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

\[
\frac{1}{\sqrt{f}} = 1.14 - 2.0 \times \log \left( 0.75 \times 0.015 \times \sqrt{\frac{8G \rho_f}{fG^2D}} + \frac{9.35}{\text{Re} \sqrt{f}} \right)
\]

Calculate \( \tau_w \), \( U_t \) and \( D_b \) by:

\[
\tau_w = \frac{fG^2}{8 \rho_f} \quad U_t = \frac{\tau_w}{\rho_f} \quad D_b = 0.015 \times \sqrt{\frac{\partial D}{\tau_w}}
\]

Assume a \( q_{im} \)

1. Calculate NVG point

a. Generally, calculate \( \Delta T_d \) from the Ahmad model as:

\[
\Delta T_d = \frac{q_m}{h_{l-A}}
\]

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

\[
h_{l-A} = 2.44 \frac{K_f}{D} \left( \frac{GD}{\mu_f} \left( \frac{C_{pl} \mu_f}{K_f} \right)^{1/3} (\frac{H_{in}^*}{H_f}) (\frac{H_{fg}}{H_f}) \right)^{1/3}
\]

where \( H_{in} \) 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 \( T_{in}<30^\circ C \) or \( G \geq 40000 \text{ kg/m}^2\text{s} \), calculate \( \Delta T_d \) from the Levy model:

\[
\Delta T_d = q_m \left( \frac{1}{h_l} - \frac{T^*_g}{C_{pl} \rho_f U_t} \right)
\]

where \( h_l = 0.023 \frac{k_f}{D} \left( \frac{GD}{\mu_f} \right)^{0.8} \left( \frac{C_{pl} \mu_f}{k} \right)^{0.4} \)
\[
\begin{align*}
T_b^* &= Pr_f Y_b^* \quad 0 \leq Y_b^* \leq 5 \\
T_b^* &= 5 \left[ Pr_f + \ln \left( 1 + Pr_f \left( \frac{Y_b^*}{5} - 1 \right) \right) \right] \quad 5 \leq Y_b^* \leq 30 \\
T_b^* &= 5 \left[ Pr_f + \ln \left( 1 + 5 Pr_f \right) + 0.5 \ln \left( \frac{Y_b^*}{30} \right) \right] \quad Y_b^* > 30
\end{align*}
\]

where \( Y_b^* = \frac{Y_b U_r \rho_f}{\mu_f}, \quad Y_b = 0.015 \left( \frac{OD}{\tau_w} \right)^{1/2} \)

c. Compare \( \Delta T_d \) with \( \Delta T_{in} \). If \( \Delta T_d > \Delta T_{in} \), which means the physics valid net vapor generation is tube inlet, replace \( \Delta T_d \) by \( \Delta T_{in} \).
d. Calculate \( Z_0 \) (the distance from the tube inlet to the NVG point) by:
\[
Z_0 = GDC_{pt} (\Delta T_{in} - \Delta T_d) / (4 q_m)
\]
\( C_{pt} \) here is specific heat at the NVG point.
If \( Z_0 \geq L \), which means the NVG point can not be reached in the tube, increase \( q_m \) and repeat the above procedures. Otherwise, significant boiling length \( Z_{sh} \) is calculated by:
\[
Z_{sh} = L - Z_0
\]

2. Calculate \( \chi_{out} \) and \( \alpha_{out} \)
\[
A = (q_m \times Z_{sh}) / (GDC_{pt} \Delta T_d / 4)
\]
\[
B = H_{ft} / (C_{pt} \Delta T_d)
\]
The \( C_{pt} \) in the above two equations are specific heat at the NVG point.
\[
\chi_{equat} = (A - 1) / B,
\]
\[
\chi_d = - \left( 1 / B \right)
\]
\[
\chi_{equat} = \chi_d \exp \left( \frac{\chi_{equat}}{\chi_d} \right)
\]
\[
\chi_{equat} = \frac{1 - \chi_d \exp \left( \frac{\chi_{equat}}{\chi_d} \right) - 1}{\chi_d}
\]
If \( \chi_{equat} \geq 1 \), decrease \( q_m \) and repeat the above procedures. Otherwise,
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\[
S = \left( \frac{\rho_f}{\rho_g} \right)^{0.205} \left( \frac{GD}{\mu_f} \right)^{-0.036}
\]

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

3. Calculate \( T_{out} \)

\[
T_{out} = T_{sat} - \Delta T_a e^{(\alpha_a)}
\]

If \( T_{out} \geq T_{SAT} \), decrease \( q_{in} \) and repeat the above procedures.

4. Calculate \( V_e \) and \( U_B \)

Core region two-phase average density \( \rho_a \) is calculated from:

\[
\rho_a = (1 - \alpha_{out}) \times \rho_{out} + \alpha_{out} \times \rho_g
\]

where \( \rho_{out} \) is liquid density at exit temperature.

\( V_e \) is calculated as:

\[
V_e = G / \rho_a
\]

Then \( U_B \) is calculated as:

\[
U_B = \frac{V_e}{1 + \sqrt{\frac{\rho_e + \rho_g}{\rho_e}}}
\]

5. Calculate \( L_B \)

\[
L_B = 2\pi \sigma f \left( \rho_g U_B^2 \right)
\]

6. Calculate \( U_{Bl} \)

At low pressure (P<1MPa):

\[
U_{Bl} = U_B - \sqrt{\frac{2L_B f (\rho_f - \rho_g)}{\rho_f C_D}}
\]

where \( C_D \) is got by:

\[
C_D = \frac{2}{3} \frac{D_B}{\left( \frac{\sigma}{g(\rho_f - \rho_g)} \right)^{0.2}}
\]
Otherwise:
\[ U_{re} = U_{b} - 2g(\rho_f - \rho_g)D_bL_b / (48\mu_f) \]

If \( U_{re} \leq 0 \), increase \( q_m \) and repeat the above procedures.

6. Calculate distance \( y^* \)
\[
\begin{align*}
U_{re}^+ &= y^* & 0 \leq y^* \leq 5 \\
U_{re}^+ &= 5.0 \ln y^* - 3.05 & 5 \leq y^* < 30 \\
U_{re}^+ &= 2.5 \ln y^* + 5.5 & y^* \geq 30
\end{align*}
\]

where \( U_{re}^+ = \frac{U_{re}}{U_{e}}, \ y^* = y \frac{\rho_f}{\mu_f} \)

7. Calculate \( \delta \)
\[ \delta = y - D_b / 2 \]

If \( \delta < 0 \), increase \( q_m \) and repeat the above procedures.

8. Calculate critical heat flux
\[ q = \rho_f \delta H_f U_{b} / L_b \]

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 (\( P \geq 17.5 \) MPa) or high mass flux (\( G \geq 50000 \) 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 \( D_B < 1.5D_{B, Levy} \). Because the calculated CHF by doing the modification to the vapor blanket equivalent diameter is actually the lowest possible CHF value (\( q_{mvo} \)) and is occasionally just the same as the analyzed CHF value for the data group, the CHF is therefore predicted successfully.