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MARS-KS Assessment of TRACE Fundamental Problems

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Abstract

MARS-KS has been developed for a realistic analysis of thermal hydraulic transients in nuclear power plants. This study is intended to provide additional validation of the MARS-KS code by solving TRACE fundamental test problems. A total of five simple problems are used to evaluate the MARS code: Oscillating manometer for liquid motion in a frictionless U-tube manometer, ANL vertical two-phase flow tests for adiabatic two-phase upward-flow in a simple vertical pipe, TPTF horizontal flow tests for horizontal two-phase flow in a relatively large-diameter pipe, single tube flooding (test of CCFL model) for comparison of code void fraction predictions against experimental data, and CISE adiabatic tube for vertical upward two phase flow. Each assessment includes examined whether unphysical deviation exists, and in case where analytical solution exists, the accuracy of the code were evaluated. It seems to us that are caused by flow regime model in MARS code. Other than that, MARS results agree fairly accurately with the analytical solutions and TRACE results, which demonstrate that the predictions of the thermal-hydraulic behavior in MARS-KS are accurate.

1. Introduction

The main objectives of this study were to offer the additional validation data of MARS(Multi-dimensional Analysis for Reactor Safety – Korea Standard) code [1] by solving TRACE(The TRAC/RELAP Advanced Computational Engine) fundamental test problems [2]. A total of five simple problems were used to evaluate the MARS code. This study is to investigate base capabilities of MARS for predicting the behaviour of nuclear power plant. For this investigation, comparing code predictions against experimental data and the physics were conducted.

2. MARS-KS Assessment

2.1. Oscillating Manometer

The oscillating manometer, selected for the assessment, consists of the U-tube shaped frictionless pipe of constant cross-sectional area, 0.01 m^2 containing a water column of length L, and modelled as shown in Fig.1. The total length of the manometer is 20 m and its cross-sectional area is 0.01 m^2. The system is filled with water and air so that both arms of manometer, which is 5 m from the bottom. Initial conditions are an initial water level of 5.0 m and an initial velocity of 2.1 m/s. With these initial conditions, the analytical solutions are as follows. Actually, in MARS-KS 1.2 Version, the code did not correctly predict the amplitude of the oscillation of liquid level. However, recently KAERI corrected the MARS code, in which this error was fixed as shown in the Fig. 2. The result is in excellent agreement with the analytical solution.

$$x(t) = 5.0 - \frac{2.1}{\sqrt{2\frac{g}{L}}} sin\left(\sqrt{2\frac{g}{L}t}\right) \quad (1)$$

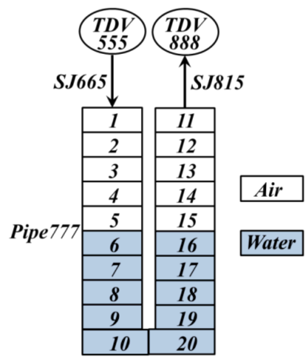

Figure 1. MARS nodalization of the manometer.

