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Recent Improvements of MARS-KS Code

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1. Introduction

The Korea Institute of Nuclear Safety (KINS) has maintained the MARS-KS code at the contemporary technical level by implementing the solution to the problems reported by code users, the recent research results, and improvements of RELAP5/MOD3.3 to improve the quality of audit analysis.

The KINS released the MARS-KS V1.6 (Subversion-168) in August 2021 [1, 2]. This study introduces the main improvements of MARS-KS after the release of MARS-KS V1.5 (Subversion-145) in July 2018.

2. Main Improvements of MARS-KS V1.6

2.1 Development of TANK Component

A new component, TANK, is developed to improve the capability for simulating the thermal-hydraulic phenomena in the large tank like the core makeup tank or safety injection tank of SMART. The single control volume can simulate the behavior of subcooled water and saturated (or superheated) steam inside the tank.

The TANK component is developed by adding several functions to BRANCH component. The key features of TANK component are as follows: (1) lumped volume with complete separation of gas and liquid, (2) full mixing in gas and liquid, (3) complete thermal stratification in liquid side, (4) wall boiling and condensation with different level of heat structure in the lumped volume, (5) no liquid side interfacial heat transfer to eliminate the numerical oscillation due to rapid steam condensation at the gas/liquid interface.

The data card requirements of TANK component basically similar to that of BRANCH component. The initial liquid level, the variation of height according to the volume, the lower and higher elevation of each slab of heat structure are additionally required.

2.2 Implementation of Horizontal Condensation Heat Transfer Model

Recently, many studies have been performed to assess the predictive capability of system analysis codes for the passive auxiliary feedwater system (PAFS). It was found that the existing condensation model of MARS-KS code highly underestimated the condensation heat transfer inside the nearly-horizontal heat exchanger of the PAFS. To improve the predictive performance of MARS-KS code, Ahn et al. [3] developed the horizontal stratified condensing heat transfer model consisting of the heat partition angle, the condensation heat transfer model, and the convective heat transfer model.

This model is implemented in MARS-KS V1.6 as user's option model (Option No.98). The model can be applied to circular tubes with the inner diameters of 30-45 mm and downward inclination angles ranging from 0-10 degrees under pure steam condensation, and at pressures of 1-67 bar and mass fluxes of 10-329 kg/m^{2}s.

2.3 Improvement of Moving Reactor Model

A marine or floating reactor is affected by external forces due to ocean conditions. Although the MARS-KS code already incorporates the moving reactor model that is first developed by KAERI as a user's option model (Option No. 80), the validation and verification of this model has not been performed.

Beom et al. [4, 5] investigated the moving reactor model of MARS-KS using conceptual problems, and found several deficiencies in the model. Three major modifications are made to the MARS-KS V1.6. Firstly, the volume direction unit vector is automatically generated by using rotation matrix to make the motion input model more user-friendly. Secondly, the error is corrected so that the direction of acceleration is properly calculated under the translational motion. Finally, the code is modified so that the moving reactor model is properly working under the cross-junction connection between volumes.

2.4 Implementation of Heat Transfer Models for Crossflow

The MARS-KS has used Zukauskas' heat transfer model [6] developed for in-line tube array in crossflow as the single-phase convective heat transfer of shell side of helical tubes. More recent research results suggested by Zukauskas [7] are implemented in the MARS-KS V.16. To expand user's option, the heat transfer models for in-line and staggered arrangement of tubes are implemented. In addition, the model for the staggered arrangement of finned tubes is also implemented for the research purpose. Each model is activated when the convective boundary type is set to 162, 160, or 161, respectively. The 16-word format additional boundary is required for the new models.

2.5 Implementation of Turbulent Diffusion Layer Model

Lee et al. [8] investigated the condensation heat transfer in the presence of noncondensable in the containment during a hypothetical accident. They found out that the MARS-KS code tended to under-predict the heat transfer rate. To improve the predictive capability of MARS-KS, they adopted the diffusion layer model and modified it. The correlations to calculate heat and mass transfer on a vertical external surface for various flow conditions are adopted. The turbulent diffusion coefficient is applied to consider the effect of turbulence on mass diffusion. Additional modification was made by introducing the boundary layer theory for natural convective flow.

