Critical Heat Flux (CHF) Update to RELAP5-3D

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This article discusses code upgrades to improve the performance of RELAP5-3D when modeling Critical Heat Flux.

Introduction

The RELAP5-3D has two Card 1 options of Critical Heat Flux (CHF) geometry correction factors which support CHF modeling at various geometries and flow conditions: 1986 Groeneveld CHF factors; and 2006 Groeneveld CHF factors. The user feedback problems #179 and #186 noted the need of "the vertical low-flow factor" update as well as full documentation of the 2006 Groeneveld CHF factors. This article summarizes update and verification of 2006 Groeneveld CHF factors in chftab06.F. The 2006 CHF factors provided a greater level of conservatism.

Update of 2006 Groeneveld CHF factors

1. Review of current RELAP5-3D

In1986, Gorenenveld et al., proposed seven CHF geometry correction factors which are coded in chftab.F [1]. He upgraded the factors in 2006 to eight factors and RELAP5-3D coded in chftab06.F [2]. However, it was confirmed that current chftab06.F does not include all of the latest CHF geometry factors proposed in 2006.

2. Update of chftab06.F

New update includes a total of nine CHF geometry correction factors in chftab06 as follows. K1, K2, K6, K7 and K8 were updated. K3, K4 and K5 were retained from chftab.F. Factor K9 was added from 1986 version.

The K-factors are described as follows:

K1: sub-channel / tube-diameter, cross section geometry factor

chftab.F	chftab06.F (updated)
$K1=(0.008/D)^{0.33}$ for $D<0.016m$ $K1=(0.008/0.016)^{0.33} = 0.79$ for $D>0.016m$	$K1=(0.008/D)^{0.5}$ for $0.003<D<0.025m$ $K1=(0.008/0.025)^{0.5} = 0.57$ for $D>0.025m$

Here *D* is the heated equivalent diameter.

K2: Bundle geometry factor

chftab.F	chftab06.F (updated)
$K2=min[0.8, 0.8exp(-0.5X_{lim}^{0.33})]$ for rod bundles $K2=1.0$ for other surfaces	$K2 = min\left[1, \left(\frac{1}{2}+\frac{2\delta}{D}\right)exp\left(\frac{-(X_{lim})^{1/3}}{2}\right)\right]$ where δ=minimum rod spacing (=P-D)

where $X_{lim}=min[1, max(0,X)]$. Here X is thermodynamic quality and P is the pitch between fuel rods.

K3: Grid spacer factor (for 37 CANDU element bundle) (same as chftab.F)

$K3 = 1+A \cdot exp(-0.1L_{SP}/D)$, where $A=1.5K_{loss}0.5(G/1000)^{0.2}$

Here G is the mass flux, K_{loss} is the grid pressure loss coefficient and L_{SP} is the distance from grid spacer.

K4: Heated-length factor (same as chftab.F)

For $L/D>5$

$K4 = epx\left[\left(\frac{D}{L}\right)exp(2\alpha)\right]$, where $\alpha = \frac{X_{lim}}{X_{lim}\rho_f+(1-X_{lim})\rho_g}$

Here L is the heated length from entrance to point, α is the void fraction, ρ_f is density of the liquid and ρ_g is the density of vapor.

K5: Axial flux distribution factor (same as chftab.F)

For $X<0$; $K5=1.0$ and for $X>0$; $K5 = q''/q''_{bla}$

Here q'' is local heat flux and q''_{big} is average heat flux from start of boiling to point.

