

Comparison of MARS-KS to COBRA-TF for models and correlations in pre-CHF regime

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ABSTRACT

To evaluate the safety of a Korean Nuclear Power Plant (NPP), one dimensional system analysis code, MARS-KS, is being used by the Korean regulator. The governing equations of MARS-KS are based on two-phase two-field model. MARS-KS code also includes COBRA-TF as well for sub-channel analysis of the reactor core. In contrast to MARS-KS, COBRA-TF is based on two-phase three-field governing equations. In this paper, the two phase flow regime map and correlations are compared between MARS-KS and COBRA-TF while considering the difference in the governing equations. This exercise is not only important for the basic understanding of the two phase flow modeling, but also it is important for the future Korean regulatory activity for assessing the appropriateness of SPACE (Safety and Performance Analysis Code for nuclear power plants) developed by a consortium led by Korea Hydro & Nuclear Power Co., Ltd. (KHNP). The governing equations of SPACE are also based on two-phase (liquid and gas phase) three-field (continuous liquid, gas and droplet) governing equations like COBRA-TF. The effect of the implemented two phase flow regime map and correlations will be evaluated by modeling the selected separate effect test case with both MARS-KS and COBRA-TF and this will be followed by the discussion on the assessment results.

KEYWORDS

Two phase flow regime map, Correlation, two-phase flow, two-field model, three-field model

1. INTRODUCTION

To evaluate safety of a Korean Nuclear Power Plant (NPP) MARS-KS code is being used by the Korean regulator. The governing equations of MARS-KS are based on two-phase and two-fluid model. Recently, SPACE (Safety and Performance Analysis Code for nuclear power plants) was developed by a consortium led by Korea Hydro & Nuclear Power Co., Ltd. (KHNP), which the code is aimed for evaluating the safety of the designed nuclear power plant. The governing equations of SPACE are based on two-phase (liquid and gas phase) three-fluid (continuous liquid, gas and droplet) model. However,

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MARS-KS and SPACE have different governing equations, as well as model and correlations implemented in two codes. In this respect, the authors are studying the difference in the analysis result of system analysis codes with different governing equations and models and correlations. As the first step, the two phase flow regime map and correlations are compared between MARS-KS and COBRA-TF. The COBRA-TF is already included in MARS-KS as a three-dimensional vessel module. Governing equations of COBRA-TF are two-phase/three-field model like SPACE. Since the governing equations of COBRA-TF is different with MARS-KS, which has two-phase/two-field model, this study will be a helpful exercise to understand SPACE in the future. In this study, the authors summarize the flow regime map and correlations of MARS and COBRA-TF codes firstly. To investigate the effect of modeled flow regime map and correlations of each code, SUBO (Subcooled Boling) experiment performed by KAERI [1] is selected as the reference calculation. The assessment results and discussions are presented.

2. COMPARISON OF FLOW REGIME MAP AND CORRELATION

Since MARS-KS and COBRA-TF has different governing equations, flow regime map and correlations are different from each other. And, the authors think that implementation flow regime is very important, because correlations for heat transfer and friction factor are determined after the decision of flow regime at certain time and control volume. Therefore, the difference between each code in terms of flow regime map is summarized as the following.

2.1. Comparison of Flow Regime Map on MARS-KS and COBRA-TF

In MARS-KS code, the flow regime map is divided into Pre-CHF, Transition and Post-dryout regions. In COBRA-TF, the map is divided into normal flow regime and hot wall flow regime. Pre-CHF regime map of MARS-KS corresponds with normal flow regime of COBRA-TF. Figure 1[2-3] shows the normal flow regime of COBRA-TF selection logic and schematic of vertical flow regime map of MARS-KS. Selection criteria of normal flow regime of COBRA-TF is simpler than those of pre-CHF regime of MARS-KS.

