Thermal Hydraulic Models of THALES Code

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1. Introduction

The subchannel analysis code, THALES (Thermal Hydraulic AnaLyzer for Enhanced Simulation of core) would be applied to the core thermal hydraulic design of OPR1000, APR1400, and Westinghouse type nuclear power plants [1]. The governing equations are discretized to the finite difference forms. The staggered mesh is used to remove the pressure discrepancy of the existing COBRA family codes. This paper presents the thermal hydraulic models implemented in THALES-β and shows the prediction performance of the code and the model effects on the prediction.

2. Thermal Hydraulic Models in THALES

Basically, conservative equations of mass, momentum, and energy are solved on the homogeneous flow field. The capabilities of three mixture equation homogeneous model have been expanded by the models to reflect subcooled boiling and liquid/vapor slip. The thermal hydraulic models implemented in THALES-β are summarized in Table I.

Table I: Thermal hydraulic models of THALES-β

TH Parameters	Correlation/Model
Turbulent mixing	No turbulent mixing $w' = a\,\mathrm{Re}^b\,\overline{G}s$ $w' = a\,\mathrm{Re}^b\,\overline{G}D_h(s/l)$, etc.
Friction	Blasius, Rohsenow-Clark
Two-phase friction multiplier	Homogeneous Sher-Green and Martinelli-Nelson Armand
Void/quality	Homogeneous, Levy Modified Martinelli-Nelson Modified Armand, Constant slip ratio
Heat transfer coefficient	Dittus-Boelter, Jens-Lottes, Thom, Chen, Bergles-Rohsenow
CHF	KCE-1, CE-1, WRB-2

3. Prediction Performance and Model Effects

To evaluate the prediction performance of THALES-β, a thermal hydraulic test was selected out of many test cases to validate computer code. Columbia University 4x4 bundle test with six spacer grids [2] was configured as shown in Fig. 1 to measure the exit flow rates and enthalpy distributions at the various operating conditions.

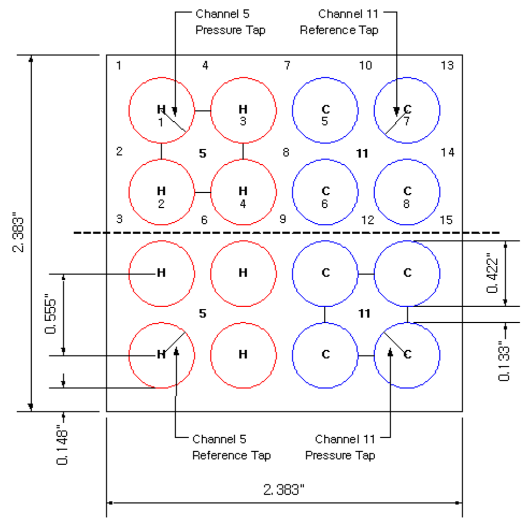


Fig. 1. CU 4x4 rod bundle test section [2]

The local coolant conditions were predicted by several subchannel analysis codes and compared each other. Most of the combinations of thermal hydraulic models and operating conditions showed good agreement, but the combination with Levy model didn't. The worst combination is as follows and the results are focused in this paper.

TH Parameters	Correlation/Model
Turbulent mixing	$w' = 0.005\cdot\overline{G}\cdot s$ (TDC=0.005)
Friction	$0.184\cdot\mathrm{Re}^{-0.20}$
Two-phase friction multiplier	Homo.: $\phi_{fo}^2 = \frac{\rho_f}{\rho_m}\left[X\frac{\mu_g}{\mu_f} + (1-X)\right]^{0.20}$
Void/quality	Homo.: $\alpha = \frac{X v_g}{(1-X)v_f + X v_g}$ Levy: $X = X_e - X_d \exp\left(\frac{X_e}{X_d} - 1\right)$, if $X_d \le X_e$
Heat transfer coefficient	Dittus-Boelter (non-boiling regime) Jens-Lottes (nucleate boiling regime)

Run #	Pr. (psia)	Tin (^{o}F)	Gavg (Mlbm/ft^2-hr)	q" (MBtu/ft^2-hr)
73	500	318.9	2.00	0.59067

The codes of TORC [3], COBRA-EN [4], MATRA [5] are used to compare the results from THALES-β.

