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Verification and Validation of Heat Transfer Model of AGREE Code

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1. Introduction

In order to support the US NRC evaluation model of Next Generation Nuclear Plant (NGNP), the University of Michigan (U of M) has been developing a computer code named AGREE (Advanced Gas REactor Evaluator). The AGREE code was originally developed as a multiphysics simulation code to perform design and safety analysis of Pebble Bed Reactors (PBR) [1]. Currently, additional capability for the analysis of Prismatic Modular Reactor (PMR) core is in progress. Newly implemented fluid model for a PMR core is based on a subchannel approach which has been widely used in the analyses of light water reactor (LWR) cores [2]. For a heat transfer phenomena in a PMR core, AGREE adopts multi-dimensional and multi-scale models. A hexagonal fuel (or graphite block) is discretized into triangular prism nodes having effective conductivities. Then, a meso-scale heat transfer model is applied to the unit cell geometry of a prismatic fuel block. Both unit cell geometries of multi-hole and pin-in-hole types of prismatic fuel blocks are considered in AGREE.

The main objective of this work is to verify and validate the heat transfer model newly implemented for a PMR core in the AGREE code. The measured data in the HENDEL experiment [3] were used for the validation of the heat transfer model for a pin-in-hole fuel block. However, the HENDEL tests were limited to only steady-state conditions of pin-in-hole fuel blocks. There exist no available experimental data regarding a heat transfer in multi-hole fuel blocks. Therefore, numerical benchmarks using conceptual problems are considered to verify the heat transfer model of AGREE for multi-hole fuel blocks as well as transient conditions. The CORONA [4] and GAMMA+ [5] codes were used to compare the numerical results.

2. Verification and Validation Results

2.1 Heat Transfer in Pin-in-hole Fuel Block

HENDEL (Helium Engineering Demonstration Loop) was constructed for large-scale tests to support the design of the HTTR components such as pin-in-hole fuel column. Therefore, the experimental data of HENDEL are invaluable for the validation of the heat transfer model for pin-in-hole fuel blocks. Figure 1 shows the test section of the HENDEL experiment. The dimensions of the graphite fuel block are the same as those used for HTTR. Electrically heated rods were used to simulate fuel rods in HTTR. Seven graphite fuel blocks were stacked to simulate the active core of HTTR. Helium gas flowed downward through the annular channel between the graphite block and the simulated fuel rod.

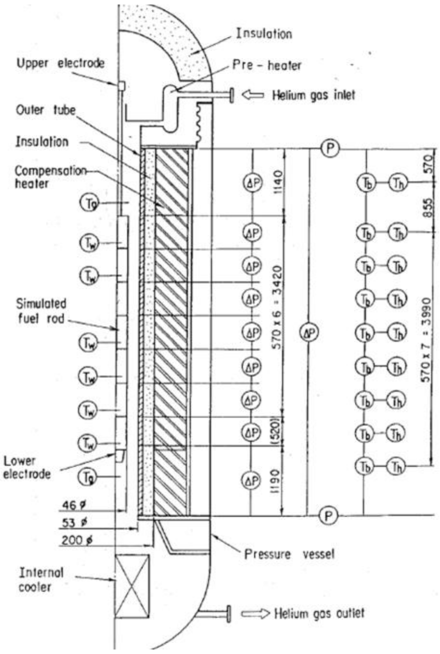

Fig. 1. Test section of HENDEL experiment [3].

For the validation of AGREE, the convective heat transfer correlation developed from the HENDEL experiment was applied. Figure 2 shows a comparison of AGREE prediction with the measured data.

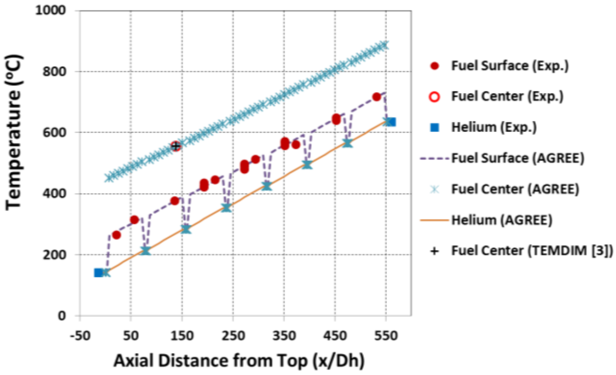

Fig. 2. Comparison of AGREE calculation with HENDEL experimental data (RUN 1830).