When compared with the original condensation heat transfer model of MARS-KS, their model showed better results for both forced and natural convection flows. The turbulent diffusion layer model is implemented in MARS-KS V1.6 as a user's option model (Option No. 92)

2.6 Implementation of Modified Nuclear Fuel Industry (NFI) Model

The thermal conductivity of UO_2 is degraded by irradiation. To consider the degradation of fuel conductivity with burnup, MARS-KS has used the material property table. It is inconvenient for modeling the multiple burned fuels, because the property tables are required as many as the number of burnups to be modeled.

To make the modeling of multiple burned fuels easier, the modified NFI model as a function of burnup, fuel theoretical density and gadolinium weight fraction is implemented in gap data card (1CCCG001) [9-10]. If Word 4 of the gap data card is entered, NFI UO_2 thermal conductivity at Word 4 burnup is used with the fuel theoretical density in Word 5, and gadolinium weight fraction in Word 6.

2.7 Implementation of Recent Improvements of RELAP5/MOD3.3

The recent improvements of RELAP5/MOD3.3 [11] was analyzed, and those are implemented in MARS-KS code. The main improvements are as follows:

(1) The new control component type of MPLEX is implemented. This component can be used to simplify modeling of selector switches. Previously, one would need four control variables to select an output value from two input values. A more complicated system can be created by combining switches in cascading fashion to form a so-called multiplexer. The implementation of the control variable MPLEX was designed to model both the simple selector switch and the N-stage multiplexer.

(2) The new function is added to control the pump impeller driving torque from the control variable. If Word 4 of Pump Index and Option card (CCC0301) is greater than 10,000, then the value of Word 4 minus 10,000 refers to the control variable number which will provide the pump motor torque.

(3) The modification is made to the CANCHAN interfacial drag logic to prevent the interfacial drag coefficient from becoming zero. The same problem was also found in the interfacial heat transfer logic. This problem is solved in V1.6.

(4) The code is modified to terminate execution with an error message if a negative number is entered to kinetic feedback weighting factor. Previously, the code was executed without problem in some cases. However, using the negative weighting factor can cause the problem for the tabular feedback.

(5) After the inertial check valve opened, it abnormally continued to open even when the differential pressure (DP) across the valve falls below the cracking DP. Although MARS-KS uses a different model from RELAP5/MOD3.3 for inertial check valve, it is found that MARS-KS has the similar problem. This problem is solved in V1.6.

2.8 Correction of Calculation of Hydraulic Diameter of Multi-dimensional Component

When the user enters zero as the hydraulic diameter (D_h) in the multi-dimensional volume friction data cards (Cards CCC2NNN) or junction data cards (CCC3-CCC5999), the D_h is automatically computed using the flow area and the associated wetted perimeter. It was found that there was an error in the automatically calculated value when zero is entered at D_h. This problem is solved in V1.6.

2.9 Modification of Multiple Junction Control Flags

Previously, the applying of v-flag (horizontal stratification entrainment/pull through option) option was not allowed at the multiple junction. At the request of code user, the control flag option is modified for the user to apply the v-flag option in V1.6.

2.10 Correction of Execution Failure

It was found that the execution of MARS-KS V1.5 was failed in the calculation of 3-D vessel module (COBRA-TF), the feedback type of TABLE4 in reactor kinetics, the radiation heat transfer model, the 2006 AECL lookup table (Option No.44), and coupling calculation with CONTEMPT code using Qwin executable. These problems are solved in V1.6.

3. Conclusion

The KINS has maintained the MARS-KS code at the contemporary technical level by implementing the solution to the problems reported by code users, the recent research results, and improvements of RELAP5/MOD3.3. To improve the quality of audit analysis, the performance of MARS-KS code needs to be continuously checked and maintained.

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