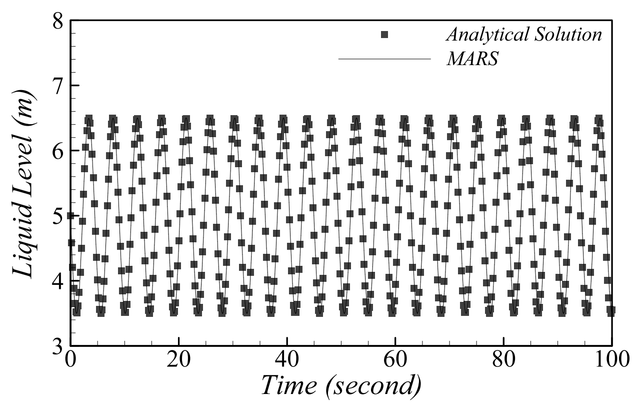

Figure 2. Variation of liquid level for the manometer problem

2.2. ANL Vertical Two-phase Flow Tests

Next topic is about the assessment of Argonne National Laboratory (ANL) vertical two-phase flow tests. The modeling of the two-phase flow behavior is important for the realistic prediction of the coolant inventory distribution. The objective of this test is to examine MARS base capabilities for predicting the behavior of adiabatic two-phase upflow by comparing code prediction against experimental data and TRACE results. The experimental data is obtained by ANL. The test section modelled is represented by a vertical PIPE component with ten volumes. The air-water mixer is modeled by a Branch component with two single volumes. And for defining initial boundary conditions for air and water injection, two Time-Dependent Volumes and Junctions are used.

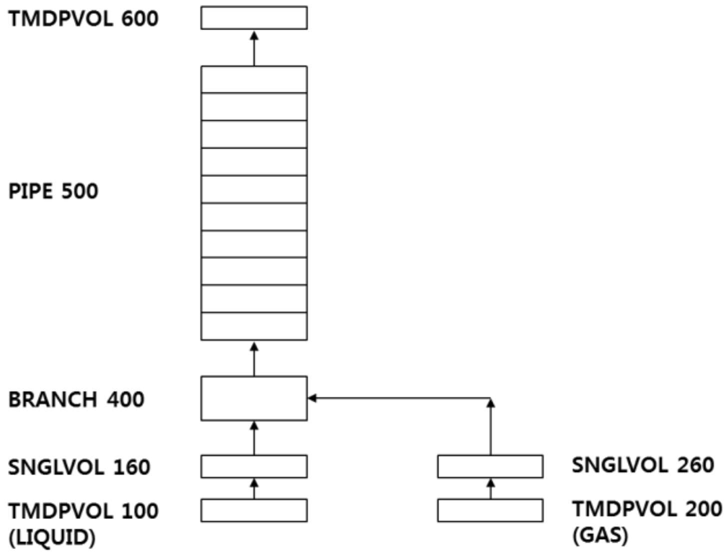

Figure 3. Nodalization scheme of the ANL loop MARS model

The ANL loop test runs consisted of seven test series that comprise 161 tests in total. But in this study, only 47 test runs in TRACE assessment manual are used [6]. Below two figures show the comparison results of predicting void-fraction. The first figure shows the result of MARS and second figure shows the result of TRACE. In these figures, horizontal and vertical axes represent the experimental measurement and the simulation results, respectively. The predicted void-fraction of MARS is bounded about +/- 0.1 void range, while TRACE bounded in +/- 0.05 range.

