Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Assessment Using ANL Experiments on Void Fraction in a Vertical Tube

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1. Introduction

A licensing application of a safety analysis code, SPACE, was submitted and is currently under KINS' review. This code was developed to consider three fluid fields, i.e. liquid, vapor and droplet, for a realistic simulation of accident phenomena. Therefore, there may be a concern that this code could predict different behavior compared to the existing codes. To assess the important performance independently and to compare with prediction results of SPACE might be helpful to regulatory review for identifying validity of the code. The interfacial friction could largely affect prediction of thermal hydraulic phenomena during LOCA or non-LOCA. This paper provides MARS-KS prediction of void fraction experiments in a vertical tube by ANL and compares with SPACE prediction results.

2. The experiment and modeling

2.1 The ANL vertical tube experiments

The vertical air-water mixture flow experiments were performed in natural-circulation loops. The loops consisted of two vertical legs known as the riser and downcomer, respectively, which were connected at the top to a vented separator tank; a horizontal pipe made the connection at the bottom. The gas and the liquid were mixed in a special mixer sleeve at the bottom of the riser. The liquid was recirculated through the downcomer. Schematic representation of the loop is given in Fig. 1.

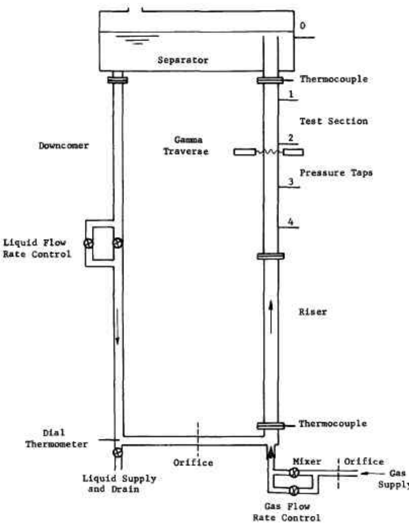

Fig. 1. Schematic representation of air-water loop

The liquid was introduced into the loop through a supply line at the bottom of the downcomer. The air-water experiments were made with regular tap water. The air for the air-water experiments was supplied by the laboratory 100-psi compressed-air line. The riser was a 2.75-in.(7cm)-ID Lucite pipe, 124.5 in. long, made from two equal sections. The upper 5ft was considered as the actual test section in which four pressure taps were mounted. [1]

A total of 161 void fraction measurements with different combinations of air velocity and liquid velocity were made in this experiments. Among them, the licensee presented 47 measurements for the purpose of the verification of the code SPACE, which is shown in Table 1.

Table 1. Selected experimental data

No	Run	Water velocity (m/s)	Air velocity (m/s)	Air/Water velocity ratio	Void fraction
1	A-1	0.000	0.875	-	0.597
2	A-2	0.000	0.835	-	0.600
3	A-3	0.000	0.771	-	0.584
4	A-4	0.000	0.704	-	0.553
5	A-5	0.000	0.637	-	0.553
6	A-6	0.000	0.561	-	0.514
7	A-7	0.000	0.430	-	0.481
8	A-8	0.000	0.296	-	0.419
9	A-9	0.000	0.210	-	0.339
10	A-15	0.000	2.027	-	0.733
11	A-16	0.000	1.426	-	0.689
12	A-17	0.000	1.012	-	0.619
13	A-18	0.000	0.802	-	0.577
14	B-1	0.030	2.067	68.900	0.703
15	B-5	0.030	0.796	26.533	0.559
16	B-10	0.030	0.747	24.900	0.566
17	B-11	0.030	0.515	17.167	0.475
18	B-12	0.030	0.341	11.367	0.419
19	B-13	0.030	0.217	7.233	0.303
20	B-14	0.030	0.048	1.600	0.108
21	B-16	0.030	0.032	1.067	0.067
22	C-1	0.061	2.070	33.934	0.694
23	C-2	0.061	1.417	23.230	0.644
24	C-3	0.061	0.945	15.492	0.578
25	C-9	0.061	0.509	8.344	0.475
26	C-10	0.061	0.287	4.705	0.377
…	…	…	…	…	…
38	G-4	0.244	0.677	2.775	0.425
39	G-8	0.244	2.807	11.504	0.659
40	G-10	0.244	1.628	6.672	0.589
41	G-11	0.244	1.183	4.848	0.534
42	G-17	0.244	4.676	19.164	0.709
43	H-1	0.305	3.417	11.203	0.659
44	H-2	0.305	2.874	9.423	0.652
45	H-3	0.305	2.426	7.954	0.647
46	H-4	0.305	2.012	6.597	0.613
47	H-5	0.305	1.759	5.767	0.609

2.2 Code models

The code models of interfacial friction used to predict ANL experiments are as given in the Table 2 for MARS-KS and SPACE. Both codes incorporate similar correlations for vertical bubbly-slug flow. However, the detailed model in the codes cannot be compared and two similar models may lead to different predictions. Thus, comparison of the code assessment results will be requested.

