Sensitivity Analysis of Reflood Model with RBHT Experiment

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1. Introduction

In the last few years, the analysis of thermal-hydraulic behavior in reactor systems has been conducted by using the best-estimate codes. In order to provide realistic predictions of nuclear power plant (NPP) systems, the best-estimate codes employ numerous numerical methods and physical models. Therefore, the importance of assessing the best-estimate code capability to predict complex and wide range phenomena in reactor systems becomes evident. One of such phenomena that can occur in a pressurized water reactor (PWR) is the reflood phase of a large break loss of coolant accident (LOCA). The reflood is particularly interest for the code assessment as it requires the system code to accurately predict specific fuel heat transfer and two-phase phenomena [1]. During the reflood phase, several different heat transfer regimes (or modes) such as single-phase liquid convection, subcooled nucleate boiling, subcooled film boiling, transition boiling, dispersed flow, and single-phase vapor convection exist in the core. Sometimes all the modes appears simultaneously [2]. That is why predicting the thermal-hydraulic phenomena accurately occurring during the reflood phase is regarded as extremely difficult. Therefore, the best-estimate codes such as MARS-KS, RELAP5 and TRACE has a special package to predict core thermal-hydraulic characteristics during the reflood phase, and the code package is only applied to the reflood phase.

In the nuclear system analysis code such as RELAP5, MARS and TRACE, the governing equations are solved by the 1st order numerical scheme in both space and time discretization. The 1st order numerical scheme is very robust and stable. However, the 1st order numerical scheme on the fixed mesh can yield excessive numerical diffusion problem. The existence of strong numerical diffusion in codes with 1st order numerical scheme is well known. However, in case of the semi-implicit scheme, when the Courant number approaches to unity, the numerical diffusion disappears.

In this study, the RBHT (Rod Bundle Heat Transfer) experiment is modeled by MARS-KS code. The authors conducted the sensitivity tests of the number of mesh and time step size for this experiment to identify the numerical diffusion in the reflood model.

2. Modeling

2.1 RBHT experiment

The RBHT (Rod Bundle Heat Transfer) facility was designed by the team of Penn State University with a special focus on development and validation of the reflood model. This experimental facility consists of a test section, coolant injection, steam injection systems, steam separator and steam collection tanks as shown in Fig. 1 [3-5]. The test section consists of the heated rod bundle, flow housing, lower and upper plenums as shown in Fig. 2. And the heated rod bundle simulates a small portion of a 17x17 PWR reactor fuel assembly.

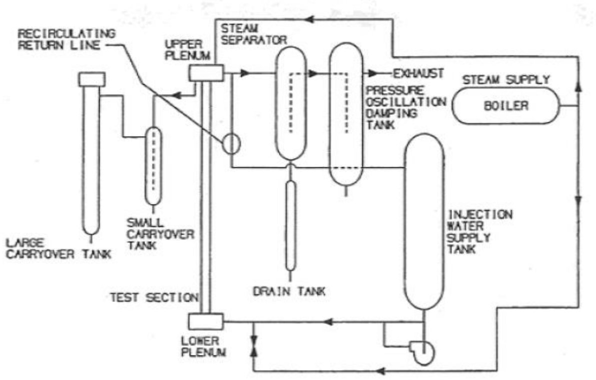


Fig. 1. Schematic of RBHT facility [3]

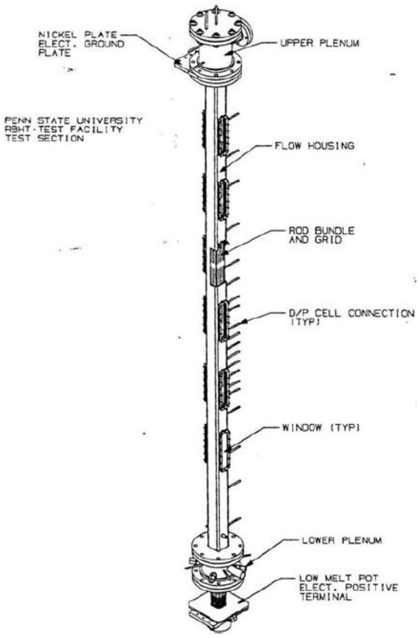


Fig. 2. Isometric view of test section [3]

2.2 Code modeling

The test section of the RBHT facility is modeled for the simulation in MARS-KS code. The 45 heated rods, 4 unheated rods, flow housing, lower and upper plenums of the test section are modeled as shown in Fig. 3. The lower and upper plenums are represented by a time-dependent volume as the pressure boundary conditions. The heated and unheated rods are modeled as a pipe component with heat structures. The heat structures in the test section are modeled as 45 heated rods, 4 unheated rods and the flow housing wall. The reflood model is applied in the heated rods.

