Void Fraction Predictability of System Codes Based on PSBT Bundle Test

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1. Introduction

This study has been conducted to assess and compare the void fraction predictability of the system codes, MARS-KS 1.4 [1] and TRACE V5.0 patch5 [2], based on OECD/NRC PSBT benchmark data [3]. The assessment has been performed using one- and multi-dimensional model of each system code, respectively. Therefore, in addition to the code-to-code comparison, the predictability of multi-dimensional component of each system code has been assessed against the one-dimensional model. In total, 219 cases from steady-state bundle test have been utilized to this assessment.

2. Model Description

The reference of assessment model is NUPEC Test facility, which consists of high pressure and temperature recirculating loop. More detailed description about the test facility is available in the reference [3]. In this section, description of the assessment model for each system code is made, based on brief introduction to the steady-state bundle test.

2.1 Test Conditions for Steady-state Bundle Test

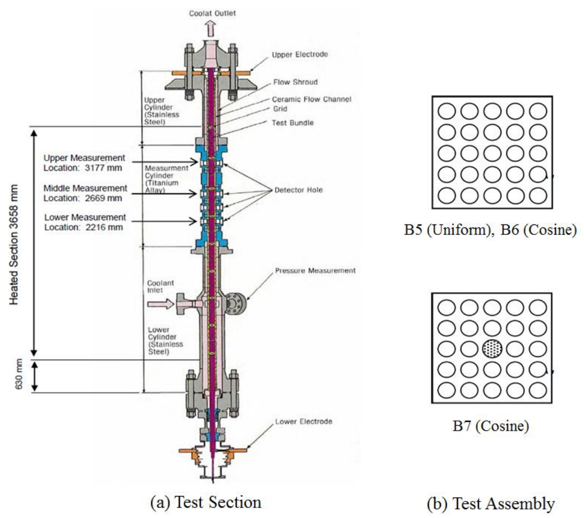


Fig. 1. Test section used in bundle test

As depicted in Fig. 1, total heated length is 3.658 m, and the void measurements are conducted along the heated section at three different measuring points: lower (2.216 m), Middle (2.669 m), and Upper (3.177 m). At each measuring point, the void fraction is measured at four-central subchannels as depicted in Fig. 2. There are three-different test series, namely B5, B6, and B7. The difference between each test series comes from test geometry, or axial power condition. Especially, B7 test utilizes the test assembly containing a thimble rod, which has no electrical heat generation, at the center of the channel.

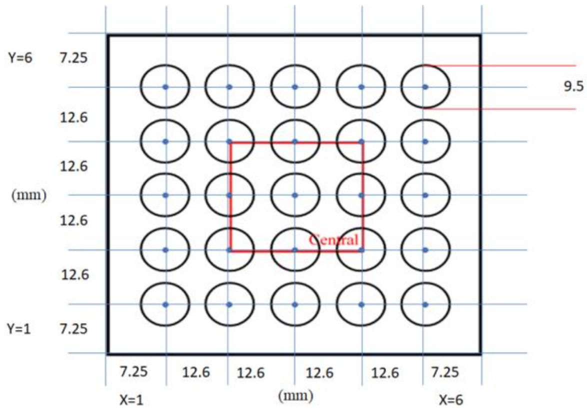
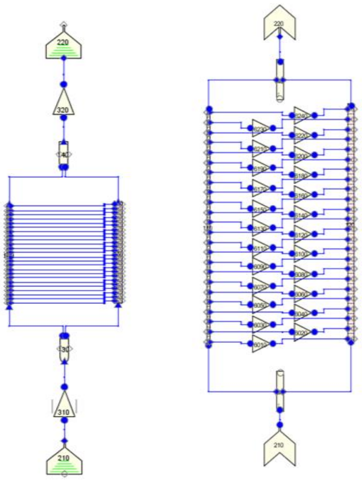


Fig. 2. Cross-sectional view of test channel

2.2 One-dimensional Model

As shown from the nodalization of each system code in Fig. 3, the heated section is implemented by two channels, which are modeled by pipe component with 24 axial levels, and both channels are connected by multiple junctions for the cross-flows between them. Additional hydraulic volume is connected at the upstream and downstream respectively, in order to distribute and gather the flow for each channel. The boundary conditions are given through the connection with the time dependent components. In case of MARS-KS, time dependent volume and junction component are connected for the flow conditions at upstream and downstream respectively. By the way, in TRACE, fill component is connected to give the upstream flow conditions, and for the downstream flow conditions, break component is connected. The implementation of the electrical heating to each channel is conducted by heat structure component, and one heat structure is modeled to each channel. That is, for the central channel, one heat structure implements the equivalent heating from 9 heater rods, and the other implements 16 heater rods within peripheral volume.

