Prediction of Quenching of Hot Solid Sphere under Uniform Flow with STAR-CCM+

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1. Introduction

If the reactor vessel is damaged and corium is released to ex-vessel in the event of a severe accident of nuclear power plant, the corium is fragmented by interaction with coolant and deposited in the lower reactor cavity to form a layer of debris. Since the properties of the debris layer are determined by the Fuel-Coolant interaction (FCI), the FCI phenomena, corium jet breakup and heat transfer between the corium and the coolant are very important. High temperature corium cooled by coolant, sedimented and deposited is expected to be above Leidenfrost Temperature, and the cooling process undergoes quenching through the film boiling region where the minimum heat flux occurs and into transition boiling region where the heat flux increases rapidly. Quenching is a phenomena in which unstable vapor film collapses and heat transfer occurs through direct contact between liquid coolant and particles, resulting in a sharp decrease in particle surface temperature. In order to simulate the phenomena more accurately, it is very significant to model the heat transfer process in detail, and as a result, it is necessary to refine the overall heat transfer coefficients, including nucleate boiling, transition boiling, and film boiling. Heat transfer coefficients are highly dependent on the shape, size, temperature, fluid flow, and temperature of the particles. In this study, CFD analysis was performed by modifying the overall heat transfer coefficient as a basic step to refine itself, and the results were compared to the quenching experiment.

2. Physical modeling

In this paper, the quenching experiment on single sphere cooling under forced convection condition [1] was simulated and analyzed using the commercial CFD code STAR-CCM+. Heat transfer inside the solid sphere applies conduction. The Volume Of Fluid multiphase model is used because the working fluid is abnormal flow of liquids and vapors, and K-ε turbulence model calculates turbulence. In addition, the two-layer all y+ wall treatment was applied. The heat transfer between the solid surface and the liquid is basically convection, while the heat transfer between the liquid and the vaper is applied with a STAR-CCM+ built-in transition boiling model. This model provides a correlation including nucleate and transition boiling region and is curved as shown Fig.1.

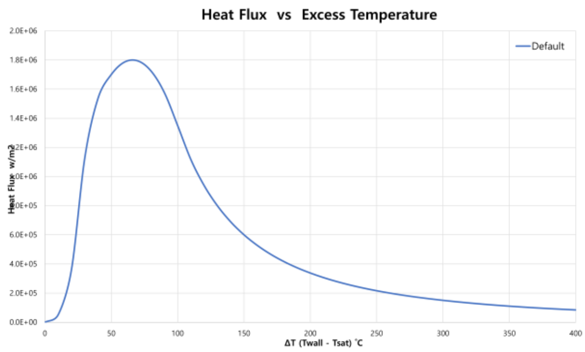

Fig. 1 Boiling curve of STAR-CCM+ built-in transition boiling model.

3. Simulation Methodology

The experimental conditions are shown in Table 1, and the geometric shape modeled with STAR-CCM+ of experimental facility is shown in Fig. 2.

Sphere material	Stainless steel
Sphere diameter	3 cm
Initial sphere temp.	800 ℃
Subcooled temp.	35.6 ℃
Flow velocity	0.035 m/s

Table. 1 Initial conditions of quenching experiments.

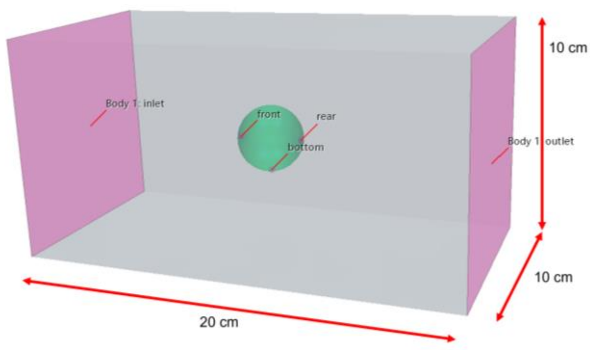

Fig. 2 The geometric shape of experimental facility.

