Assessment of Void Fraction Predictability of System Codes in Subchannel and Bundle geometry

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1. Introduction

The evaluation of the void fraction predictability of system codes in subchannel and bundle geometry is essential to valid its applicability to the detailed evaluation of core thermal hydraulic phenomena during accident conditions. This study aims to assess the void fraction predictability of three different system codes, TRACE V5.0 Patch 5 [1], MARS-KS 1.4 [2], and RELAP5/MOD3.3 Patch 5 [3]. The assessment has been conducted against the experimental data from OCED/NRC PSBT (PWR Subchannel and Bundle Test) benchmark [4]. The test cases under steady-state conditions with subchannel and bundle geometries have been selected to the evaluation.

2. Model description

This section includes description of the model made for three different system codes. For the assessment the model for each system code has been developed consistently to avoid possible discrepancy in results by the nodalization and user effect.

2.1. Single Subchannel Model

As depicted in Table I, four different types of test section are employed to each test series, and Fig. 1 shows the nodalization of the test section for each system code. The height of the test section is 1555 m and the void measurement was conducted at an elevation of 1400 m. The test section is modeled by one pipe component with 24 axial nodes, and near the measuring point fine mesh volumes with a length of 0.02 m are used to obtain more precise void fraction. MARS-KS and RELAP5 use time dependent volume and time dependent junction components, and TRACE uses fill and break component for upstream and downstream, respectively. The heater is modeled by means of a heat structure component and the power to the heater is given by a control variable.

2.2. Bundle Model

Table II shows the specification of the test section used in bundle test, and the nodalization is depicted in Fig. 2. The heated length of the test section is 3.658 m and the void measurement was done at three different measuring points, upper (3.177 m), middle (2.669 m), and lower (2.216 m) respectively. The test section is modeled by two pipe components with 24 axial nodes as distinguished by radial power distribution, and each flow channel is connected by cross flow junctions. There are two volumes connecting those pipe components to the flow path for upstream and downstream, respectively. Time dependent components are modeled for the same purpose as those in the single channel models. The test section is equipped with three different kinds of spacer grids. The pressure drop due to the spacer is modeled by Reynolds number independent loss coefficients given by the specification [4]. The heater rods are modeled by using the heat structure to each pipe component considering the radial power distribution. Total power is given by the control variable.

Table I: Single Subchannel Test Section Geometry

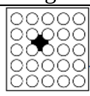
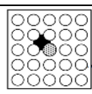
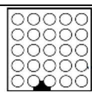
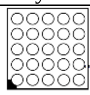
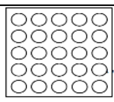
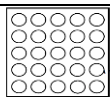
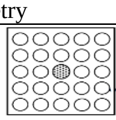
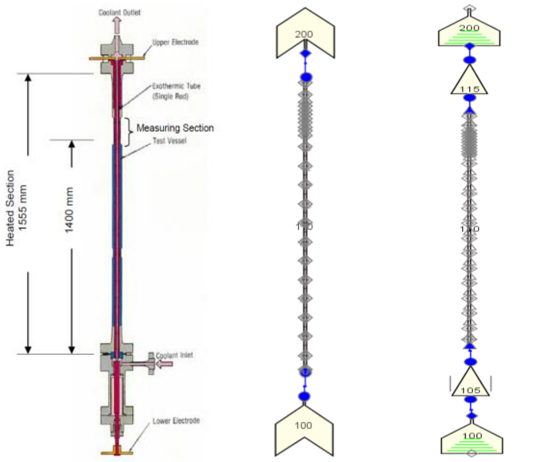
Test section	 S1	 S2	 S3	 S4
Type	Center (Typical)	Center (Thimble)	Side	Corner
(#) of heaters	4 x 1/4	3 x 1/4	2 x 1/4	1 x 1/4