Table 2. Drift flux void fraction correlations for vertical bubbly-slug flow

Flow rates (kg/m^{2}s)	MARS-KS (0.018m<D<0.08m)	SPACE (0.018m<D<Dcrit)
G>100	Chexal-Lellouche	Chexal-Lellouche
50<G<100	Transition	Transition
0<G<50	Churn-turbulent bubbly flow, transition, Kataoka-Ishii	Kataoka-Rouhani

2.3 Vertical tube calculation model

The licensee modeled the vertical air-water mixture upward flow for the SPACE calculation. Mainly the riser part was considered with PIPE component composed of 10 horizontal nodes as the boundary conditions are clearly given. The gamma detector was placed at the 7th node from the bottom (inlet) of the tube for measuring void fraction. As described in section 2.1, air and water are supplied through the inlet of the tube and the outlet pressure is set at atmospheric pressure.

In the MARS-KS calculations, a vertical tube with 10 nodes of a PIPE component was used, which is almost identical to the licensee's modeling method. Two sets of time-dependent volumes and junctions were defined for air and water injections, respectively. The air and water are then mixed in the mixer which is modeled as a BRANCH component, and the mixture gets into the bottom of the tube. The outlet of the tube is connected with a single junction and a time-dependent volume which is set at 1atm. Figure 2 illustrates MARS-KS model of the vertical tube experiment.

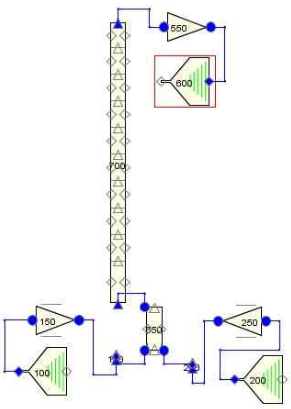

Fig. 2. MARS-KS model for the vertical tube experiment

3. Calculation results

In this study, a total of 47 experimental results were calculated using MARS-KS code. Liquid velocities vary from 0m/s to 0.305m/s and air velocities from 0.032m/s to 4.676m/s. The experimental void fraction came out to be from 0.067 to 0.733 and our calculation results are presented along with the license applicants' predictions.

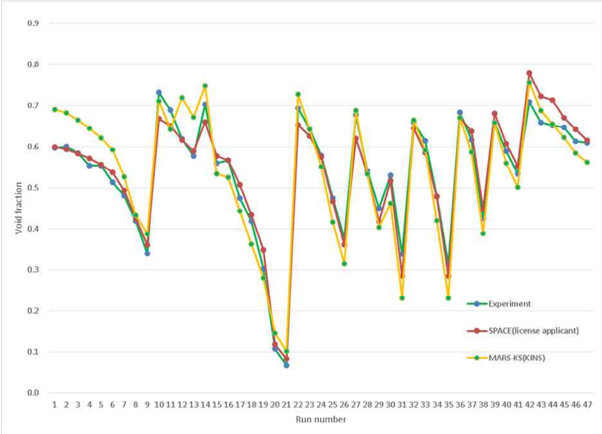

Fig. 3. Forty seven experimental data with predictions

Lower run numbers correspond to slower liquid velocities and faster gas velocities with some regular intervals as given in Table 1. Except zero liquid velocity and intermediate gas velocities (0.5m/s< v <1m/s), run numbers 1 through 6, 12 and 13, overall MARS-KS predictions agree well with experimental data and SPACE calculations. The statistical data shown in Table 3 also show good agreements between two codes.

Table 3. Statistics of calculation/experiment ratio

	MARS-KS/Experiment	SPACE/Experiment
μ	1.007	1.011
σ	0.143	0.068

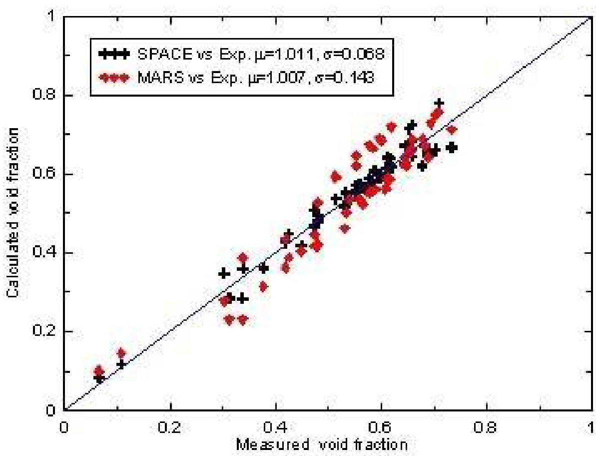

Fig. 4. Comparison of void fraction calculations

In a slight different presentation of the calculation results given in Fig. 4, the calculations by MARS-KS code generally agree well with experimental values and SPACE calculations. However, an empty space is found in the void fraction region ranging from 0.108 to 0.303, which necessitates further study.

4. Conclusions

In order to support regulation, comparison of drift flux interfacial friction models of SPACE code and MARS-KS code for ANL vertical tube experiment was made. It was found that the similar interfacial friction model adopting the drift flux correlations were implemented in both codes. Experimental void fractions of the ANL test presented in this paper correspond to bubbly, slug and churn flow regions. Agreements in general sense between the experiment and the predicted values were identified through calculations. Thus, similar accuracy for this experiment can be expected in SPACE and MARS-KS. It was also shown that drift flux interfacial friction model for intermediate flow channel (diameter of 7cm) is valid.

REFERENCES

[1] G. E. Smissaert, Two-component two-phase flow parameters for low circulation rates, AEC Research and Development Report, ANL-6755, July 1963.

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[3] SPACE 2.14 MANUAL Volume 5: Auxiliary equations manual, July 2013