The figure shows a good agreement. The predicted fuel center temperature by TEMDIM [3] is also provided for a comparison. The difference between the AGREE and TEMDIM predictions is seen to be very small.

2.2 Heat Transfer in Multi-hole Fuel Block

In order to verify the heat transfer in multi-hole fuel blocks, single column of multi-hole fuel blocks under steady-state conditions of PMR200 is considered.

Figure 3 compares the AGREE and CORONA results of the temperature profile at the fuel center. An excellent agreement can be seen in the figure.

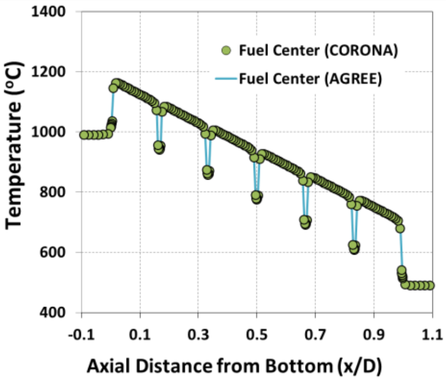

Fig. 3. AGREE and CORONA results of steady-state fuel temperature prediction of single multi-hole fuel column.

2.3 Heat Transfer under Transient Conditions

Two transient simulations were performed with the two types of the prismatic fuel blocks.

Figure 4 compares the predicted fuel temperatures with AGREE and GAMMA+ for the case of the power transient with single column of multi-hole fuel blocks. It is assumed that the fuel power follows the decay curve but the forced convection of the coolant is not changed. A good agreement is shown between the results of AGREE and GAMMA+.

Figure 5 shows a comparison of the numerical results for the case of the coolant transient with single column of pin-in-hole fuel blocks. In this scenario, it is assumed that the mass flow rate of the coolant is linearly dropped by 50% and completely recovered but the fuel power is not changed during the transient. The figure also shows a good agreement between the results of the two codes.

3. Conclusions and Outlook

In this work, the verification and validation study were performed for the heat transfer model of the AGREE code using the HENDEL experiment and the numerical benchmarks of selected conceptual problems. The results of the present work show that the heat transfer model of AGREE is accurate and reliable for prismatic fuel blocks. Further validation of AGREE is in progress for a whole reactor problem using the HTTR safety test data such as control rod withdrawal tests and loss-of-forced convection tests.

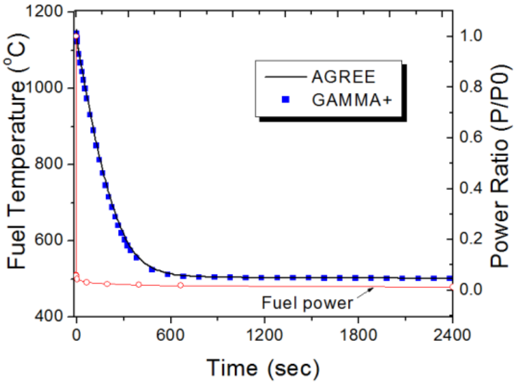

Fig. 4. AGREE and GAMMA+ results on power transient simulation with single multi-hole fuel column.

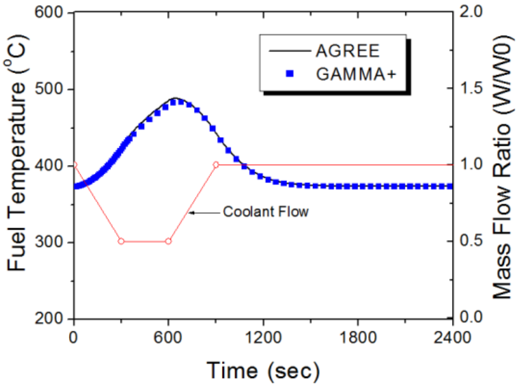

Fig. 5. AGREE and GAMMA+ results on coolant transient simulation with single pin-in-hole fuel column.

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