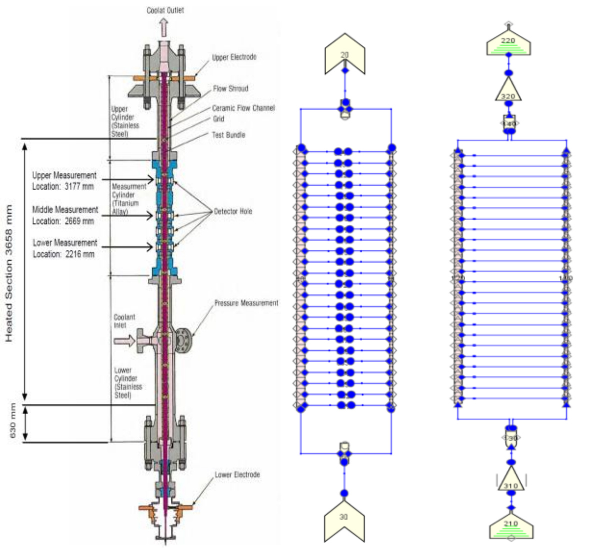
Table II: Bundle Test Section Geometry

Test section	 B5	 B6	 B7
(#) of heater rods	25	25	24
(#) of thimble rods	-	-	1
Radial power shape	0.85 0.85 0.85 0.85 0.85 0.85 1.00 1.00 1.00 0.85 0.85 1.00 1.00 1.00 0.85 0.85 1.00 1.00 1.00 0.85 0.85 0.85 0.85 0.85 0.85	0.85 0.85 0.85 0.85 0.85 0.85 1.00 1.00 1.00 0.85 0.85 1.00 1.00 1.00 0.85 0.85 1.00 1.00 1.00 0.85 0.85 0.85 0.85 0.85 0.85	0.85 0.85 0.85 0.85 0.85 0.85 1.00 1.00 1.00 0.85 0.85 1.00 0.00 1.00 0.85 0.85 1.00 1.00 1.00 0.85 0.85 0.85 0.85 0.85 0.85
Axial power shape	Uniform	Cosine	Cosine
(#) of MV spacer	7	7	7
(#) of NMV spacer	2	2	2
(#) of Simple spacer	8	8	8



(a) Single channel (b) TRACE (c) MARS and RELAP5

Fig. 1. Single channel test section and nodalization of each system code



(a) Bundle (b) TRACE (c) MARS and RELAP5

Fig. 2 Bundle test section and nodalization of each system code

3. Results

The assessment of the void fraction predictability using three different system codes has been conducted. All the test cases selected are under steady-state conditions. 125 test cases for single subchannel and 221 cases for bundle test have been assessed.

3.1. Single Subchannel test

Fig. 3 shows the results of void fraction calculated by each system code against the experimental data in each test series, and Fig. 4 depicts the plot of void fraction results for all cases. The statistical analysis results are summarized in Table III. The hypothesis test is performed to confirm whether the mean absolute error is located within 2σ of CT measurement error with a confidence of 95%. The results show that all the codes generally predict the void fraction without significant discrepancy from two standard deviations. Considering the adjusted R^2, MARS-KS and RELAP5 have systematical characteristics by a linear function, and in the case of TRACE the prediction characteristics could be approximately correlated by linear function with an accuracy of 87.6%. However, all the codes show overprediction in low void fraction condition and subsequently underpredict in high void fraction condition. This causes the standard deviation of average error being relatively high even though the mean error is very small. The tendency could be identified clearly from the residuals of the experimental data against the linear regression as depicted in Fig. 5. With comparison of the calculated results of absolute error it is shown that TRACE predicts the void fraction with higher error than MARS-KS and RELAP5.