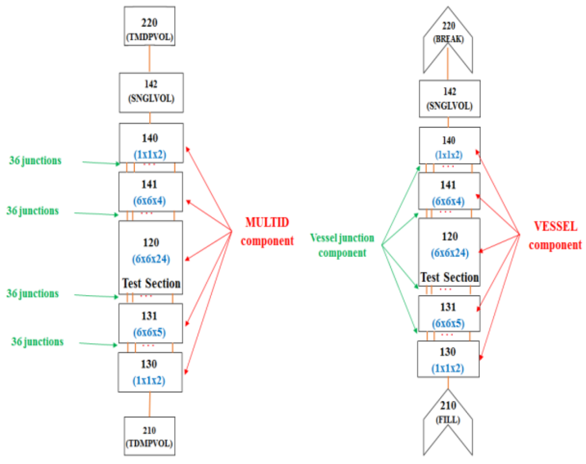


(a) MARS-KS (b) TRACE

Fig. 3. Nodalization of one-dimensional model

2.3 Multi-dimensional Model

As depicted in Fig. 2, the test section consists of 36 subchannels. Therefore, 36 subchannels are modeled with 24 axial levels for the multi-dimensional model of each system code. As depicted in Fig. 4, in case of MARS-KS, MULTID component is utilized to model the heated section. And, in case of TRACE, VESSEL component is utilized. In addition to the heated section, additional multi-dimensional hydraulic volumes are connected at upstream and downstream, in order to prevent the flow concentration to the central channels. Interconnection between multi-dimensional components is made by multiple junctions. As done in one-dimensional model, the boundary conditions are given by the time dependent components of each system code. By the way, the implementation of the electrical heating is made by modeling one heat structure as an averaged heater rod to each subchannel. Therefore, in total, 36 heat structures are modeled to the heated section.

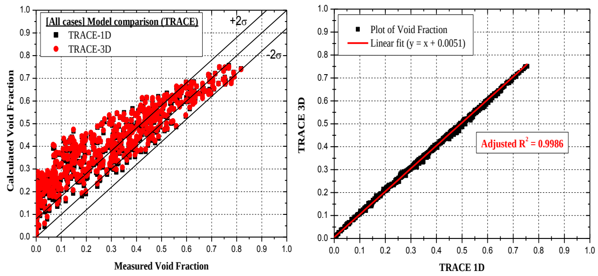


(a) MARS-KS (b) TRACE

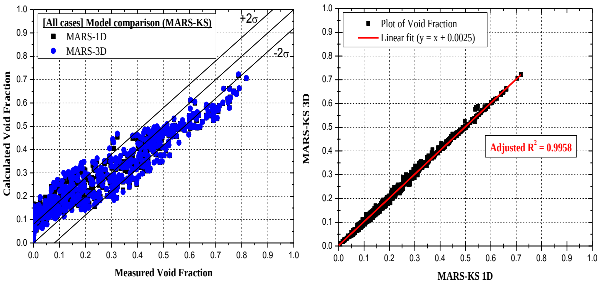
Fig. 4. Nodalization of multi-dimensional model

3. Calculation Results

Based on 219 steady-state bundle test cases, void fraction calculations of each system code have been conducted. The calculated void fraction of each system code's model is plotted against the measured void fraction data, and the results are depicted in Fig. 5 and Fig. 6, respectively. Fig. 5 shows the results of model comparison of each system code, and the results indicate that there is no significant difference between the one- and multi-dimensional model for both system codes. This conclusion is clearly supported by high adjusted R^2 of the linear fit to the plots of 3D model against 1D model in both system codes. Although the calculated results of 3D model for both system codes show slightly higher prediction tendency compared to 1D model, this difference is quite small and, thus, negligible.



