Simulation of RBHT Tests using MARS-KS Code

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1. Introduction

The OECD/NEA RBHT (Rod Bundle Heat Transfer) project was launched in October 2019, with a three-year project period. This project aims at addressing thermal-hydraulic safety issues through reflood experiments in the RBHT facility and improving on the accuracy of thermal-hydraulic codes used in the analysis and licensing of nuclear reactors [1].

In the framework of project, a total of eleven open tests were carried out for the participants to develop and correct their input models and obtain an accurate simulation of the data. In this study, we assess the reflood model [2] of MARS-KS V1.5 and our input model using the open test results.

2. Description of RBHT Facility

Figure 1 shows the test section of RBHT facility. The test section consists of 7 x 7 full-length rods having a diameter of 9.5 mm with a pitch of 12.6 mm placed in a square flow housing of 90.2 mm. There are 45 electrically heated rods and 4 unheated support rods in the corners. The bundle has a top-skewed axial linear power profile having a peak power at 2.74 m elevation. The heated length is 3.66 m. The bundle has seven mixing vane spacer grids with a design prototypical of a commercial fuel bundle [3].

The lower plenum is attached to the bottom of the flow housing is used as a reservoir for the coolant prior to injection into the rod bundle during reflood.

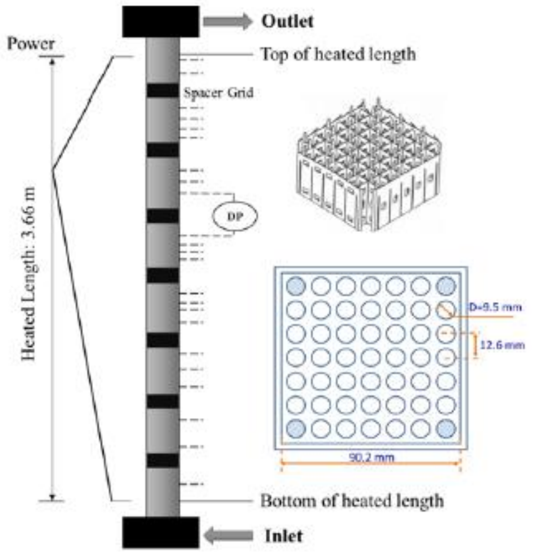

Fig. 1. Test section of RBHT facility [1].

3. Test Matrix for Open Tests

Table 1 shows the test matrix for the open tests. The experimental conditions were determined to cover various flow regimes expected in the reflood condition [1]. The experiments were performed under various combination of flooding rate, heater power, inlet water subcooling (ΔT_{sub}), and upper plenum pressure.

With the exception of some tests, most of tests are conducted for steady and constant coolant injection flow rate conditions. Tests O-7 and O-8 are carried out in oscillating and variable flow conditions, respectively. Test O-10 has a gradually reducing bundle power. Test O-11 is a repeat of test O-5 and is performed to demonstrate test repeatability.

4. Description of MARS-KS Input Model

Figure 2 shows the RBHT nodalization with axial power profile. The input model is developed using SNAP 3.1.1. The heated length is modeled using the one-dimensional PIPE component (PIPE-220), and has a total of 34 axial nodes with varying lengths from 0.05 m to 0.1392 m. The node lengths near peak power are relatively short. The lower and outlet plenums are

Table 1 Test Matrix

Test ID (Test No.)	Flooding Rate (cm/s)	Power (KW)	ΔT_{sub} (K)	Pressure (MPa)
O-1 (9021)	2.5	144	10	0.265
O-2 (9026)	2.5	144	80	0.266
O-3 (9015)	15	252	10	0.273
O-4 (9014)	15	252	80	0.276
O-5 (9005)	5	144	10	0.265
O-6 (9027)	2.5	144	30	0.268
O-7 (9012)	2.5 Oscillatory	144	10	0.267
O-8 (9011)	8 (0-15s) 5 (15-30s) 3 (30-40s) 1.3 (40-1500s) 1.14 (>1500s)	144	25	0.272
O-9 (9043)	0.5	35	2.8	0.270
O-10 (9029)	2.5	222 decay	47	0.265
O-11 (9037)	5	144	10	0.273

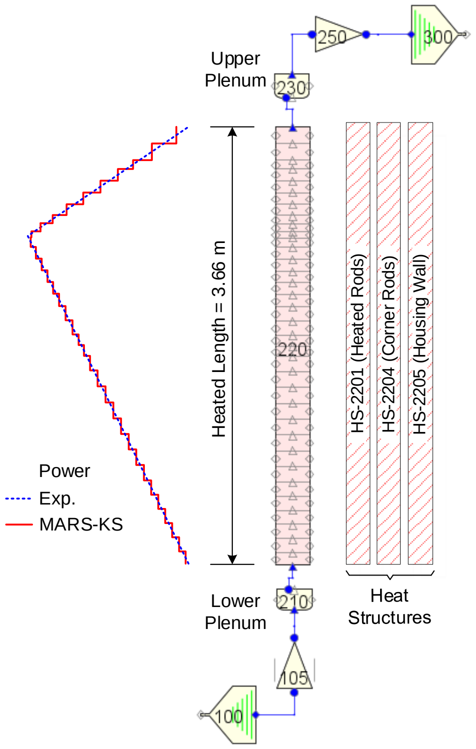

Fig. 2. Nodalization.

modeled using BRANCH components. The form loss of spacer grid is set to 2.0. The bundle has a top-skewed axial linear profile in the experiment, whereas the axial power profile in the simulation has a stepwise change.