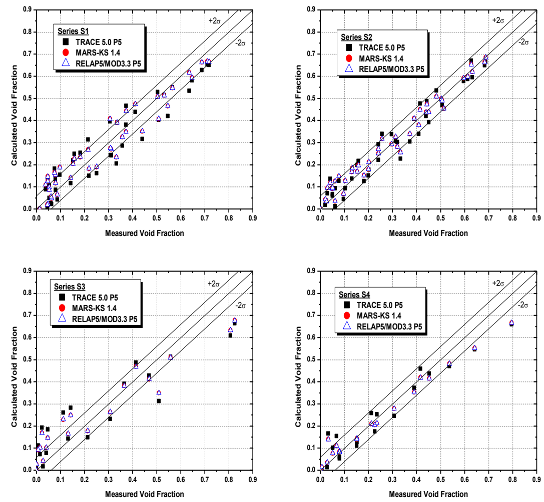


Fig. 3 Calculated void fraction results of each test series in single subchannel test

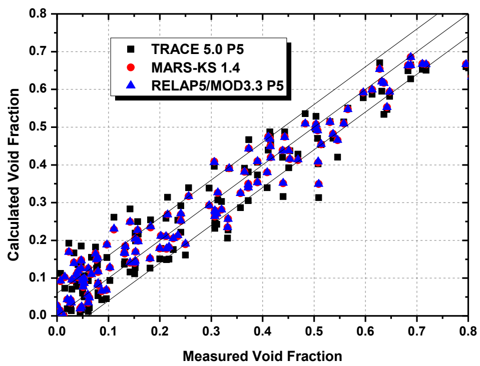


Fig. 4 Calculated void fraction results of call cases in single subchannel test

Table III: Summary of statistical results in single channel test

Code	TRACE	MARS	RELAP5
mean error	-3.22e-3	4.47e-3	4.77e-3
Standard deviation of average error	6.24e-3	5.11e-3	5.11e-3
Adjusted R^2	0.876	0.915	0.915
Mean absolute error	5.54e-2	4.39e-2	4.39e-2
Standard deviation of mean absolute error	4.21e-2	3.67e-2	3.66e-2
t Statistic	-1.21	-4.90	-4.91
Probability > t	0.886	1	1
Results of hypothesis test at 0.05 level	The average of the mean absolute error is NOT significantly greater than the test mean (2σ)		

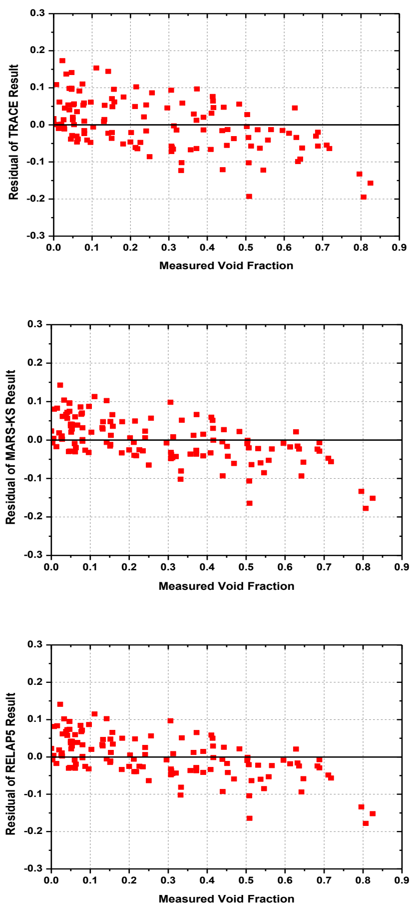


Fig. 5 Residuals of the experimental data against the linear regression

3.2. Bundle test

Fig. 6 shows the results of calculated void fraction of all cases distinguished by each measuring point, lower, middle, and upper respectively, and the plot of all calculations is depicted in Fig. 7. It is shown that TRACE predicts the void fraction higher than other codes, and the results from MARS-KS and RELAP5 are almost identical. As depicted in Table IV, all the codes fail to predict the void fraction with an error range of 2σ. Due to the higher error and scattering of the prediction, the predictability of each code decreases compared to the single channel results. However, it is clearly shown that all codes predict higher error in lower point, whereas the middle and upper are generally predicted in the range of 2σ. In addition, Table V indicatess that prediction under 30% void fraction shows higher error, whereas the opposite predicts within 2σ. This tendency could be also identified in the summary of PSBT benchmark [5], The same conclusion is obtained as in the single channel test. The system codes overpredict the void fraction in low void condition, and it leads to the need for further investigation on the subcooled boiling regime.

