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Verification analysis for the Improved MARS-KS Core Sub-channel Analysis Module

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1. Introduction

The sub-channel thermal hydraulic analysis is required for the reactor core design and the safety analysis. MARS-KS [1] regulatory safety analysis code has been used for the regulatory safety review by the Korea Institute of Nuclear Safety (KINS). MARS-KS has been developed by Korea Atomic Energy Research Institute (KAERI) and KINS based on the COBRA/RELAP5 code [2] using implicit pressure matrix coupling method between 1-Dimensional (1D) and 3-Dimnnsional (3D) interfaces. MARS-KS sub-channel analysis module of COBRA-TF was not commonly used due to inconveniences and thus was improved in this study by replacing COBRA-TF with improved CTF [3].

CTF code has been improved to better predict the core sub-channel flows especially for the turbulent mixing, void drift and spacer grid models from the COBRA-TF code. CTF code was also improved numerical methods and heat transfer correlations for the single and two-phase flows.

In this paper, MARS-KS inherent implicit pressure matrix coupling with CTF sub-channel module is briefly described and its verification and validation tests for the conceptual problems and Separate Effect Tests (SETs) are presented herein.

2. Code coupling strategy of the MARS-KS and CTF

Coupling problems of the MARS-KS and CTF codes include integration of the input, initialization, unit conversion, time step and implementation of the CTF transient calculation logics into the MARS-KS code. Detailed coupling methods were described in the previously study [4] and briefly summarized herein.

Both codes use a semi-implicit, finite difference method based on a staggered grid and donor cell scheme. All variables except pressure are shared through Sub Domain Boundary Volume (SDBVOL) which is 1D/3D interface. In integrating CTF module with the MARS-KS code, physical variables are sent from the 1D system analysis region (Ri) to the 3D Vessel region (Ci) according to the existing MARS-KS code coupling method and then the calculated pressure in the 3D Vessel region must be used to solve the 1D system pressure matrix. This sequence of steps and processes of the MARS-KS 1D/3D coupling is shown in Figure 1.

3. Verification of the MARS-KS and CTF code coupling

This study uses conceptual problems and SETs for verification and validation analysis (V&V) and simulates physical phenomenon and compares it with the experiment or previous results of MARS-KS V&V results to verify the MARS-KS and CTF integrated code coupling.

3.1. Conceptual problems

The conceptual problems such as vertical steady flow, nine volumes, fill and drain, and manometer oscillation were used for the verification of the MARS-KS 1D/3D coupling.

Nodalizations of the vertical pipe tests for the four cases are shown in Figure 2. White color is 1D region and shaded color is 3D vessel region, respectively. Case A is for the MARS-KS 1D system and Case B is for the 1D/3D problem of the improved MARS-KS. Cases AA and BB have a large 3D area.

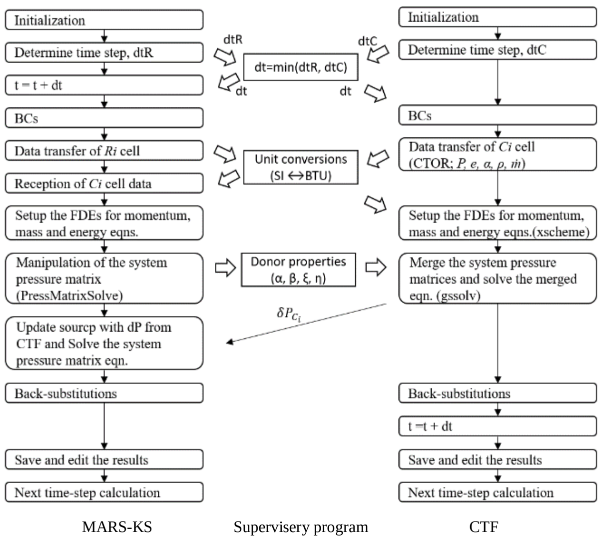

Fig. 1. Schematic diagram of the modified calculation logic of MARS-KS and CTF code coupling [4].

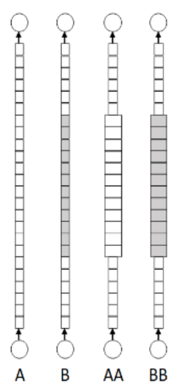

Fig. 2. Nodization of the vertical pipe test.

Boundary conditions of the vertical steady flow are shown in Table 1. Three cases were tested. The results for each case are shown in Tables 3, 4, and 5, and these results show that the mass is conserved when only 1D components are used, when calculated using 1D and 3D vessel modules and when flow area changes. It was confirmed that there is no difference for pressure drop.