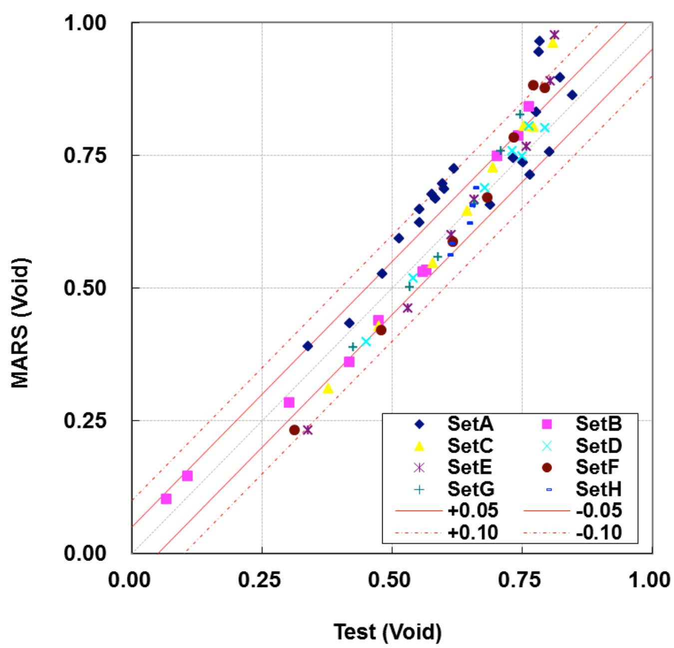

Figure 4. Comparison of MARS predicted and measured void fractions

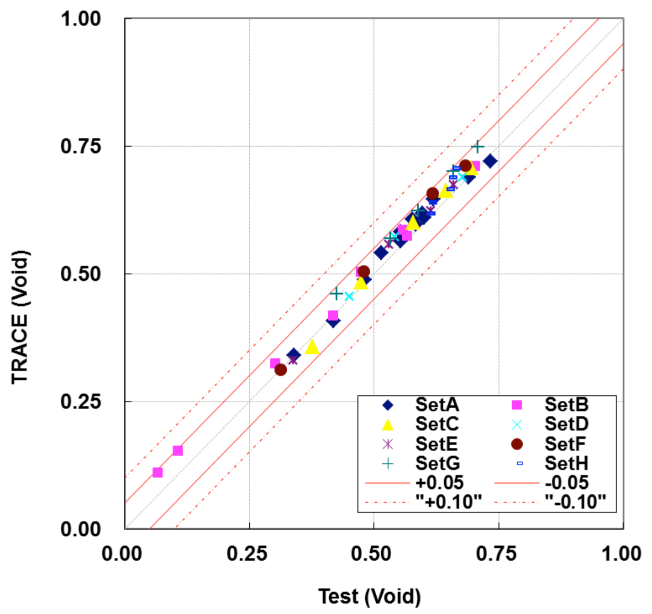

Figure 5. Comparison of TRACE predicted and measured void fractions

As seen from figure 4, almost data points were obtained scatter within 0.1 void fraction differences. However, the predicted void fractions with the test series A (in the case of the liquid superficial velocity is equal to zero) and the highly voided two-phase conditions were exhibited significant differences.

In figure 5, it shows that TRACE results were good agreement within 0.05 void fraction differences. It is needed to check the predictions with the highly voided two-phase conditions, and compare to MARS results.

Table 1. Summary of ANL Air-Water Tests applied for MARS Assessment [2]

Test Set	J_L (m/s)	J_G (m/s)	Void (-)
A	0.000	0.210 – 7.248	0.339 – 0.847
B	0.031	0.032 – 3.664	0.067 – 0.763
C	0.061	0.287 – 7.431	0.377 – 0.809
D	0.091	0.482 – 7.254	0.450 – 0.794
E	0.122	0.283 – 10.970	0.338 – 0.813
F	0.183	0.296 – 10.994	0.313 – 0.794
G	0.224	0.677 – 7.001	0.425 – 0.747
H	0.305	1.759 – 3.417	0.609 – 0.659

2.3. TPTF Horizontal Flow Tests

Next assessment is for two phase horizontal flow tests. The objective was to examine MARS prediction capabilities for the behavior of horizontal two-phase flow in a large-diameter pipe via comparing void fraction predictions against experimental data obtained at the TPTF(Two Phase Test Facility). The TPTF facility consisted of a horizontal test section discharging into a large vertical vessel. The test section was a 10 m long with an internal diameter of 0.18 m. The vessel water was heated to the saturated condition at the desired pressure from 3.0 to 8.6 MPa [3]. Steam and water were supplied into mixer, and then injected into test section. The water level in the vessel was adjusted either above or below the test section outlet, which simulate hot/cold leg exit flow conditions. Void fractions were measured at L/D 17 and 48. At code prediction, void fraction at L/D 17 was used as a boundary condition, and void fraction at L/D 48 was predicted. Predicted void fraction was compared with experimentally measured value.

