Assessment of a Subchannel Code MATRA for OECD/NRC PSBT Benchmark Exercises

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1. Introduction

The OECD/NRC PWR Subchannel and Bundle Tests (PSBT) benchmark was organized on the basis of NUPEC database. The purposes of the benchmark are the encouragement to develop a theoretically-base microscopic approach as well as the comparison of currently available computational approaches. The benchmark consists of two separate phases: void distribution benchmark and DNB benchmark. Subchannel-grade void distribution data was employed for validation of a subchannel analysis code under steady-state and transient conditions. DNB benchmark provided subchannel fluid temperature data which can be used to determine the turbulent mixing parameter for a subchannel code. The NUPEC PWR test facility consists of high pressure and high temperature recirculation loop, a cooling loop, and data recording system[1]. The void fraction was measured by two different methods; A gamma-ray beam CT scanner system was used to determine the distribution of density/void fraction over the subchannel at steady-state flow and to define the subchannel averaged void fraction with an accuracy by ±3%. A multi-beam system was used to measure chordal averaged subchannel void fraction in rod bundle with accuracies of ±4% and ±5% for steady-state and transient, respectively. The purpose of this study is to provide analysis results for PSBT benchmark problems for void distribution, subchannel mixing, and DNB, as well as to evaluate the applicability of some mechanistic DNB models to PSBT benchmark data with the aid of subchannel analysis results calculated by the MATRA code.

2. Analysis

2.1 Description of the experimental data

Void fraction measurement has been performed by NUPEC in a vertical square 5x5 rod array, which simulates a PWR fuel assembly, using an X-ray CT scanner system. The tests were carried out in an out-of-pile test facility under high pressure and high temperature fluid conditions. The experimental data is available for the participants in the OECD/NRC PSBT benchmark program. As a part of this program, the steady-state and transient subchannel void distribution data was assessed by employing a subchannel analysis code MATRA.

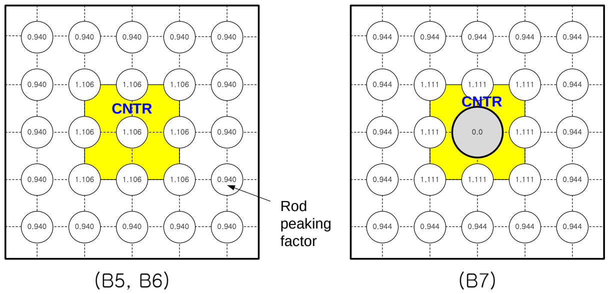

Figure 1. Cross-sectional view of the 5x5 test bundles.

The cross-sectional view of the test bundles and the subchannel nodalization scheme is provided in Fig. 1.

2.2 Subchannel analysis model

A subchannel analysis code MATRA[2] is adopted for the assessment of benchmark exercises. Important models of MATRA code for the analysis of PSBT benchmark are summarized in Table 1.

Table 1. MATRA models for PSBT analysis

Parameters	Values
Two-phase models	
Field equations	HEM
Subcooled boiling	Levy model
Bulk boiling	Mod. Armand model
Two-phase friction multiplier	Armand model
Subchannel interaction models	
Crossflow resistance factor	0.5
TDC for single-phase	0.04
Two-phase mixing model	EM model
Hydraulic Resistance Models	
Bundle friction factor	$0.184\ Re^{-0.2}$
K_{grid} (MV/ NMV/ SS)	1.0/ 0.7/ 0.4

MV: MixingVaned, NMV: Non-Mixing Vaned, SS: Simple Support

2.3 Analysis result

Single subchannel void distribution benchmark provides cross-sectional averaged void fraction at the exit of four different subchannel types found in a PWR assembly: central typical, central thimble, side, and corner subchannel types. The single channel void fraction data was used for the evaluation of void fraction correlations in the subchannel code MATRA. The boiling models described in Table 1 revealed slightly over-prediction of channel exit void fraction for central typical and side subchannels. The mean error and standard deviation of the predicted void fraction(P) minus measured void fraction(M) for the benchmark test series S1 through S4 were calculated by 0.02 and 0.06, respectively.

The benchmark data provided steady-state void fraction averaged over the four central subchannels (CNTR) as shown in Figure 1. The experimental data include chordal averaged void fraction at three axial elevations. The predicted void fraction at three axial levels are compared with corresponding measured data as shown in Figure 2. As the axial elevation increases, the mean error of (P-M) decreases from 0.049 to -0.035 while the standard deviation remains within 0.06 to 0.069 for all axial levels. The maximum error of (P-M) was calculated by 0.11 at the lower elevation of B7 which has central unheated rod and cosine axial power shape. The mean error and standard deviation for all axial levels of test bundles were calculated by 0.014 and 0.073, respectively.

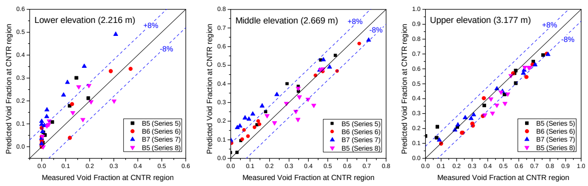

Figure 2. Void fraction at various axial levels

Transient bundle void distribution benchmark provided subchannel averaged void fraction under four transient conditions: power increase (PI), flow reduction (FR), depressurization (DP), and temperature rise (TI). These data are important for the benchmark of the subchannel analysis codes in terms of predicting CHF for reactor transient or accident conditions. The homogeneous equilibrium model employed in the MATRA code revealed the maximum error of (P-M) for the four different transients of PI, FR, DP, and TI as 0.234, 0.216, 0.144, and 0.255, respectively. For the flow reduction transient, the maximum and minimum error of (P-M) were calculated by 0.076/-0.126 for B5, and 0.216/-0.077 for B7. The maximum deviation was found at the lower elevation of of B7 bundle as shown in Figure 3.

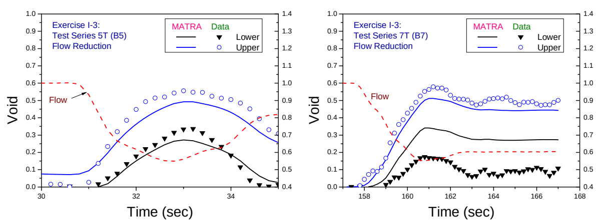

Figure 3. Void fraction for flow reduction transient

3. Conclusion

A subchannel code MATRA was employed for evaluation of void distribution benchmark. For the steady-state subchannel void distribution in test bundles, the mean error and standard deviation were calculated by 1.4% and 7.3%, respectively. MATRA code tended to over-predict the void fraction at the central region at lower elevation, and the maximum mean error was calculated by 11.0% for the test bundle with cosine axial power shape. Similarly, for transient void benchmark, relatively large prediction error was observed at lower elevations.

REFERENCES

[1] A. Rubin, et. al., "OECD/NRC Benchmark Based on NUPEC PWR Subchannel and Bundle Tests (PSBT) Volume I: Experimental Database and Final Problem Specifications", NEA/NSC/DOC(2010)1, Nov. 2010.

[2] Y.J. Yoo, D.H. Hwang, and D.S. Sohn, "Development of A Subchannel Analysis Code MATRA Applicable to PWRs and ALWRs," *J. Korean Nuclear Society*, **31**, 314, 1999.