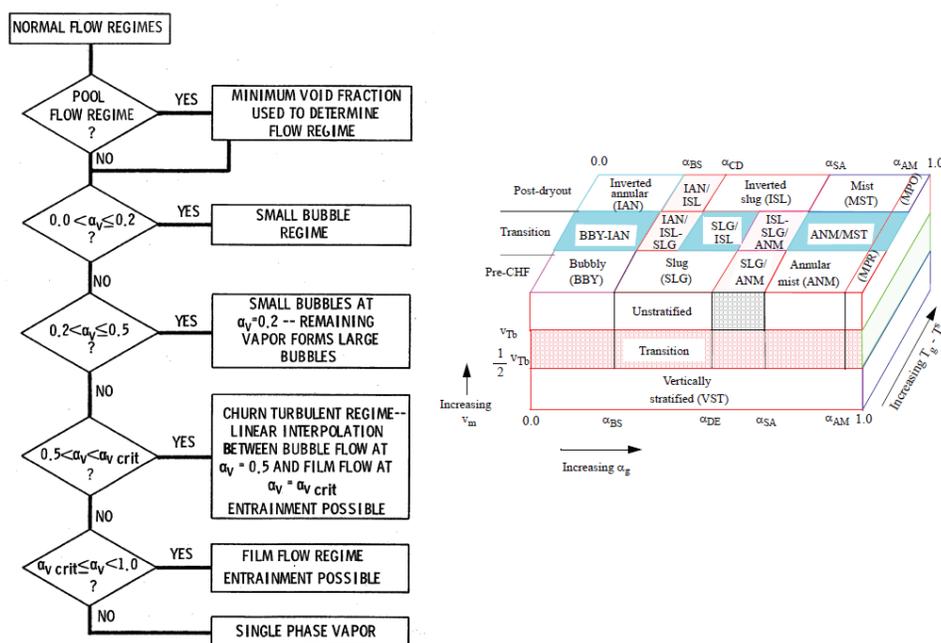


Figure 1. Normal Flow Regime of COBRA-TF/ Vertical Regime Map of MARS-KS. [2-3]

First, boundaries between bubbly and slug flow of each code are compared. In COBRA-TF, when void fraction is less than 0.2 and the fluid is not single phase liquid, the flow is determined as bubbly flow. In MARS-KS, the flow regime boundary varies with mass flux. For example, when the mass flux of flow is less than 2000kg/m²-s, void fraction of the bubbly flow boundary is 0.2, but when the mass flux is higher than 3000kg/m²-s, the void fraction of the bubbly flow boundary becomes 0.5. The selection criteria between slug flow and churn flow are compared. In COBRA-TF, when the void fraction is higher than 0.5, and it is less than critical void fraction, defined in eq.1.[2] , the flow is determined as churn flow.

$$a_{vcrit} = 1.0 - 4.0c_1\sigma/\rho_v \left| u_{vl} \right|^2 D_H \quad (1)$$

But in MARS-KS, complex criteria are used to determine churn flow. The selection criteria of annular mist flow in pre-CHF vertical flow map of MARS-KS are more complex than those of COBRA-TF as well. Generally, the pre-CHF vertical flow map is divided into smaller regimes in MARS-KS than COBRA-TF.

Post-dryout map of MARS-KS is compared to hot wall flow regime map of COBRA-TF. In MARS-KS, post-dryout regime consists of inverted annular flow, inverted slug flow and dispersed droplet flow. In COBRA-TF, hot wall regime consists of inverted annular flow, liquid chunk, dispersed droplet flow and falling film regime. Figure 2 [2-3] shows the form of flow regimes of each code.