Figure 3 shows nodalization of the fill and drain test. This test is a conceptual problem designed to confirm water packing and numerical diffusion. Case A has only 1D region and Case B has both 1D and 3D regions. Initial conditions of the pressure and temperature of the vertical tube are 0.4 MPa and 418.2 K. Saturated water under a vertical tube is injected with 1 m/s during 15 seconds and then withdrawn with -1 m/s as shown in Figure 4.

Void fractions of the upper, middle and lower parts are compared in Figures 5, 6 and 7 and the pressure of the middle part in Figure 8. Both cases show that the void fraction and pressure for the injection or withdrawal of water are physically predicted. No water packing occurs at the 1D/3D interface due to the incorporation of the pressure relaxation techniques in the improved MARS-KS code.

Table 1: Boundary conditions of vertical steady flow

Case	Inlet			Pressure (MPa)
	State	Mass flow rate (kg/s)	Temp. (K)	
1	Subcooled water	10	600	15
2	Saturated water, vapor	4.4, 0.6	Saturated	12
3	Superheated vapor	0.3	400	0.1013

Table 2: Difference of inlet and outlet mass flow rate (kg/s)

Case	A	B	AA	BB
1	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0
3	0.0	0.0005	0.0	0.00045

Table 3: Pressure drop (Pa)

Case	A	B	AA	BB
1	17441	17220	16951	16909
2	10340	9520	10547	9651
3	742.43	694.43	167.61	176.64

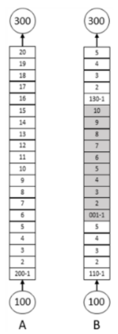

Fig. 3. Nodization of the fill and drain test.

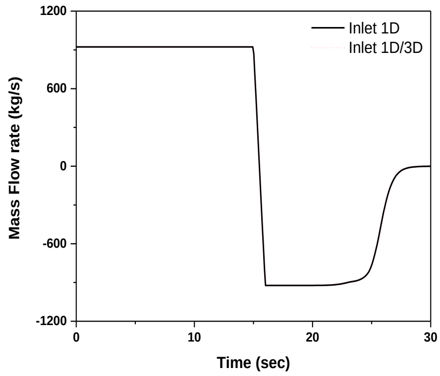

Fig. 4. Injected mass flow rate.

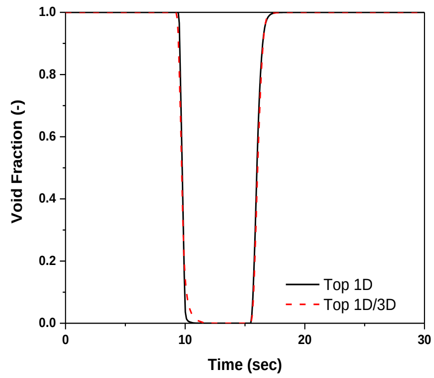

Fig. 5. Void fraction comparison at the top.

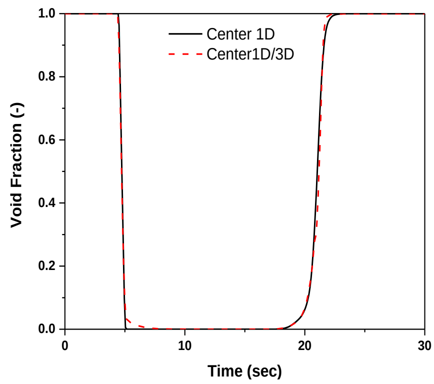

Fig. 6. Void fraction comparison at the middle.

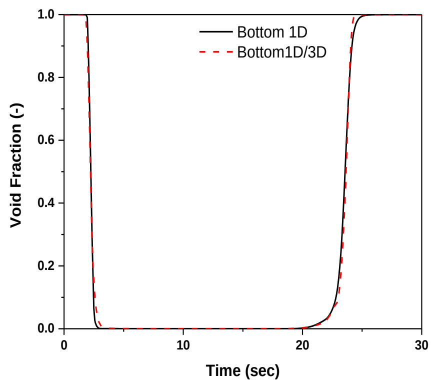

Fig. 7. Void fraction comparison at the bottom.

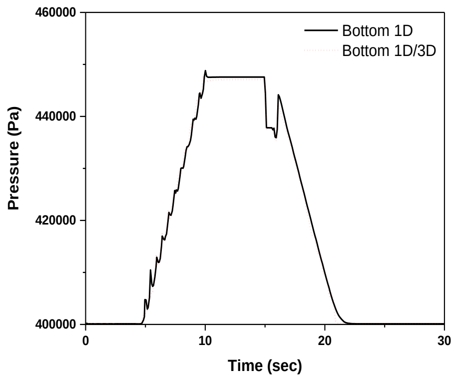

Fig. 8. Pressure comparison at the middle.