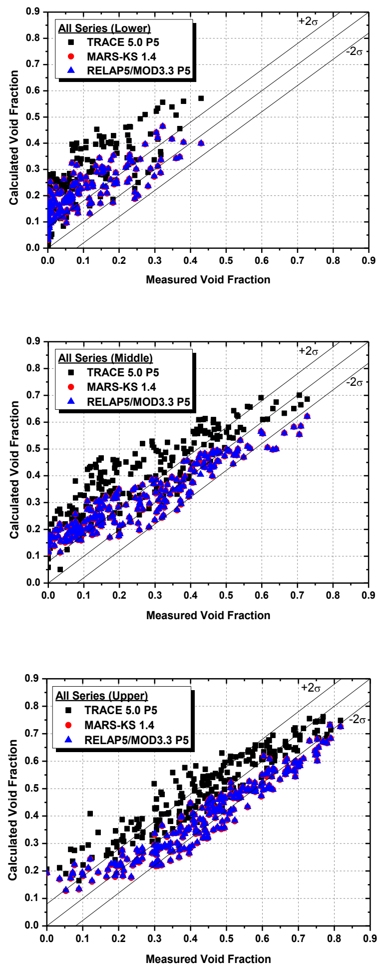


Fig. 6 Calculated void fraction results of all cases distinguished by measuring points

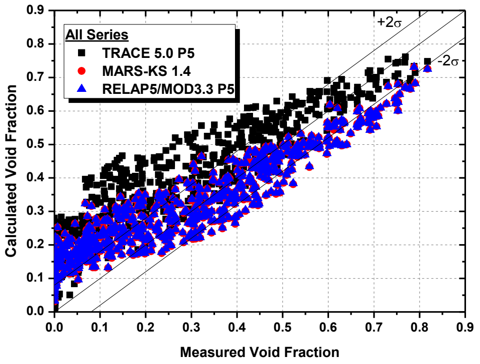


Fig. 7 Calculated void fraction results for all test series

Table IV: Summary of statistical results in bundle test

Code	TRACE	MARS	RELAP5
All cases			
mean error	1.12e-1	3.82e-2	3.94e-2
Standard deviation of average error	8.87e-2	9.30e-2	9.30e-2
Adjusted R^2	0.759	0.602	0.598
Mean absolute error	1.19e-1	8.64e-2	8.66e-2
Standard deviation of mean absolute error	7.98e-2	5.16e-2	5.18e-2
Hypothesis test	The mean absolute error is significantly greater than 2σ at 0.05 level?		
All cases	Y	Y	Y
Lower	Y	Y	Y
Middle	Y	N	N
Upper	N	N	N

Table V: Statistical results by void fraction

Code	TRACE	MARS	RELAP5
Mean absolute error (void < 0.3)	1.55e-1	1.05e-1	1.06e-1
Standard deviation (void < 0.3)	7.63e-2	5.11e-2	5.11e-2
Mean absolute error (void ≥ 0.3)	6.78e-2	6.01e-2	5.97e-2
Standard deviation (void ≥ 0.3)	5.19e-2	3.95e-2	3.95e-2
Hypothesis test	The mean absolute error is significantly greater than 2σ at 0.05 level?		
Void < 0.3	Y	Y	Y
Void ≥ 0.3	N	N	N

4. Conclusion

The void fraction predictability of the system codes, TRACE, MARS-KS, and RELAP5, have been assessed against experimental results from OECD/NRC PSBT benchmark. The calculated results for single channel cases indicate that all the system codes systematically overpredict the void fraction in low void conditions, and the overprediction tendency could be also identified in bundle cases whereas in high void condition the prediction lies within 2σ. The statistical investigation confirms that TRACE results in higher prediction error compared to MARS-KS and RELAP5. The overprediction tendency is confirmed clearly for under 30% void fraction condition. Thus, further assessment on the subcooled boiling regime should be performed.

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