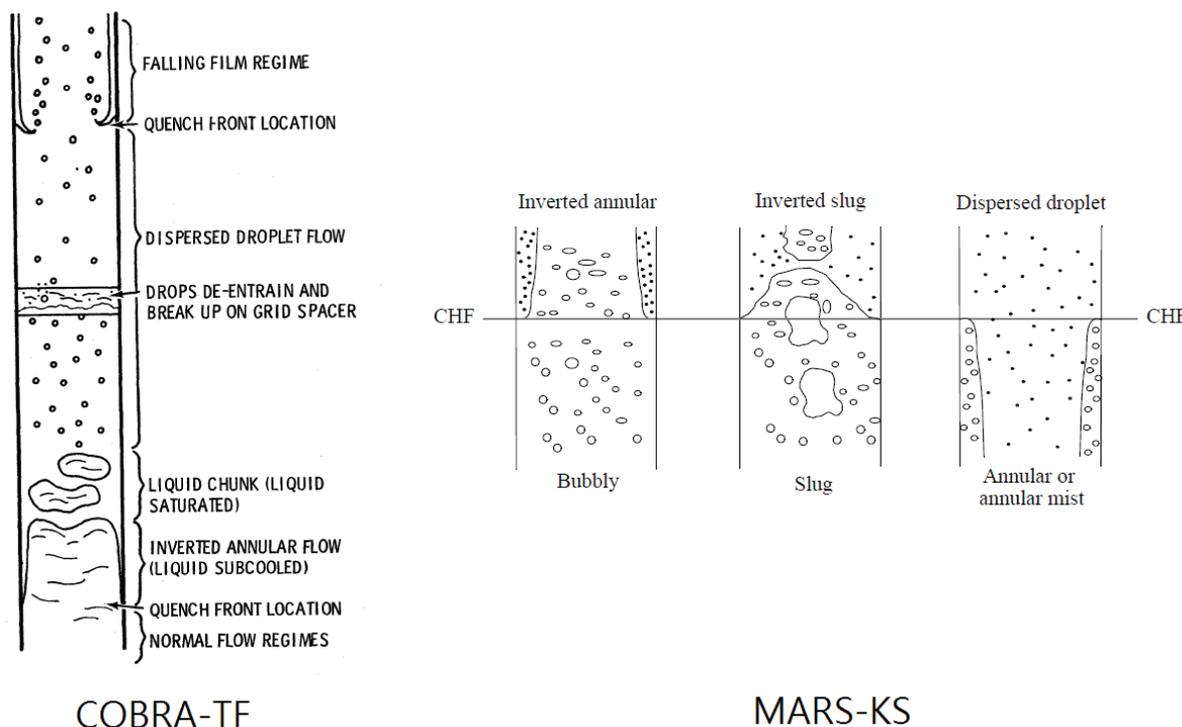


Figure 2. Hot Wall Flow Regime of COBRA-TF/ Post-Dryout Map of MARS-KS. [2-3]

In the manual of MARS-KS, it is not exactly explained how the post-dryout regime and pre-CHF regime are divided. It just mentions that if the wall temperature is too high to allow surface wetting, the code selects post-dryout regime [2]. However, in the manual of COBRA-TF, it is exactly mentioned if a mesh cell contains a solid surface with a temperature greater than 750 degree F, the hot wall flow regimes are used [3]. Figure 3 [3] shows the hot wall flow regime decision logic of COBRA-TF

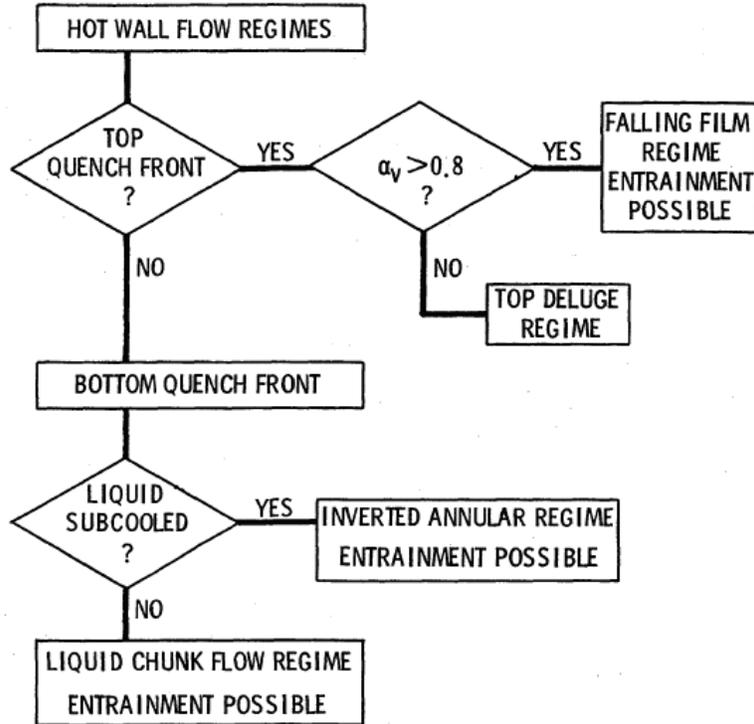


Figure 3. Hot Wall Flow Regime Selection Logic of COBRA-TF. [3]

2.2. Comparison of Wall Heat Transfer Model on MARS-KS and COBRA-TF

The heat transfer package of both codes consist of a library of heat transfer correlations and a selection logic. In MARS-KS, there are 11 wall heat transfer models. Heat transfer mode is selected by the difference of wall temperature, liquid temperature, and vapor temperature. Void fraction and several heat flux (e.g. CHF) conditions are considered for the heat transfer mode selection in MARS-KS. Figure 4 shows the wall heat transfer mode selection chart of MARS-KS and COBRA-TF. Selection logic of COBRA-TF is simpler than that of MARS-KS.