K6: Radial or circumferential flux distribution factor (updated)

For $X_e < 0$; $K6 = 1.0$ and for $X_e > 0$; $K6 = q''(z)_{max}/q''(z)_{avg}$

Here $q''(z)_{max}$ is the maximum radial heat flux and $q''(z)_{avg}$ is the average radial heat flux

K7: Horizontal flow factor

chftab.F	chftab06.F (updated)
$K6=1$ if vertical $K6=0$ if horizontal stratified $K6=1$ if horizontal high flow $K6$=interpolate if medium flow	$K7 = 1 - exp(-(T_1/3.0)^{0.5})$ where $T_1 = \left(\frac{1-X_e}{1-\alpha}\right)^2 \frac{f_L G^2}{gD_e\rho_f(\rho_f-\rho_g)\alpha^{0.5}}$ Friction factor of the channel, $f_L = 0.046Re^{-0.2}$

K8: Vertical flow factor

chftab.F	chftab6.F (updated)
For $G<-400$ or $G>100 kg/m^2s$ $K7 = 1.0$ For $-50<G<10\ kg/m^2s$ $K7=(1-\alpha)$ for $\alpha<0.8$ $K7 = (1-\alpha)\frac{0.8+0.2\rho_f/\rho_g}{\alpha+(1-\alpha)\rho_f/\rho_g}$ CHF table value at $G=0, X=0$ For $10<G<100\ kg/m^2s$ or $-400<G<-50\ kg/m^2s$ interpolate	For $G<-400\ kg/m^2s$ or $X<<0$ $K8 = 1.0$ For $-400<G<0\ kg/m^2s$ Linear interpolation between table value $CHF_0 = CHF_{G=0,X=0}(1-\alpha)C_1$ For $\alpha<0.8$; $C_1 = 1.0$ For $\alpha>0.8$; $C_1 = \frac{0.8+0.2\rho_f/\rho_g}{\alpha+(1-\alpha)\rho_f/\rho_g}$

Here CHF_0 is the CHF table value of G=0 and X=0 at given pressure.

K9: Pressure out-range factor (remain from chftab.F)

$$K9 = \frac{prop(out)}{prop(border)}$$, where $$prop = \rho_g^{0.5} h_{fg} \left[\sigma(\rho_f - \rho_g)\right]^{0.25}$$

Here σ is the surface tension.

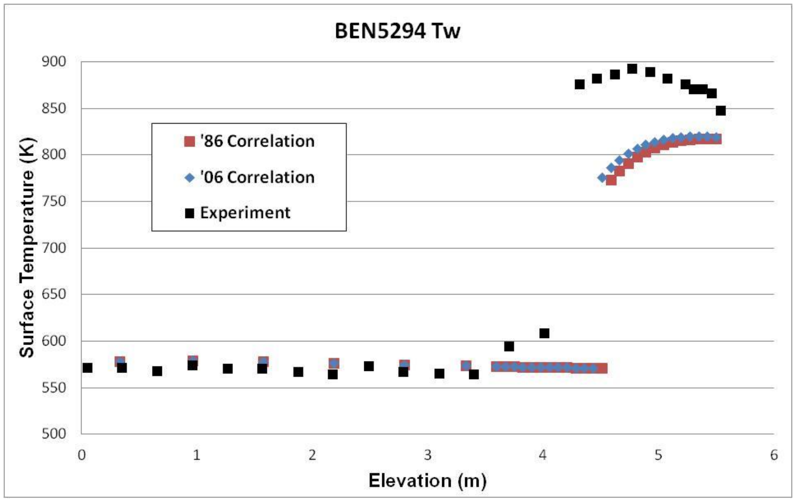
3. Verification of updated chftab06.F

The updated geometry factors were first verified by hand calculation. Then the CHF values at specific values of pressure, quality and mass flux were calculated using RELAP5-3D and verified with 2006 Groeneveld CHF look-up tables in the reference.