3.2. Separate Effect Tests

Edward pipe test is used to verify blowdown behavior with flashing of pressurized water using 3D vessel module of the improved MARS-KS code. The horizontal pipe is filled with water at high temperature and high pressure (502K, 70bar), and the single junction (SJ) and time dependent volume (TDV) are set to air with pressure of 1bar and quality of 1.0 as shown in Figure 9. In the CTF code, boundary conditions must be given to the top and bottom nodes. Blind boundary condition (BBC) is set when there is no 1D or 3D node connected above and below the 3D node.

Comparing the test results of the experiment, MARS-KS 1D analysis, and MARS-KS 1D/3D analysis, the results show good agreements with respect to the MARS-KS 1D/3D coupling.

Figures 10 and 11 show the pressure and void fraction at channel 8 of the 3D region and overall underestimated predictions. The underestimated predictions might be related to the inherent properties of the CTF sub-channel code and initial void fraction. The trends of the pressure and void fraction were closer to the experiment when the initial void fraction is set to four percent than the case of single phase flow with zero void fraction as shown in Figures 10 and 11.

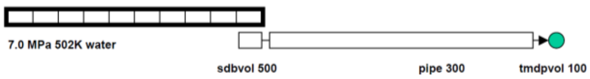

Fig. 9. Nodalization of Edward pipe test.

4. Conclusions

The MARS-KS was upgraded with the improved CTF code and existing implicit pressure matrix coupling method was used to couple the MARS-KS and CTF codes. Using a conceptual problem of the steady state vertical flow test, the fill and drain test and blowdown test, coupling of the improved MARS-KS code has been verified. Through the simulation of the experimental tests such as conceptual tests and SET, the improved MARS-KS code shows a good agreement with the experimental data or existing MARS-KS results. However, further validation is needed for the improvement of the MARS-KS code. In addition, DNBR calculation methodology for the safety analysis of the non-LOCA design basis events should be developed as well as the enhancements in user interfaces.

REFERENCES

[1] KAERI, MARS CODE MANUAL VOLUME I: Code Structure, System Models, and Solution Methods, KAERI/TR-2812/2004, 2009.

[2] Lee, S.Y., Jeong, J.J., Kim, S.H., and Chang, S.H., COBRA/RELAP5; A Merged Version of the COBRA-TF and RELAP5/MOD3 Codes, Nuclear Technology, Vol. 99, pp. 177-187, 1992.

[3] Avramova, M.N., Blyth, T.S., Salko, R.K., CTF user's manual, CASL-U-2016-1111-000, 2016.

[4] N.H. Hoang, Y.K. Kwack, S.H. Bae, S.K. Sim, Main Steam Line Break Analysis of the APR1400 using Improved MARS KS Core Subchannel Analysis Module, 27th International Conference on Nuclear Engineering (ICONE), Japan, May 19-24, 2019.

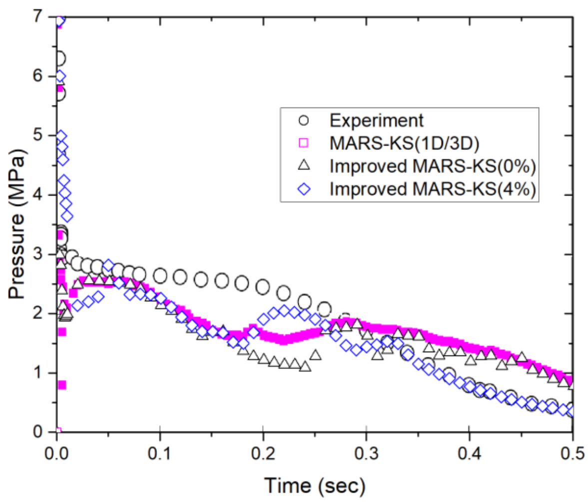

Fig. 10. Pressure comparison at vessel channel 8.

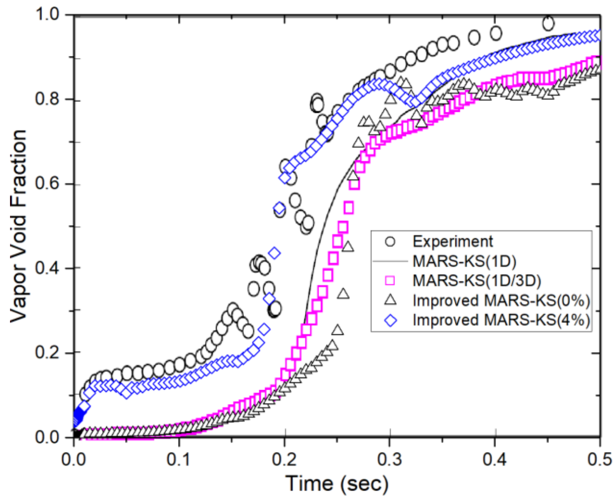

Fig. 11. Void fraction comparison at vessel channel 8.