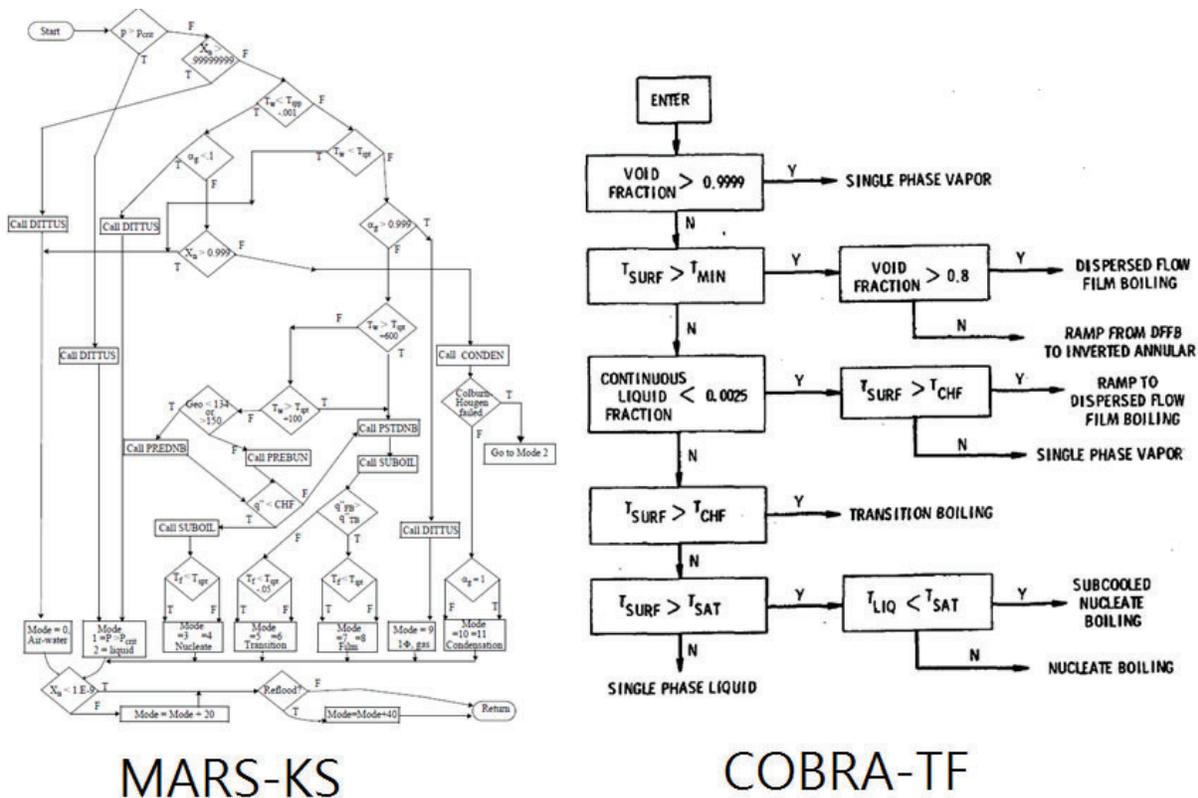


Figure 4. MARS-KS and COBRA-TF Wall Heat Transfer Flow Chart. [2]

In this case, the experimental conditions of the SUBO experiment seem to belong to the subcooled nucleate boiling and single phase liquid regime. Chen’s correlation is applied to wall heat convection heat transfer of subcooled nucleate boiling regime in MARS-KS and COBRA-TF. Actually it was based on saturated liquid conditions, but it is extended to subcooled boiling region.

3. SUBO EXPERIMENT CALCULATION ON MARS-KS AND COBRA-TF

3.1. Problem Definition

To investigate the difference of each code, with particular emphasis on the flow regime map and wall heat transfer, the following comparison was made for SUBO (SUBcooled Boiling flow) experiment [1]. Test section of the SUBO facility is shown in Fig. 1[1]. SUBO Test facility consists of pipes and rod type heater. Subcooled water flows from the bottom to the top with constant mass flow rate, and it is heated by the rod type heater. The authors modeled heater as radially 3 node because diameter of heater is thin. Tables I to IV show the boundary and analysis conditions.

TABLE I. Boundary Condition of SUBO Experiment

Heat Flux(kW/m ²)	472.92
Mass Flux(kg/m ² s)	1115.89
Inlet Pressure(kPa)	192.55
Outlet Pressure(kPa)	160.47
Inlet Temperature(K)	374.63
Heat(kW)	45.77
Mass Flow Rate(kg/s)	1.017

TABLE II. Hydraulic Components Geometry

Hydraulic Components		
Area		9.1126E-4m ²
Length (Component)	Lower	0.229m
	Heated	3.087m
	Upper	0.384m
Hydraulic Diameter		0.02552m
Roughness		4.6E-5m
Pressure	Inlet	192.55kPa
	Outlet	160.47kPa
Temperature		374.63K

Table III. Time Step of Analysis

Time	
Minimum Time Step(s)	1.0E-7
Maximum Time Step(s)	0.01
Final Time(s)	50.0

Table IV: Heat Structure Geometry

Heat Structure	
# of Meshes	3
# of Nodes	20
Heated Length	0.15435m
Heated Diameter	0.00998m