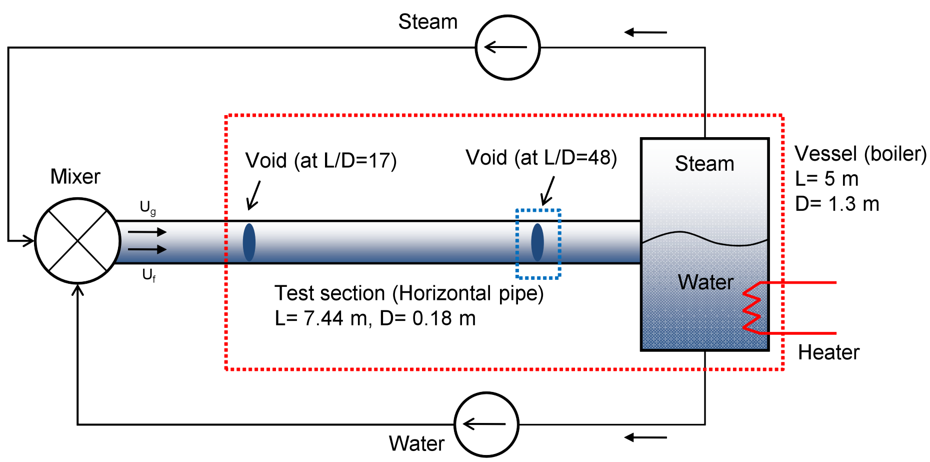

Figure 6. Experimental setup

Three different nodalizations were prepared for validation of the modeling and for proper simulation the water level in the vessel. The differences are in the vessel modeling. First one has the simplest node. It consists of two TMDPVOLs, a TMDPJUN, a PIPE, and a SNGLJUN. In this case, it is not available to simulate the exit level condition of test section due to lack of vertical vessel. For exit water level adjustment, single volume was inserted between pipe and time-dependent volume at case 2. In case3, vertical vessel was changed to pipe instead of single volume. In addition, a time-dependent volume was added, so that steam and water can flow separately. Code options and boundary conditions were given without discrimination. The results of three nodalizations were compared. There was little difference among the three different nodalizations.