3.1 Flow Distribution

The predicted data by THALES, MATRA, and COBRA-EN with TDC value of 0.005 for the hot subchannel 5 show good agreements with the measured data and are better than those for the cold subchannel 11 at relatively high quality conditions as shown in Fig.2. It is noticed in Figs. 2 and 3 that TORC code predicts different flow profiles with no subcooled void model option because it doesn't have Levy subcooled void model.

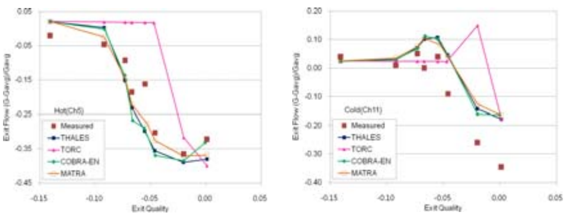


Fig.2. Prediction of exit flow and quality profiles

THALES-β shows the good agreement of axial and crossflow distributions with COBRA-EN compared to other codes as shown in Fig. 3.

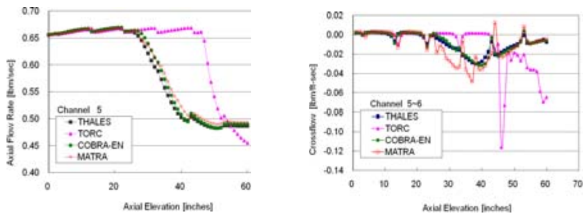


Fig.3. Prediction of axial and crossflow distribution

3.2 Void & Quality Distribution

THALES-β predicts axial variation of void & quality similar to other codes except for TORC without Levy subcooled void model as shown in Fig. 4.

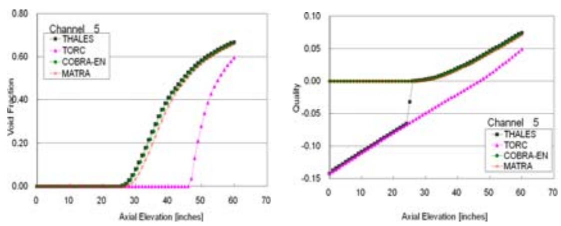


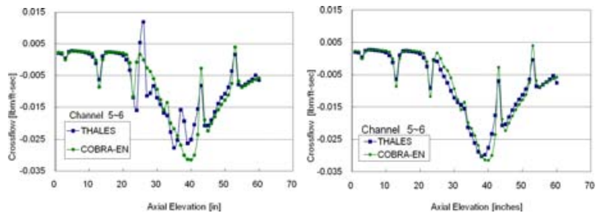
Fig.4. Prediction of void & quality distribution

3.3 Model Effects

The effect of specific volume for momentum (ν') defined as eq. (1) can be shown in Fig. 5.

$$\nu' \equiv \frac{\nu_v \chi^2}{\alpha} + \frac{\nu_l (1-\chi)^2}{(1-\alpha)} \qquad (1)$$

The crossflow distribution predicted with corrected ν' by THALES-β is changed to have same trend with COBRA-EN. The correction was to use the liquid specific volume (ν_l) instead of the saturated liquid specific volume (ν_f) in the subcooled boiling regime. The drag term and the axial momentum velocity were also changed due to the correction.



(before specific volume correction) (after specific volume correction)

Fig.5. Effect of specific volume for momentum on crossflow

The staggered effect can be shown in Figs. 3 and 5. At the peak region, the crossflow and the axial flow of THALES-β with staggered method are smoother than those of the other codes with the non-staggered method. The rounding peak effect is considered to be physically reasonable.

4. Conclusions

The prediction results using the thermal hydraulic models in the subchannel analysis code, THALES-β, show that the code has reasonable accuracy and is comparable to the other subchannel analysis codes. In this paper, the effect of specific volume in the subcooled boiling regime was cleared and the rounding peak effect of the staggered method was confirmed.

ACKNOWLEDGEMENTS

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