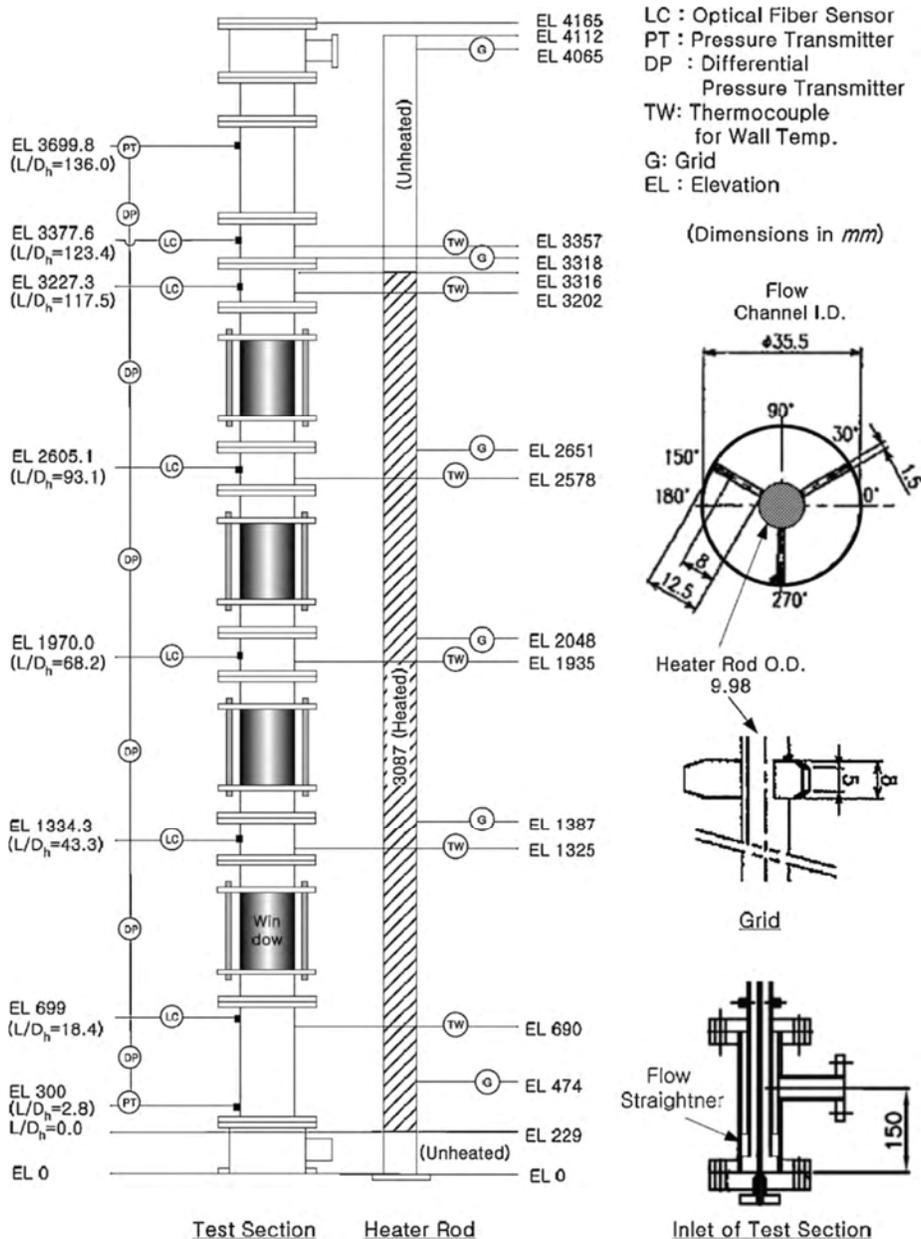


Figure 5. Test section of the SUBO facility [1].

3.2. Analysis

To obtain the analysis result, input decks for MARS-KS and COBRA-TF code with respect to SUBO experiment facility were prepared. Nodalizations of each code are shown in Fig. 2. Since the heated pipe region is the region of interest, COBRA-TF input has only heated pipe components, and other parts of input is prepared with MARS-KS. To use COBRA-TF in MARS-KS, a connection volume is needed, named as "sdbvol." In Fig. 2, highlighted sections are modeled in COBRA-TF. Since the authors divided the unheated pipe region into sdbvol and pipe components. Differences in the calculation result can occur due to the nodalization. This will be discussed in detail in the following sections.