For the sensitivity tests, the mesh number of the heated and unheated rods are 10, 20 and 40 for the sensitivity tests. The axial meshes of the heat structures are identical with that of the pipe component. The radial meshes are fixed as 9 for the heated rods, 2 for the unheated rods and 4 for the flow housing wall. The maximum time step sizes are 0.1, 0.05, 0.025, 0.0125 and 0.01. The simulation results are compared with the experimental data of RBHT Test 0945.

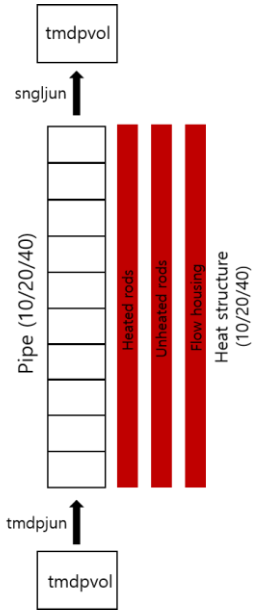
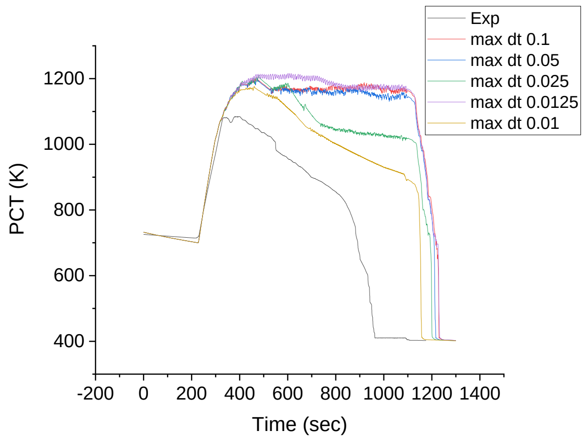
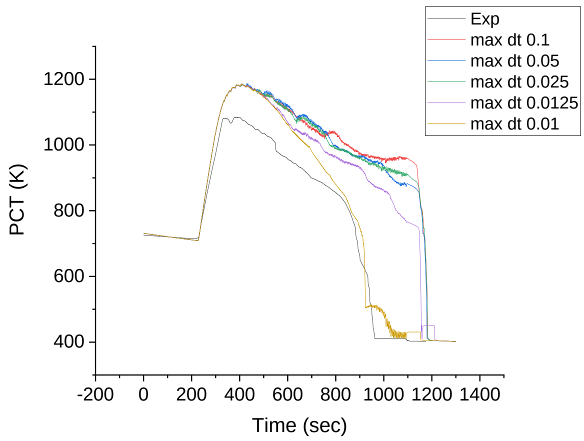


