Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

CFD Analysis on Thermal-Hydraulic Behavior in Emergency Cooldown Tank of SMART Passive Residual Heat Removal System

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1. Introduction

SMART [1] was developed by KAERI. It is a 365 MW (thermal) integral type small modular reactor (SMR). An integral effect test facility which is SMART-ITL (Integral Test Loop) [2] was established to evaluate and verify an integral simulation of transients and accidents at Korea Atomic Energy Research Institute (KAERI) as shown in Fig. 1. SMART-ITL have the simulation capability of some DBAs (design basis accidents) scenarios and system performance tests which are small-break loss of coolant accident (SBLOCA), compete loss of reactor coolant system (RCS) flow rate (CLOF) and passive residual heat removal system (PRHRS) performance for the SMART design. For an optimal design of the heat exchanger of passive residual heat removal system (PRHRS) the number of tubes in the heat exchanger was changed from 10 to 2. The CFD analysis on the 10 tubes case was performed in experimental case on SBLOCA of shutdown cooling line [3]. In this study, CFD analysis was performed to estimate the refilling time of emergency cooldown tank (ECT) by calculating the time the ECT water temperature reaches 100 ℃ in the revised design of 2 heat exchanger tubes. When the temperature of the coolant at the top reaches 100 ℃, the water at the top of the ECT evaporates and the water at the ECT begins to run dry. The calculation time to reach 100 ℃ becomes an important design parameter in selecting the requirements for water quantity calculation and refilling time of ECT.

2. Description of the System

The SMART-ITL was designed following the three-level scaling methodology which is consisted of integral scaling, boundary flow scaling, and local phenomena scaling. Its height is preserved to full scale and its area and volume are scaled down to 1/49 compared with the prototype plant, SMART. The PRHRS of the SMART is connected to the steam generator. After core shutdown due to the accidents, the decay heat is stored in the steam generator. PRHRS served to transport and remove the heat from the steam generator. The steam is filled in the loop between the steam generator and the inner heat exchanger of the PRHRS. This heat exchanger is located inside the ECT. The steam is condensed in the inside of the heat exchanger. Ultimately, decay heat is removed in the ECT which is the major component of the PRHRS. This heat exchanger is located in the vertical direction. There is an interface between the liquid and the vapor in the heat exchanger. The initial temperature of water and air was set to be 24 ℃ as in the experiment. Heat transfer was simulated by setting a specific heat flux value on the inner wall of the heat exchanger.

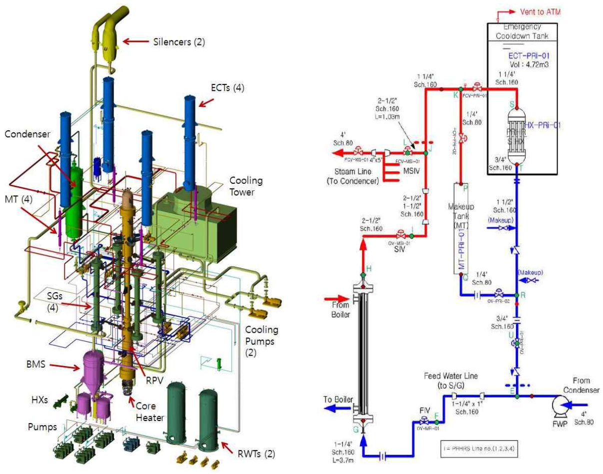

Fig. 1. Schematic diagram of SMART-ITL and PRHRS

3. Analysis Method and Results

3.1 Analysis Model and Simulation Cases

CFD analysis was performed on three cases as given Table 1; case 1 is the reference test case of F103 that simulates SBLOCA, case 2 is the case where the initial temperature is changed to 50 degrees, and case 3 is the case where the heat exchanger location is changed from 1.33 m from bottom to the bottom of ECT.

Table.1 Calculation case description

Case study	ECT Initial temp. (℃)	HX Location from ECT bottom
Case 1. Reference	24	1.33 m
Case 2	50	1.33 m
Case 3	24	0 m

The initial height of accumulated water in the ECT tank is 7.8 m. The ECT has a vent line connected to the outside at the top. PRHRS condensation heat exchanger is located at a height of 1.33 m from the bottom of ECT. The heat exchanger has a specific shape in which two tubes are connected between the upper and lower plenums. The geometry model was shown in Fig. 2. From the results of the experiment, it was confirmed that an average of about 150 kW of heat was removed by the heat exchanger. The external heat loss was simulated by setting a constant heat transfer coefficient of 8 W/m^2K and exposed to air with 24 ℃ on the outer surface of ECT.