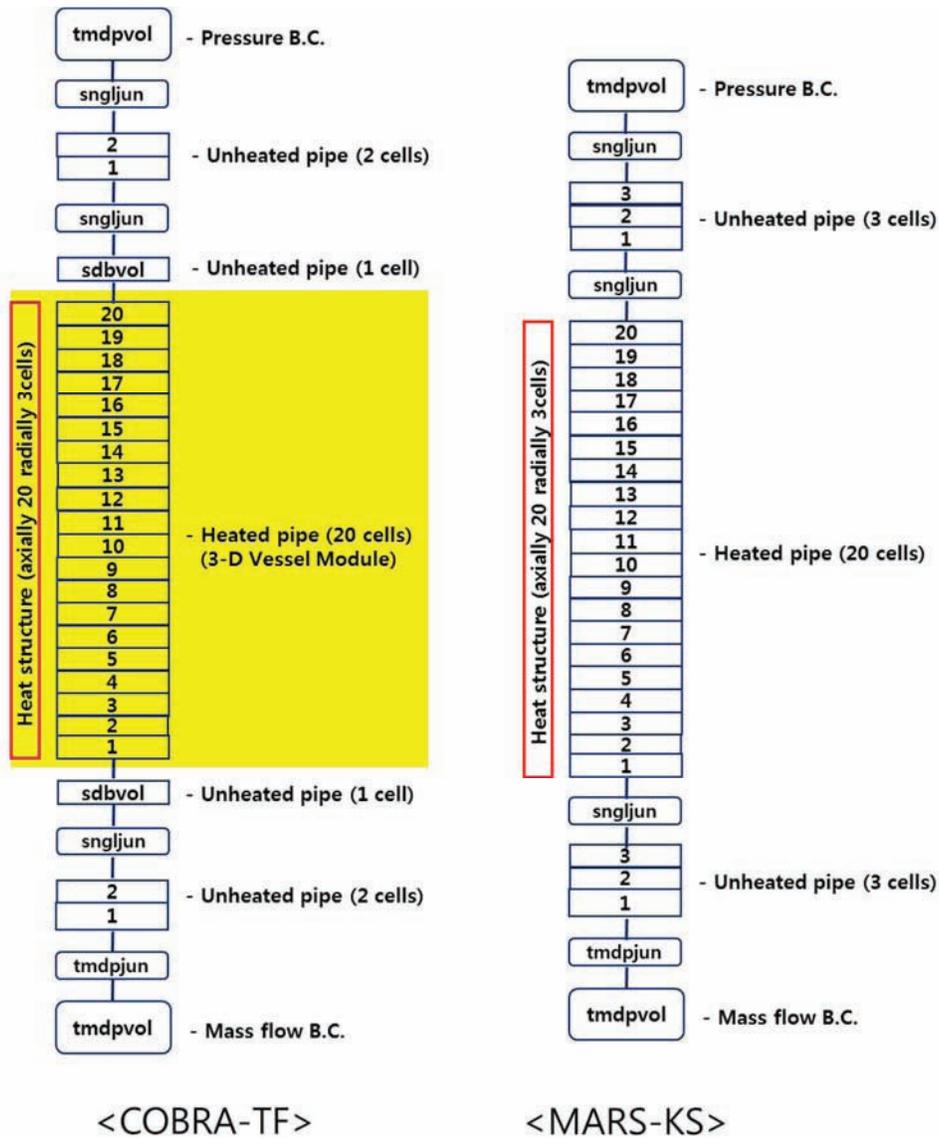


Figure 6. SUBO Nodalization for MARS-KS and COBRA-TF.

3.3. Calculation Results

The calculation results are obtained from the prepared input decks. Firstly, the experimental data are compared with calculation results. Liquid and vapor velocity, liquid temperature and void fraction are plotted on the graph, along the vertical direction. In MARS-KS output, volume and junction are distinguished, so scalar values are chosen from the volume and vector values are chosen from junction. But from COBRA-TF in MARS-KS (implemented as 3-D Vessel Module), volumes and junctions cannot be distinguished. Small error can occur due to this reason. Figures 7 to 10 show the calculation results with the experimental data.

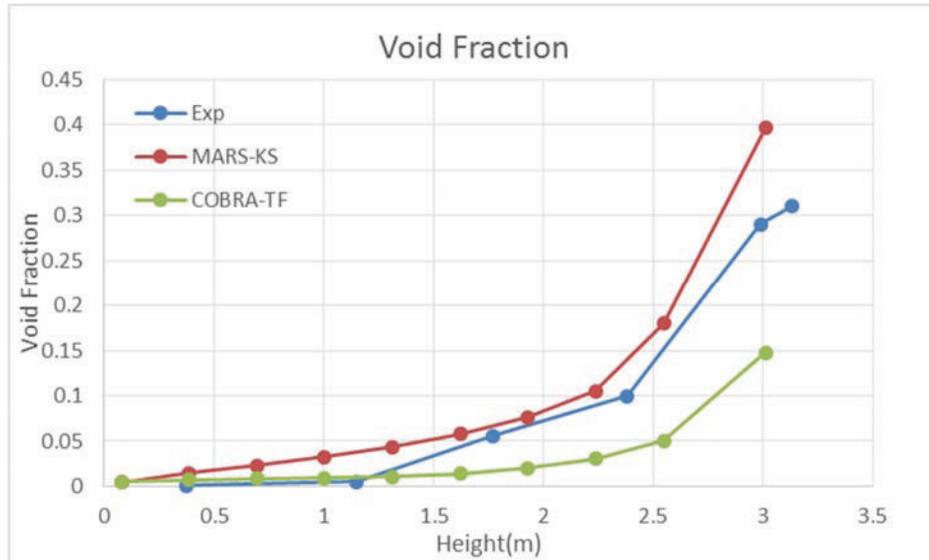


Figure 7. Void Fraction from Experimental Data and Calculation Result.