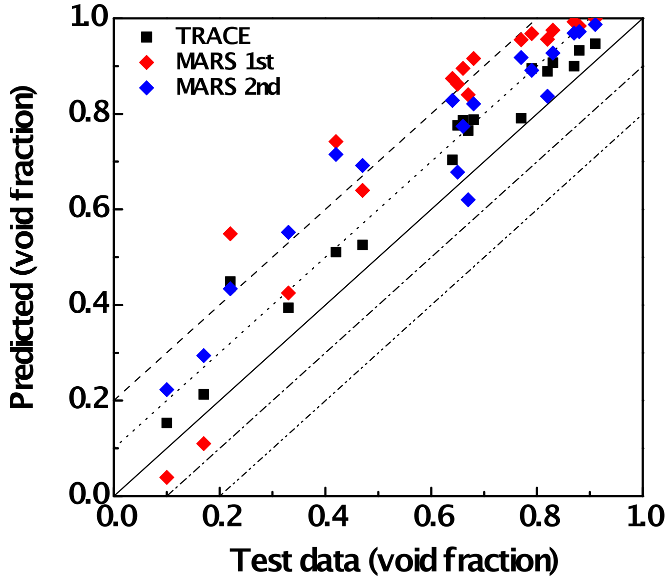

Figure 7. Bubbly flow type mixer

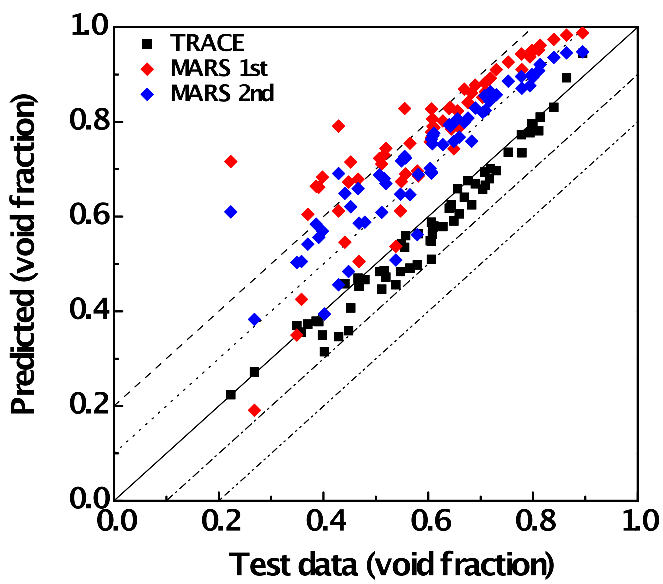

Figure 8. Separated flow type mixer

Upper two figures show the results of calculated void fraction at both MARS and TRACE. Trace predicted higher void fraction in bubbly mixer test case, and lower void fraction in separated mixer test case. On the other hand, MARS predicted higher void fraction at all cases with a little higher error. The prediction point was saturated temperature at high pressure. Void fraction is very sensitive to predicted pressure value inside pipe flow. So, there could be large errors in void fraction if the pressure loss across the pipe flow was not exactly predicted.

2.4. Test of MARS CCFL Model

Counter current flow limiting (CCFL) is an important phenomenon in nuclear reactor safety. During a large break loss of coolant (LBLOCA) accident in pressurized water reactor (PWR), counter current flow of steam and water can be limited due to flooding at high steam flow, which results in water accumulation in upper plenum. Accordingly, water accumulation by CCFL reduces the effectiveness of core cooling. The purpose of the calculations with MARS is to demonstrate that the MARS prediction of flooding and CCFL agree with the Wallis correlation for small tubes (one inch diameter) and the Kutateladze correlation for large tubes (eight inch diameter). Single tube flooding test of CCFL models were used to compare between code void fraction predictions and experimental data.

Below figure shows the nodalization of MARS assessment. It is consist of 5 parts, main pipe, top and bottom vent, air injection, water injection. The test section (pipe) was modeled with a single column and 9 vertical mesh cells as below figure. From experimental data (S.G. Bankoff [4]), when β=0, Wallis correlation factor (C) choose 0.8 and when β=1, Kutateladze correlation factor (C) choose 1.79. Initial maximum water and air mass flow rates were calculated using an EXCEL spreadsheet that calculated superficial dimensionless velocities for liquid and gas for the CCFL correlation used. The air flow rate was linearly decreased from its maximum initial condition to zero over a substantial time period, which was chosen as 150 seconds. The liquid flow rate is held constant throughout the transient at each case. With these flow rate conditions there is initially no liquid flowing down and through the CCFL junction because the system is at a CCFL condition.

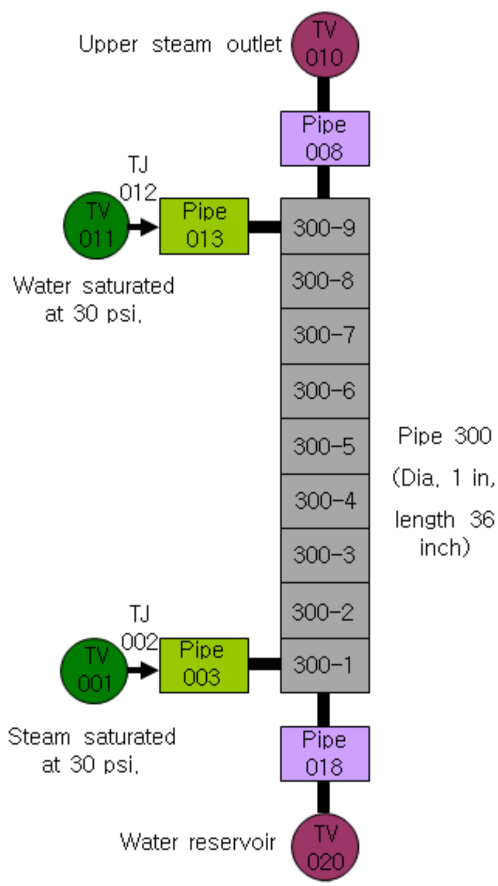

Figure 9. A nodalization diagram of CCFL single tube test

This assessment show the prediction of CCFL phenomena compared with bank-off experimental data. Small diameter results and Wallis correlation were compared. Large diameter results and Kutateladze correlation were compared. Below results were from the MARS transient results.

