APPENDIX 3

CHF CALCULATION PROCEDURE

If not specified, all properties are got at saturation condition.

Input G, P, D, L, T_{in}

Calculate friction factor f from

$$\frac{1}{\sqrt{f}} = 1.14 - 2.0 \times \log\left(0.75 \times 0.015 \times \sqrt{\frac{8\sigma\rho_f}{fG^2 D}} + \frac{9.35}{\mathrm{Rex}\sqrt{f}}\right)$$

Calculate τ_w, U_τ and D_B, by:

$$\tau_w = \frac{fG^2}{8\rho_f},\ U_\tau = \sqrt{\frac{\tau_w}{\rho_f}},\ D_B = 0.015 \times \sqrt{\frac{\sigma D}{\tau_w}}$$

Assume a q_m

1. Calculate NVG point

a. Generally, calculate ΔT_d from the Ahmad model as:

$$\Delta T_d = q_m / h_{l-A}$$

where h_{l-A} is subcooled liquid-phase heat transfer coefficient in the Ahmad model and is calculated by:

$$h_{l-A} = 2.44 \frac{K_f}{D} \sqrt{\frac{GD}{\mu_f}} \left(\frac{C_{pl}\mu_f}{K_f}\right)^{1/3} \left(\frac{H_{lin}}{H_f}\right)^{1/3} \left(\frac{H_{fg}}{H_f}\right)^{1/3}$$

where H_{lin} is inlet liquid enthalpy, C_{pl} should be the specific heat at the net vapor generation point. To simplify the calculation, this C_{pl} is approximately got at inlet temperature.

b. With the discussions in the Chapter 6-1, if T_{in}<30°C or G ≥ 40000 kg/m^{2}s, calculate ΔT_d from the Levy model:

$$\Delta T_d = q_m \left(\frac{1}{h_l} - \frac{T_B^+}{C_{pf}\rho_f U_\tau}\right)$$

where $h_l = 0.023 \frac{k_f}{D} \left(\frac{GD}{\mu_f}\right)^{0.8} \left(\frac{C_{pf}\mu}{k}\right)^{0.4}$

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

where $Y_B^+ = \frac{Y_B U_\tau \rho_f}{\mu_f}$, $Y_B = 0.015\left(\frac{\sigma D}{\tau_w}\right)^{1/2}$

c. Compare ΔT_d with ΔT_{in}. If $\Delta T_d > \Delta T_{in}$, which means the physics valid net vapor generation is tube inlet, replace ΔT_d by ΔT_{in}.

d. Calculate Z_0 (the distance from the tube inlet to the NVG point) by:

$$Z_0 = GDC_{pl}(\Delta T_{in} - \Delta T_d)/(4q_m)$$

C_{pl} here is specific heat at the NVG point.

If $Z_0 \ge L$, which means the NVG point can not be reached in the tube, increase q_m and repeat the above procedures. Otherwise, significant boiling length Z_{sb} is calculated by:

$$Z_{sb} = L - Z_0$$

2. Calculate χ_{out} and α_{out}

$$A = (q_m \times Z_{sb})/(GDC_{pl}\Delta T_d / 4)$$

$$B = H_{fg}/(C_{pl}\Delta T_d)$$

The C_{pl} in the above two equations are specific heat at the NVG point.

$$\chi_{eqout} = (A-1)/B,$$

$$\chi_d = -(1/B)$$

$$\chi_{out} = \frac{\chi_{eqout} - \chi_d \exp\left(\frac{\chi_{eqout}}{\chi_d} - 1\right)}{1 - \chi_d \exp\left(\frac{\chi_{eqout}}{\chi_d} - 1\right)}$$

If $\chi_{out} \ge 1$, decrease q_m and repeat the above procedures. Otherwise,

$$S = \left(\frac{\rho_f}{\rho_g}\right)^{0.205}\left(\frac{GD}{\mu_f}\right)^{-0.016}$$

$$\alpha_{out} = \frac{\chi_{out}}{\chi_{out} + \left(\frac{\rho_g}{\rho_f}\right)S(1-\chi_{out})}$$

3. Calculate T_{lout}

$$T_{lout} = T_{sat} - \Delta T_d e^{(-A)}$$

If $T_{lout} \geq T_{SAT}$, decrease q_m and repeat the above procedures.

4. Calculate V_c and U_B

Core region two-phase average density ρ_c, is calculated from:

$$\rho_c = (1-\alpha_{out}) \times \rho_{lout} + \alpha_{out} \times \rho_g$$

where ρ_{lout} is liquid density at exit temperature.

V_c is calculated as:

$$V_c = G / \rho_c$$

Then U_B is calculated as:

$$U_B = \frac{V_c}{1 + \sqrt{\frac{\rho_c + \rho_g}{\rho_c}}}$$

5.Calculate L_B

$$L_B = 2\pi\sigma / \left(\rho_g U_B^2\right)$$

6.Calculate U_{BL}

At low pressure (P<1MPa):

$$U_{BL} = U_B - \sqrt{\frac{2L_B g\left(\rho_f - \rho_g\right)}{\rho_f C_D}}$$

where C_D is got by: $C_D = \frac{2}{3}\frac{D_B}{\left(\frac{\sigma}{g\left(\rho_f - \rho_g\right)}\right)^{0.5}}$

Otherwise:

$$U_{BL} = U_B - 2g(\rho_f - \rho_g)D_B L_B/(48\mu_f)$$

If $U_{BL} \le 0$, increase q_m and repeat the above procedures.

6. Calculate distance y

$$\begin{cases} U_{BL}^{+} = y^{+} & 0 \le y^{+} \le 5 \\ U_{BL}^{+} = 5.0\ln y^{+} - 3.05 & 5 \le y^{+} < 30 \\ U_{BL}^{+} = 2.5\ln y^{+} + 5.5 & y^{+} \ge 30 \end{cases}$$

where $U_{BL}^{+} = \dfrac{U_{BL}}{U_\tau}$, $y^{+} = y\dfrac{U_\tau}{\mu_f}\rho_f$

7. Calculate δ

$$\delta = y - D_B/2$$

If $\delta \le 0$, increase q_m and repeat the above procedures.

8. Calculate critical heat flux

$$q = \rho_f \delta H_{fg} U_B / L_B$$

Critical heat flux, CHF, is reached when q_m=q.

It has been mentioned (chapter 4.1) that under some extreme condition, such as at high Pressure ($P \ge 17.5$ MPa) or high mass flux ($G \ge 50000$ kg/m^{2}s, with CHF up to 100 MW/m^2), with the proposed model, sometimes the final calculated q doesn't equal to the assumed q_m even after the assumed q_m has converged to a point. The reason is analyzed as the change of the CHF triggering mechanism. The CHF under such circumstance can be approximately calculated by doing a little modification to Levy D_B (by increasing D_B step by step). That is to say, if we cannot calculate CHF with the original Levy D_B, we increase D_B as D_B=1.01D_B and repeat the calculation procedure. If CHF still cannot be got, increase D_B as DB=1.02D_B.... until the CHF is calculated. Generally, the CHF can be got within D_B<1.5$D_{B\text{-}Levy}$. Because the calculated CHF by doing the modification to the vapor blanket equivalent diameter is actually the lowest possible CHF value (q_{NVG}) and is occasionally just the same as the analyzed CHF value for the data group, the CHF is therefore predicted successfully.