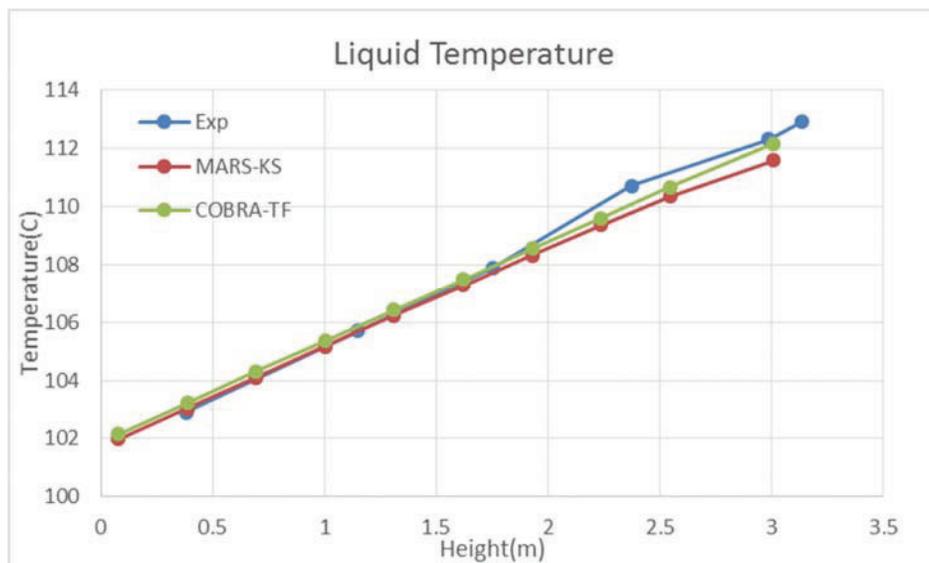


Figure 8. Liquid Temperature from Experimental Data and Calculation Result.

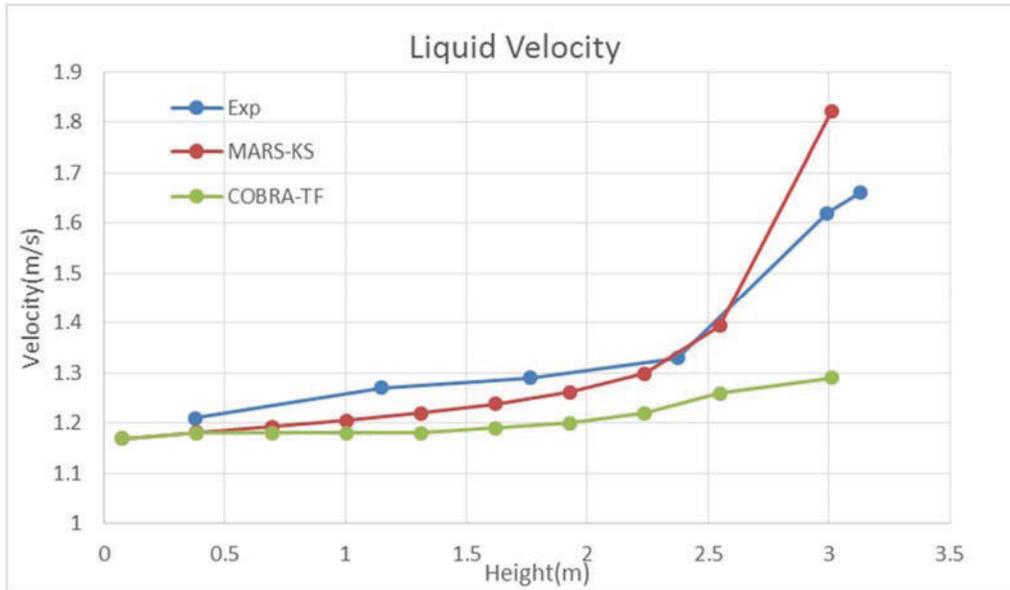


Figure 9. Liquid Velocity Experimental Data and Calculation Result.