The rectangular space is completely filled with water, and 0.035 m/s of subcooled water (35.6 ℃) flows through the inlet and outlet. Inside the 800 ℃ stainless steel sphere, there are three temperature measuring points which is thermocouple in experiment. Because the formation of the vapor film was important, the sphere and fluid interface mesh were divided into five layers using a prism layer mesh. The y+ value of the wall is not more than 0.3. In addition, the heat transfer coefficient was corrected by modifying the built-in transition boiling model, described in Fig. 3.

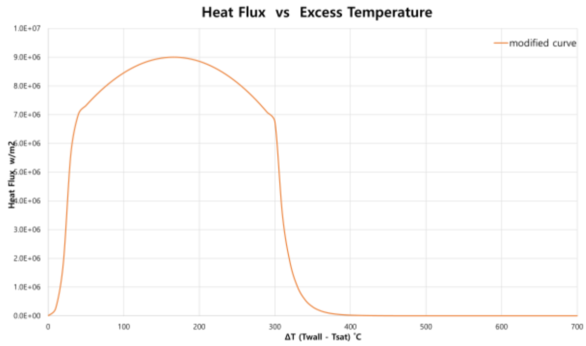

Fig. 3 Boiling curve of modifying built-in transition boiling Model.

4. Result

Fig. 4 shows steam generated in about 2 seconds moving in the direction of subcooled water flow.
Fig. 5 is a graph of the results of the analysis. The temperature at the three temperature measuring points located inside the sphere was expressed over time. The rapid temperature reduction between approximately 9 and 12 seconds is the quenching phenomenon and has similar behavior to the experimental results (Fig. 6).

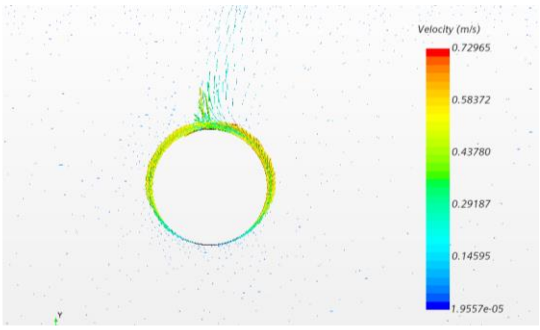

Fig. 4 Vector scene of fluid flow.

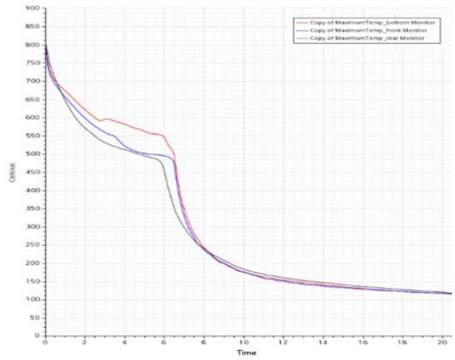

Fig. 5 Graph of temperature change at three points inside the Sphere.

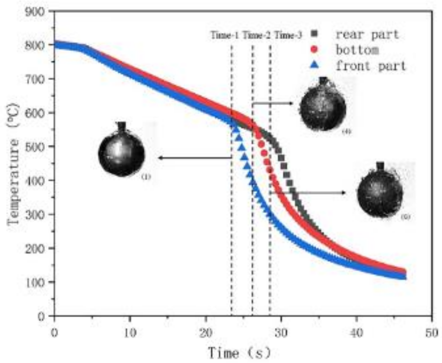

Fig. 6 Result of quenching experiments.

5. Conclusion

Fuel-Coolant Interaction (FCI) affects the formation of the debris bed and determines the temperature distribution of the debris bed according to its cooling properties. Therefore, it is very important to model the heat transfer process in detail for more precisely simulation ex-vessel corium emissions, and as a result, it is necessary to elaborate overall heat transfer coefficient involving nucleate, transition, film boiling. More sophisticated heat transfer coefficient will reduce uncertainty in interpreting severe accident of nuclear power plant.

REFERENCES

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