Fig. 3. Nodalization for the test section of RBHT facility

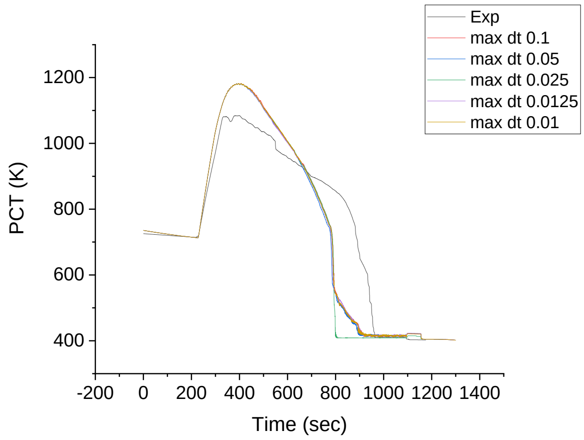
3. Results



(a) Peak cladding temperature for the mesh number 10

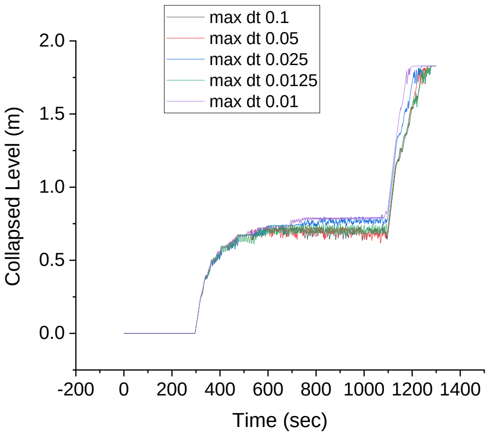


(b) Peak cladding temperature for the mesh number 20

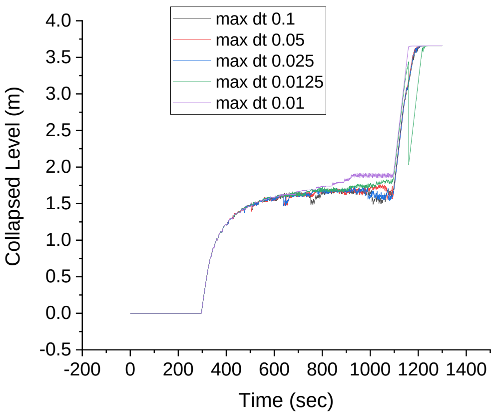


(c) Peak cladding temperature for the mesh number 40

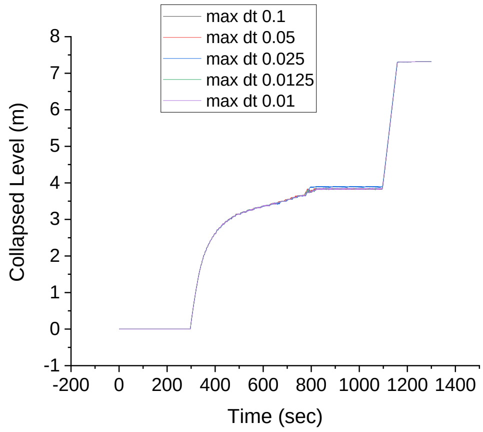
Fig. 4. Sensitivity test results of max. time step size for peak cladding tempearture



(a) Collapsed water level for the mesh number 10

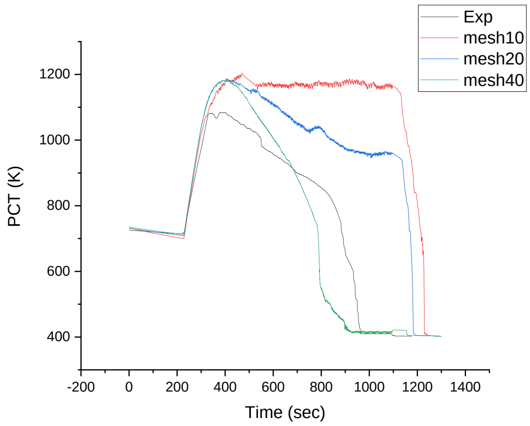


(b) Collapsed water level for the mesh number 20

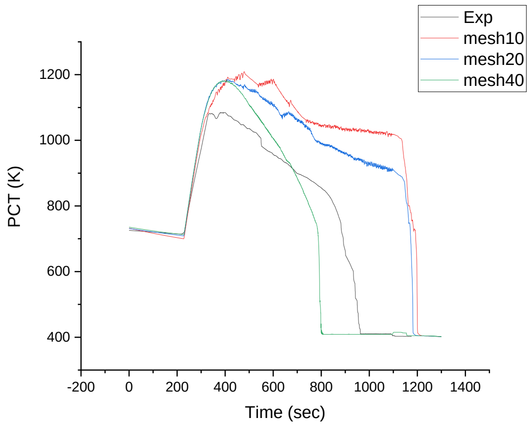


(c) Collapsed water level for the mesh number 40

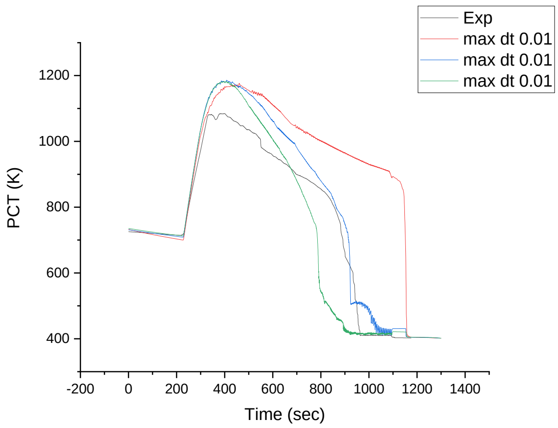
Fig. 5. Sensitivity test results of max. time step size for collapsed water level



(a) Peak cladding temperature for the max. time step size 0.1



(a) Peak cladding temperature for the max. time step size 0.025



(c) Peak cladding temperature for the max. time step size 0.01

Fig. 6. Sensitivity test results of the mesh number for peak cladding temperature

The sensitivity tests for maximum time step size and the number of meshes were conducted. The comparison was done for the experimental data of RBHT test 0945. Figs. 4 and 5 show different trends of the peak cladding temperature and collapsed water level. It means that the peak cladding temperature and the collapsed water level are dependent to the maximum time step size due to the numerical diffusion. However, in case of the mesh number 40, the peak cladding temperature and collapsed water level show similar results. This implies that when there are enough meshes, the numerical diffusion disappears and the results are independent with the maximum time step size. Similar results can be observed in Fig. 6 again.

4. Conclusions

The sensitivity tests for the maximum time step size and the number of mesh were conducted. The comparison was performed for the experimental data of RBHT test 0945. In these results, the simulation results are dependent on the maximum time step size and the number of mesh due to the numerical diffusion. However, when the number of meshes becomes larger, the simulation results are independent from the maximum time step size and the meshes in the reflood model. For further works, the higher order numerical scheme and the moving mesh method will be applied for solving the governing equations to improve the predictive capability of the code in a situation such as reflood or dramatic changes in the heat transfer / flow regimes.

ACKNOWLEDGEMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (NRF2016R1A5A1013919).

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