University of Al−Mustansiriyah
College of Engineering
Department of Mechanical Engineering

Phase Change and Applications II

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Lecture (2):

Boiling Heat Transfer Coefficients Calculations

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Nucleate Boiling Region

The following formula is used between ONB (onset of nucleate boiling) and the critical heat flux point. It is called **Rohsenow** equation:−

$$q'' = \mu_l h_{fg}\left(\frac{g(\rho_l-\rho_v)}{\sigma}\right)^{1/2}\left(\frac{c_{pl}(T_s-T_{sat})}{C_{sf}h_{fg}Pr_l^n}\right)^3 \qquad (2)$$

Where:−

C_{sf} and ***n*** are constants that depend on solid−liquid combinations and are taken from table (1).

Pr is **Prandtl** number which is a dimensionless number accounting for the type of the fluid.

$$Pr_l = \frac{\mu_l c_{pl}}{k_l} \qquad (3)$$

The boiling heat transfer coefficient can be found as follows:−

$$h_b = \frac{q''}{A(T_s - T_{sat})} \qquad (4)$$

Where A is the heat transfer area. The boiling rate $\dot{m}$ per unit area can be found as follows:−

$$\dot{m} = \frac{q''}{h_{fg}} \qquad (5)$$

It is a common practice to express the heat transfer coefficient in terms of the dimensionless Nusselt number as follows:−

$$Nu_l = \frac{h_b L}{k_l} \qquad (6)$$

Where L is the characteristic length of the heating surface.

Table (1): Values of C_{sf} and n for various surface−fluid combinations.

Surface−Fluid Combination	C_{sf}	n
Water−copper		
Scored	0.0068	1
Polished	0.0128	1
Water−stainless steel		
Chemically etched	0.0133	1
Mechanically polished	0.0132	1
Ground and polished	0.008	1
Water−brass	0.006	1
Water−nickel	0.006	1
Water−platinum	0.013	1
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

Critical Heat Flux

It is the maximum heat flux reached in pool boiling. Any increase in temperature after this point leads to a decrease in heat flux. It can be estimated as follows:−

$$q''_{\max} = C h_{fg} \rho_v \left(\frac{\sigma g (\rho_l - \rho_v)}{\rho_v^2} \right)^{1/4} \qquad (7)$$

Where:− C = 0.131 for cylinders and spheres and
C = 0.149 for horizontal plates.

Eq. (7) is valid when the heating element is much larger than the bubble diameter.

Minimum Heat Flux

It is the minimum heat flux reached after the transition region. A further increase in surface temperature after this point leads to the formation of a stable vapor film or blanket on the heating surface and the heat flux returns to increase. The decrease of surface temperature in this point causes the vapor blanket to collapse and nucleate boiling reestablishes. The minimum heat flux can be calculated as follows:−

$$q''_{\min} = C h_{fg} \rho_v \left(\frac{\sigma g (\rho_l - \rho_v)}{(\rho_l + \rho_v)^2} \right)^{1/4} \qquad (8)$$

Where C = 0.09 has been experimentally determined to give reasonable error (< 50%) for most fluids.

Film Boiling Region

When excess temperature is increased beyond Leidenfrost point (minimum heat flux), a continuous vapor film blankets the surface and there is no contact between the liquid phase and the surface. The convection heat transfer coefficient across the vapor film can be found as follows:−

$$\overline{Nu}_D = \frac{\bar{h}_{conv} D}{k_v} = C\left(\frac{g\rho_v(\rho_l - \rho_v)h'_{fg} D^3}{\mu_v k_v (T_s - T_{sat})}\right)^{1/4} \quad (9)$$

Where:− C = 0.62 for horizontal cylinders

C= 0.67 for spheres

$$h'_{fg} = h_{fg} + 0.8\ c_{pv}(\ T_s - T_{sat}\ )$$

Vapor properties are evaluated at the film temperature, T_f and ρ_l and h_{fg} at saturation temperature. Where:−

$$T_f = \frac{T_s + T_{sat}}{2}$$

At high surface temperatures (T_s > 300 °C), radiation heat transfer across the vapor film becomes significant. The effective radiation heat transfer coefficient can be found as follows:−

$$\bar{h}_{rad} = \frac{\varepsilon \sigma_{sp} \left(T_s^4 - T_{sat}^4 \right)}{T_s - T_{sat}} \qquad (10)$$

Where σ_{sp} = 5.67×10^{-8} W/(m^2 K^4), (Stefan−Poltzmann constant)

The overall heat transfer coefficient considers both effects (convection and radiation) as follows:−

$$\bar{h}^{4/3} = \bar{h}_{conv}^{4/3} + \bar{h}_{rad} \bar{h}^{1/3} \quad if \; \bar{h}_{conv} < \bar{h}_{rad} \qquad (11)$$

$$\bar{h} = \bar{h}_{conv} + \frac{3}{4} \bar{h}_{rad} \qquad if \; \bar{h}_{conv} > \bar{h}_{rad} \qquad (12)$$