There are three heat structures of 45 heater rods (HS-2201), 4 corner rods (HS-2204) and the housing wall (HS-2205). The heat loss from the housing wall to the environment is modeled. The heat transfer coefficient and environment temperature are assumed to be constant during the whole calculation. The radiation heat transfer is not applied.

The measured surface temperatures and interpolation scheme are used for the initial surface temperatures of heater rods, corner rods and housing wall. The saturated condition is assumed in the test section, lower and upper plenums at start of simulation. The measured flow rate and temperature of reflood injection are used. The exit pressure is set to constant nominal pressure.

The simulation starts at the time the heater power is turned on. The reflood injection is initiated when the maximum cladding temperature reaches target value.

5. Results and Discussion

Figures 3 shows the rod surface temperatures at 2.69 m elevation directly below the peak power. The dotted lines represent the test data, and the solid red lines represent the result of MARS-KS code. The similar trend is observed between the test data and simulation results.

The code over-predicts the maximum rod surface temperature at low flooding rate of 2.5 cm/s (O-1, O-2, O-6, O-7, and O-10), while it under-predicts the temperature at very low flooding rate (O-9). The code predicts the maximum temperatures well at medium (O-5 and O-11), high (O-3 and O-4), and variable (O-8) flooding conditions. The simulation shows fairly good results for the quenching time. However, a large discrepancy is observed at the condition of high flooding rate and low inlet water subcooling (O-3). The code shows much earlier quenching time than test data.

Figures 4 shows the results of quench front profile. The calculation results are generally satisfactory. The simulation predicts well the quench front profiles at the condition of low and medium flooding rates (O-2, O-5, O-6, O-8, O-10, and O-11). The quenching at the upper elevation is slower in the simulation than the experiment at low flooding rate and low inlet subcooling (O-1 and O-7), while it is faster in the simulation than the experiment at high flooding rate and high inlet subcooling (O-4) and at very low flooding rate (O-9).

There is a large discrepancy at the condition of high flooding rate and low inlet water subcooling (O-3), where the code result shows that the quenching time is faster than the experiment at all elevations along the axial direction of heater rods. The code fails to predict top quenching that occurs in the early stage of reflood at high flooding rate (O-3 and O-4).

6. Conclusion

The reflood model of MARS-KS code and input model were assessed using OECD/NEA RBHT open tests. Overall, the MARS-KS predicted well the rod surface temperature at 2.69 m elevation and quench front profiles. It was found that the developed input model is suitable for evaluating the reflood phenomena in the RBHT facility. The effort needs to be made to improve the predictive ability of MARS-KS code for the high flooding rate.

REFERENCES

[1] Agreement on the OECD Nuclear Energy Agency (NEA) RBHT Project, OECD/NEA, 2019.
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[3] M. K. Hanson and B. R. Lowery, Rod Bundle Heat Transfer Reflood Data from Bundle 2, Experiment RF2-9021, Quick Look Report, 2020.