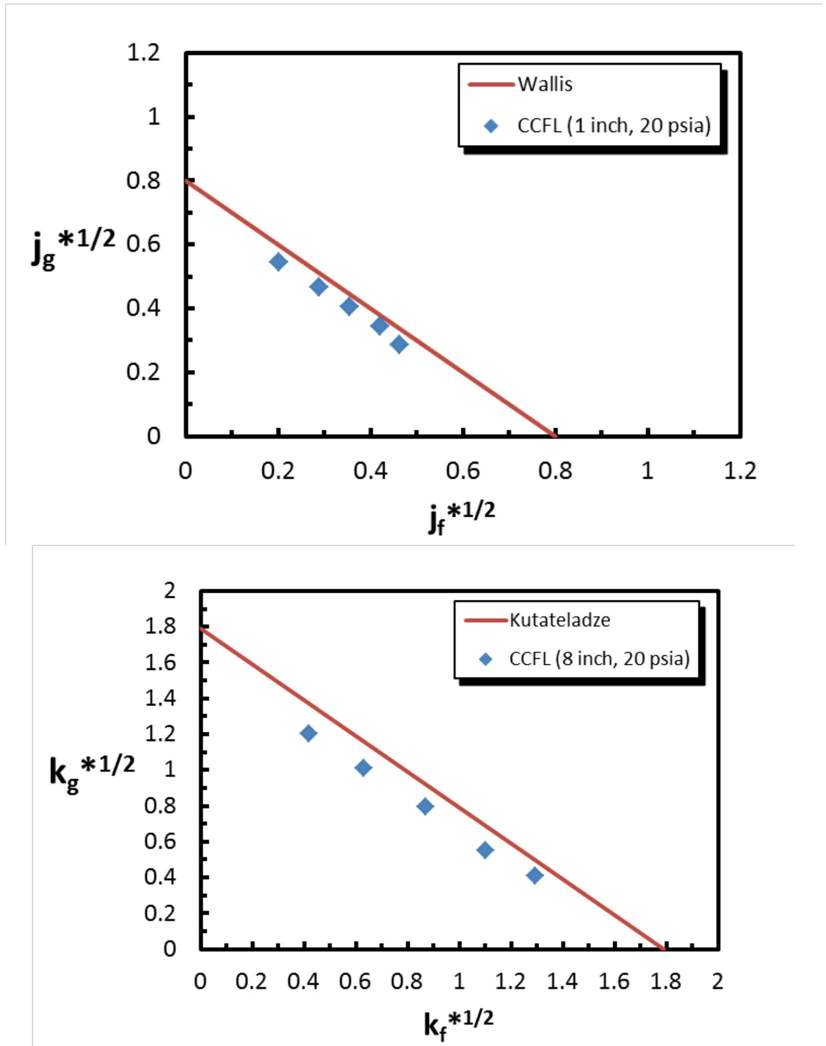

Figure 10. Gas versus liquid dimensionless superficial velocity

2.5. CISE Adiabatic Tube

When saturated steam-water flows upwards inside vertical tube, the flows develop any kinds of flow patterns. And then, there are interfacial drag between steam and water. The flow regime, and resulting interfacial drag, is primarily a function of the void fraction. The objective of this item is assessment of interfacial drag model implemented in MARS-KS and prediction of void fraction and comparison of the results with experiments of CISE adiabatic tube. When vertical upward two phase flow is flowing inside circular tube with 4.1 m as length and 0.081 m as diameter [5], the correlation between flowing quality and area averaged void fraction was calculated at TRACE. Originally, in TRACE assessment manual, the calculation was repeated at many flowing conditions. However, in this assessment, only 14 conditions were selected for calculation efficiency.