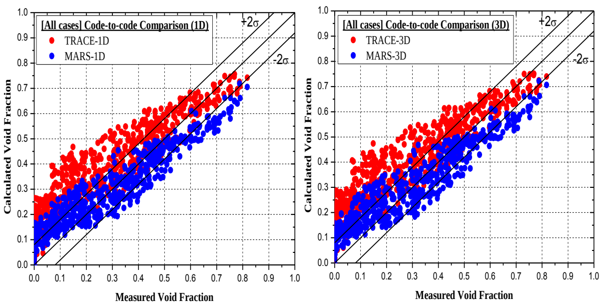
(a) TRACE



(b) MARS-KS

Fig. 5. Model comparison of each system code

By the way, it is found that TRACE generally predicts higher void fraction compared to MARS-KS. And this tendency is commonly captured for both 1D and 3D model calculations, as depicted in Fig. 6.



(a) 1D (b) 3D

Fig. 6. Code-to-code comparison of calculated results

For the assessment of the predictability of each system code, one sample t-test is performed, and it confirms whether the calculated absolute errors against measured data have significant deviation from 2σ error range, of which σ is given as a measurement error for bundle tests. The results of one sample t-tests are listed in Table I to Table III, and it is concluded that the system code MARS-KS shows better void fraction predictability compared to TRACE. By the way, it is found that TRACE generally shows significant overprediction tendency at the low void region where the void fraction is below 30%, whereas both system codes show no significant deviation from the measured error, beyond the void fraction 30%. Moreover, it is remarked that the region below the void fraction 30% is normally defined as dispersed-bubbly flow regime in TRACE. Therefore, in order to clearly define the reason of such overprediction tendency of TRACE, more investigation with calculated heat transfer coefficient is necessary based on the comparison of heat transfer package in each system code.

Table I: One sample t-test for all plot data

	TRACE 1D	TRACE 3D	MARS 1D	MARS 3D
Mean	1.11E-2	1.16E-2	7.26E-2	7.27E-2
STDEV	7.62E-2	7.79E-2	4.15E-2	4.28E-2
Mean>2σ	Y	Y	N	N
t Value	10.57	11.79	-4.59	-4.39
Prob>t	1.59E-24	1.52E-29	1.00	1.00

Table II: One sample t-test for plots below void 30%

	TRACE 1D	TRACE 3D	MARS 1D	MARS3 D
Mean	14.51E-2	15.25E-2	7.59E-2	7.73E-2
STDEV	7.43E-2	7.38E-2	3.97E-2	4.18E-2
Mean>2σ	Y	Y	N	N
t Value	17.14	19.20	-2.02	-1.24
Prob>t	1.65E-49	2.94E-58	9.78E-1	8.93E-1

Table III: One sample t-test for plots beyond void 30%

	TRACE 1D	TRACE 3D	MARS 1D	MARS3 D
Mean	6.46E-2	6.48E-2	6.79E-2	6.62E-2
STDEV	4.93E-2	4.95E-2	4.36E-2	4.33E-2
Mean>2σ	N	N	N	N
t Value	-5.19	-5.08	-4.59	-5.28
Prob>t	1.00	1.00	1.00	1.00

4. Conclusion

The void fraction predictability of the system codes, MARS-KS 1.4 and TRACE V5.0 patch5, have been assessed against the experimental data from PSBT. The assessment has been conducted with two objectives: One is the comparison of predictability between one- and multi-dimensional model of each system code, and the other is the code-to-code comparison. As a result, it is concluded that no significant difference between one- and multi-dimensional model is captured for both system codes. However, through the code-to-code comparison, it is found that MARS-KS shows better predictability compared to TRACE. And TRACE shows significant overprediction tendency at low void region below the void fraction 30%, which is normally defined as an upper limit of dispersed-bubbly flow regime in TRACE. Therefore, as a future work, the investigation of heat transfer coefficient will be made based on the comparison of heat transfer package in each system code. Furthermore, since the low void region belongs to subcooled boiling regime, an additional assessment will be performed with subcooled boiling regime.

Acknowledgements

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