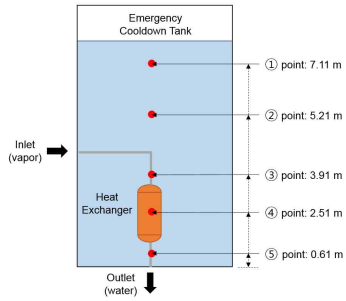

Fig. 2. CFD calculation domain and measuring points

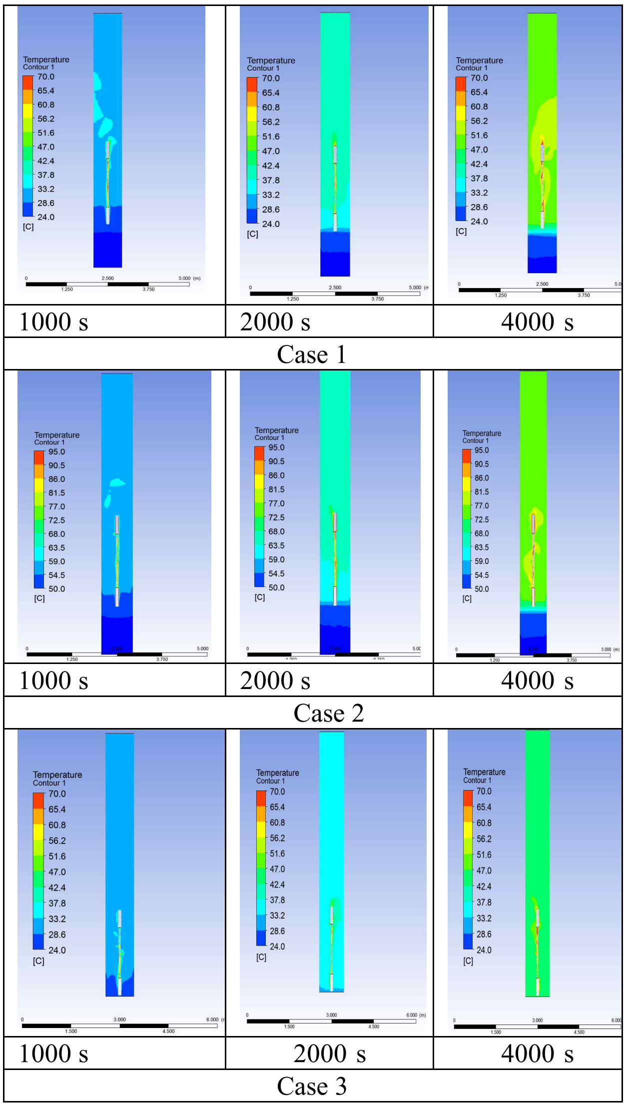

Fig. 3. Temperature distribution in calculation cases

3.2 Analysis Results

Figure 3 is the temperature distribution over time obtained from the analysis. In the calculation case on experiment, thermal stratification inside ECT is observed as the time goes on. The lower part of the ECT does not appear to contribute to the removal of heat from the heat exchanger. The heat transferred from the wall of the heat exchanger causes thermal stratification as the surrounding area of the heat exchanger is heated. The heated water rises by the density difference between the bottom and top of ECT. In the case of heat exchanger location change, thermal stratification is not observed from the bottom of ECT and the dead zone which does not contribute to heat removal disappears. Figure 4 shows the temperature trend of the ① measuring point from the CFD calculation result. In the case 1, case 2 and case 3, the time to reach 100 ℃ calculated through a linear trend line are about 7560s (2.1h), 11520s (3.2h) and 13680s (3.8h) , respectively.

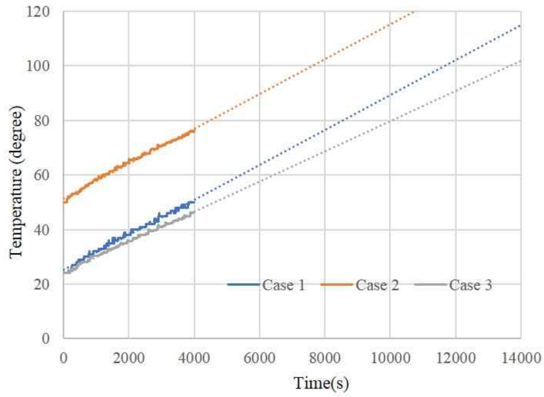

Fig. 4. Comparison of temperature trends between 3 calculation cases

4. Conclusions

The CFD analysis was performed to simulate the thermal-hydraulic behavior of the ECT caused by the small-break loss-of-coolant accident (SBLOCA). A couple of sensitivity calculations were performed for the change of ECT's initial temperature and heat exchanger location. It was confirmed that the thermal stratification was observed and the time taken for the water temperature to reach 100 ℃ inside ECT was estimated from the results of the temperature distribution in the ECT.

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