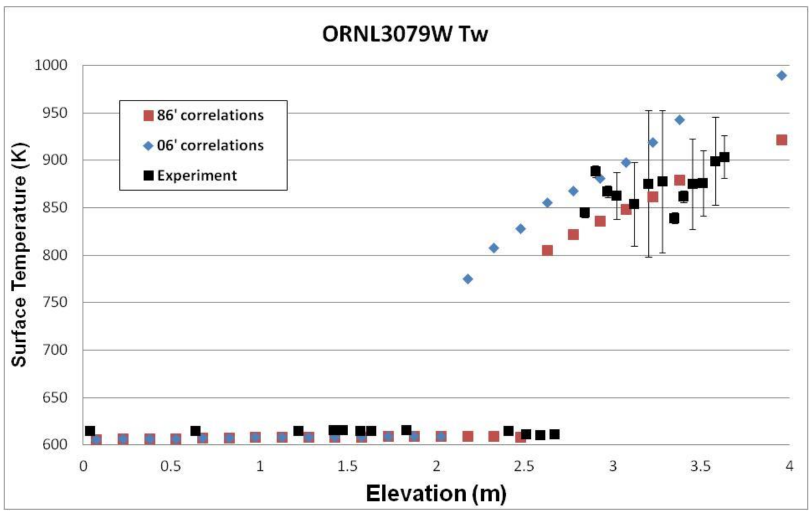
The updated chftab06.F was also tested using existing RELAP5-3D CHF test samples:

- Bennett heated tube tests
- ORNL THTF test
- RIT tube test

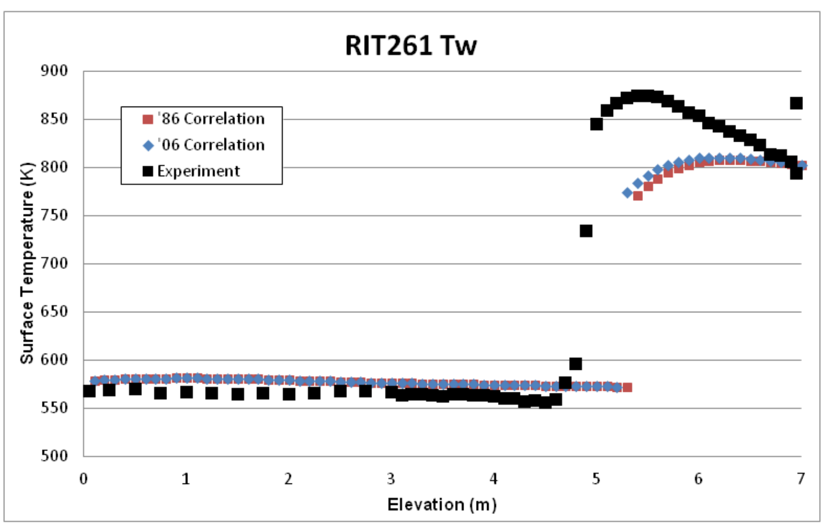
The CHF values ~~test results~~~~geometry correction factors of the~~using latest 2006 Gronenveld CHF geometry correction factors are smaller than those of using the 1986 version factors. For example, *K1* factor of chftab06.F is always smaller than that of chftab.F, and calculates CHF value from chftab06.F smaller. This produces more conservative calculations. The smaller CHF value makes earlier (lower elevation) CHF occur at all test cases, as shown in the following graphs.



< Bennett heated tube test #5294>



<ORNL THTF test #3079>



<RIT tube test #261>

Summary

The CHF geometry correction factors of RELAP5-3D have been updated taking into account latest research from Groeneveld et al., [2]. The updated chftab06.F was verified by testing existing RELAP5-3D CHF test problems. The documentation of updated CHF factors will be followed.

Bibliography

[1] D. C. Groeneveld, S. C. Cheng, and T. Doan, "1986 AECL-UO Critical Heat Flux Lookup Table," *Heat Transfer Engineering, 7,* 1-2, 1986, pp. 46-62

[2] D.C. Groeneveld et al., Lookup Tables for Predicting CHF and Film-Boiling Heat Transfer: Past, Present, and Future, Nuc. Technology 152, 2005, pp 87-104" and "D.C. Goeneveld et al., The 2006 CHF look-up table, Nuclear Engineering and Design, 237, 2007, pp. 1909-1922