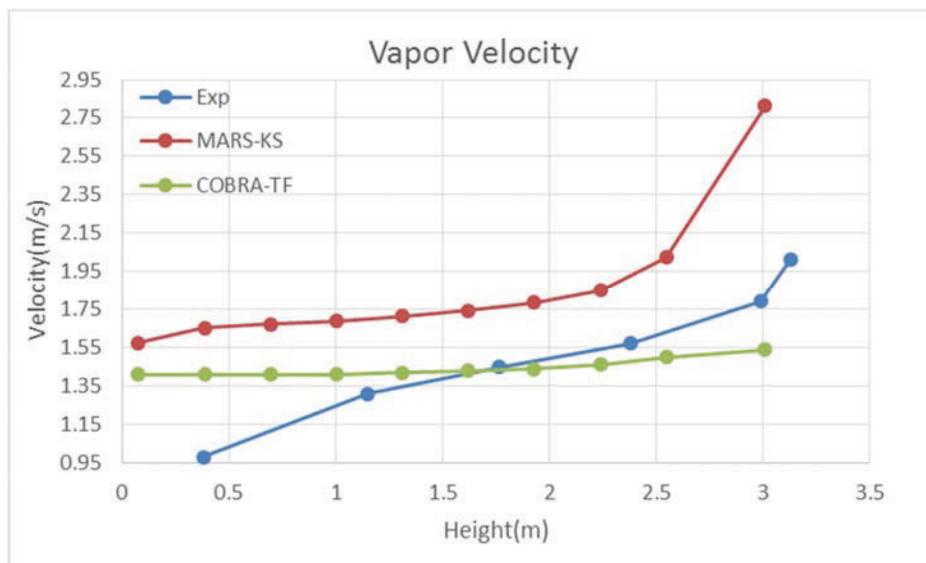


Figure 10. Vapor Velocity Experimental Data and Calculation Result.

Except for the liquid temperature, the calculation results from COBRA-TF results match poorly with the experimental data. To check the reliability of COBRA-TF calculation, the authors checked the energy balance for the added heat. To check heat balance along the heated length, the authors performed simple calculation to reconfirm the calculation results. From the experimental condition, the first added heat is calculated. In the heated pipe, the 1st and the 20th nodes are selected as reference nodes. Then added heat becomes 95% of the total added heat, since the measurement points are located at the middle of the node. Mixing cup enthalpy at each node are calculated from the vapor and liquid enthalpy, density, void fraction, fluid mass in each node. Calculation results from MARS-KS are shown in Table V. The heat

balance analyses seem to show that the initial and boundary conditions as well as the geometry information implemented in COBRA-TF and MARS-KS coincide well with the experimental condition. Therefore, further investigation is needed to understand and interpret the results.

TABLE V. Analysis Result for Heat Balance of MARS-KS Calculation

	MARS-KS	COBRA-TF
Mass flow rate (kg/s)	1.017	1.017
Enthalpy at 1 st node (kJ/kg)	42.75	42.76
Enthalpy at 20 nd node (kJ/kg)	46.95	47.02
$\dot{m}\Delta h$ (kW)	42.66	43.29
\dot{Q} (kW)	43.48	43.48
Error (%)	-1.89	-0.43

Flow regimes of each node for both codes are checked. Both codes show different flow regime at each node as it is shown in Table VI. Regime flag from the MARS-KS and COBRA-T output showed flow regime during whole nodes, but it seems that flag does not agree with void fraction distribution. In the case of MARS-KS, slug flow can occur with void fraction larger than 10^{-3} , so the result can be reasonable. But flag from COBRA-TF does not matched with flow condition, it should be discussed.

Table VI: Flow Regime along the vertical direction

Height(m)	COBRA-TF(flag)	MARS-KS(flag)
0.077	CTB high mixing bubbly (1)	Slug(5)
0.386	CTB high mixing bubbly (1)	Slug(5)
0.695	CTB high mixing bubbly (1)	Slug(5)
1.003	CTB high mixing bubbly (1)	Slug(5)
1.312	CTB high mixing bubbly (1)	Slug(5)
1.621	CTB high mixing bubbly (1)	Slug(5)
1.929	CTB high mixing bubbly (1)	Slug(5)
2.23	CTB high mixing bubbly (1)	Slug(5)
2.547	CTB high mixing bubbly (1)	Slug(5)
3.010	CTB high mixing bubbly (1)	Slug(5)

4. SUMMARY AND CONCLUSIONS

The authors compared MARS-KS and COBRA-TF codes in the view of flow regime and heat transfer mode. It is shown that the flow regime and heat transfer mode of MARS-KS is divided into smaller regimes more than those of COBRA-TF. The authors selected SUBO experiment performed by KAERI [1] as a reference experiment to observe how different flow regime and heat transfer mode can have different effects on the calculation result. From the calculation of each code, results from COBRA-TF show significant departure from the SUBO experiment as well as from the results from MARS-KS in this case. More comparison of calculation with more experimental results will be presented during the conference. As for now, the code inputs do not show any major defect which is proven from the heat balance study. More detail analyses to understand the difference and the effect of the governing equations will be presented in the presentation during the conference.

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