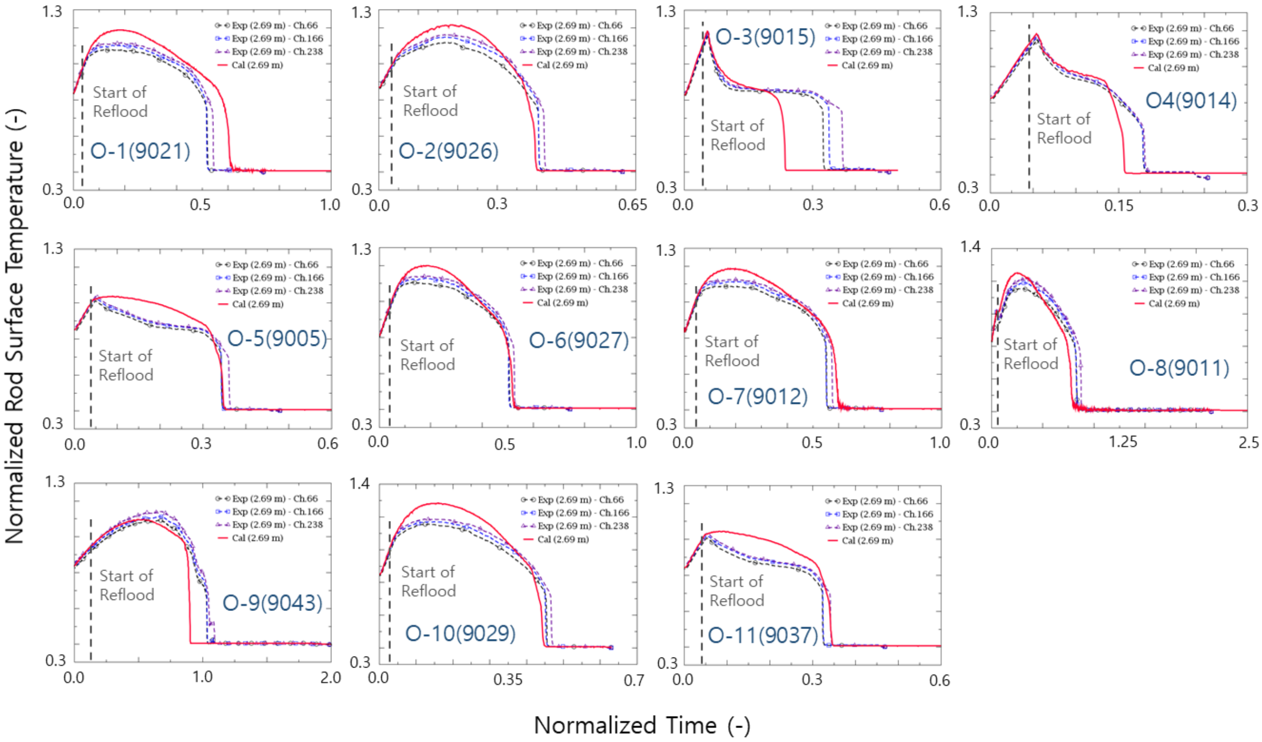

Fig. 3. Rod surface temperature at 2.69 m.

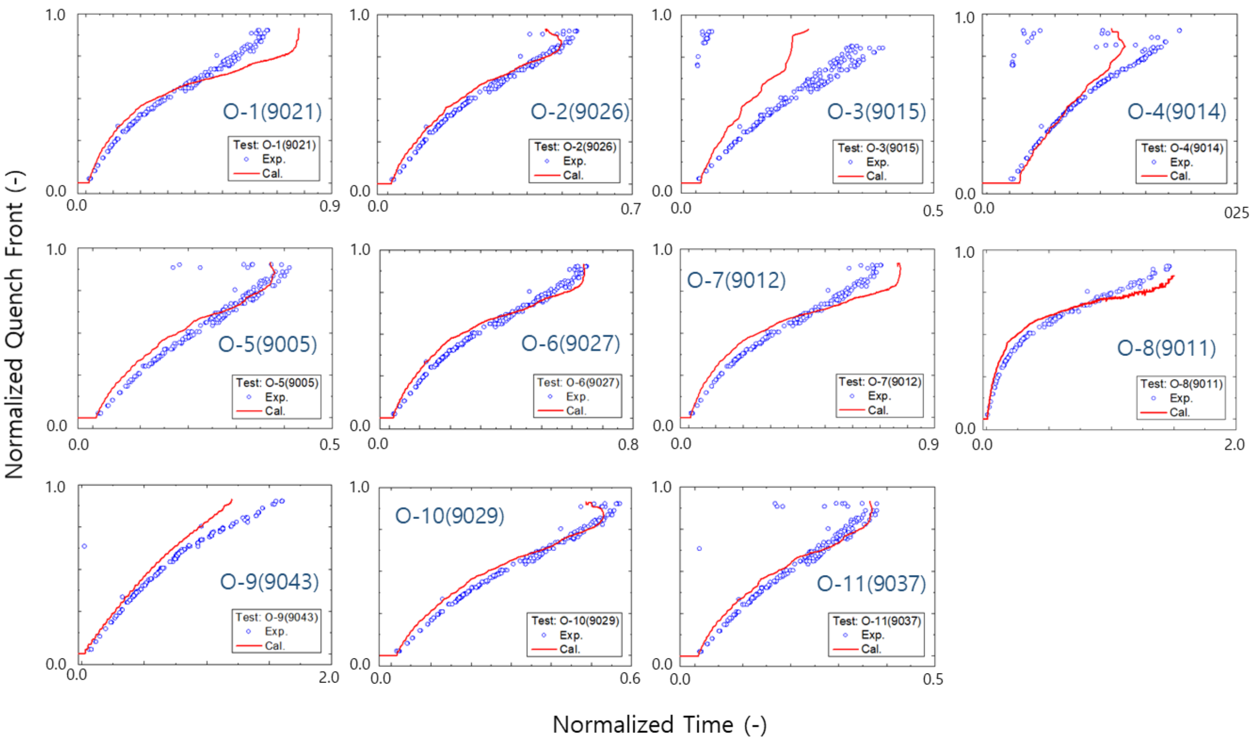

Fig. 4. Quench front profile.