepsilon\sigma(T_s^4 - T_{sat}^4)}{T_s - T_{sat}} \quad (10.11)$$

$\sigma = 5.67e-8$ *Stefan-Boltzmann*

solve for total heat transfer coefficient $\bar{h}$

$$\bar{h}^{4/3} = \bar{h}_{conv}^{4/3} + \bar{h}_{rad} \bar{h}^{1/3} \quad (10.9)$$

if $\bar{h}_{rad} < \bar{h}_{conv}$, *then use*

$$\bar{h} = \bar{h}_{conv} + \frac{3}{4}\bar{h}_{rad} \quad (10.10)$$