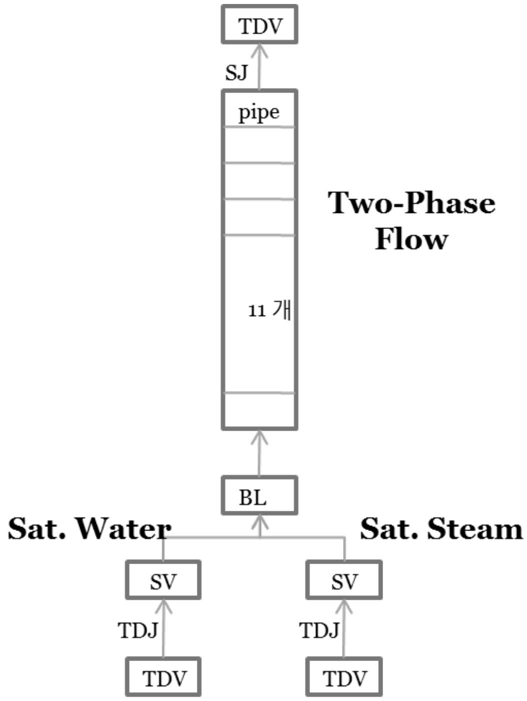

Figure 11. Nodalization of MARS

This figure shows the MARS-KS's nodalization. From two different TDV and TDJ, each phase is supplied into intermediate BRANCH forming mixture flow. And the mixture flow is supplied into PIPE. And as a outlet boundary condition a TDV is connected at the end of the pipe. Boundary conditions are like this: (Inlet water: P=4.9 MPa, x=0.0, Inlet steam: P=4.9 Mpa, x=1.0, Outlet: P=4.9 MPa, x=1.0)

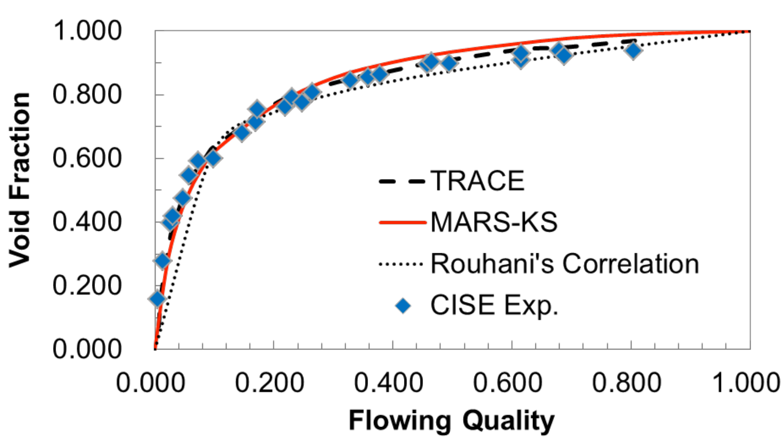

Figure 12. Results of void fraction

As shown in this figure, MARS-KS assessment has a good result. However, void fraction prediction was over-predicted under the high quality condition. It means that the interfacial drag force model may be supplemented especially about slug and annular condition. But overall void fraction prediction of MARS-KS is satisfied.

3. Conclusions

Successful evaluation of MARS-KS capabilities for predicting the thermal-hydraulic behavior of the TRACE fundamental problems was performed. Good agreement with the analytical solutions and TRACE results. MARS results agree fairly accurately with the analytical solutions and TRACE results, which demonstrate that the predictions of the thermal-hydraulic behavior in MARS-KS are accurate.

4. Acknowledgement

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5. References

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