Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 12-13, 2016

Initial Formation of Hot Water Layer in Open-pool Type Research Reactor

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1. Introduction

An open-pool type multi-purpose research reactor is designed by Korea Atomic Energy Research Institute (KAERI). In order to prove the proper functions and performances of each system in this facility, the system performance tests are conducted.

Hot water layer system in this facility is designed to generate a hot water layer at the upper part of the pool in the reactor building. The hot water layer is a kind of shielding layer which reduces the pool top radiation level. During the performance test of the hot water layer system, the hot water layer is actually formed and its forming characteristics are investigated.

In this paper, some of the test results such as the initial hot water layer temperature transitions and the development of hot water layer will be presented and those are compared with the CFD calculation results to validate the CFD method.

2. Hot Water Layer System

In an open-pool type research reactor, the reactor core is located in the lower part of the pool. The reactor core is cooled by a forced circulation flow from the primary cooling system and the removed core heat is transferred to the secondary cooling system. Then the primary cooling water is dumped into the lower part of the pool and circulates into the reactor core. During this process, a strong forced convection flow dominates in the lower part of the pool. Although the pool water is purified by the pool water management system, the water in the lower part of the pool has significant radioactivity. Therefore the water should be prevented from rising up to the pool surface to protect the workers and researchers in the reactor hall.

The hot water layer system basically consists of a pump, an ion-exchanger, and an electric heater. The pump circulates the process water from the upper part of the pool to the hot water layer system. Then the ion-exchanger removes ionic radioactive impurities dissolved in the water. Finally the electric heater increases the water temperature to the desired temperature and the process water goes back to the upper part of the pool.

The hot water layer generated by the hot water layer system is maintained in a higher temperature than the lower part of the pool. This prevents the forced convection flow in the lower part of the pool from rising up to the pool surface. Consequently a mass transport from the lower part of the pool which transfers the radioactive materials to the pool surface is largely reduced. In addition to this, the water in the hot water layer is simultaneously purified by the ion-exchanger to remove the ionic radioactive materials in the water to decrease the radioactivity level on the pool top to a negligible level.

3. Methods

3.1 Test Method

During the performance test of the hot water layer system, each component of the system is first tested to check its proper function and performance. After the component tests, the hot water layer is actually formed to reveal the overall system performance. For this test, only the hot water layer system is operated more than 2 days and the variation in the suction and discharge temperatures of the system and the hot layer temperature are investigated using RTD sensors installed in the pipe line and the pool. To measure the actual suction and discharge temperatures, the RTD sensors are located near the suction and discharge ends as possible. The RTD sensor for hot water layer temperature measurement is installed in the pool at the same height with the suction and discharge ends.

To investigate the hot water layer development characteristics, the depth-wise temperature distribution in the pool is also measured during the test using a submersible RTD sensor. This device is also equipped with a pressure sensor to detect the depth. So the depth-wise temperature distribution information is obtained by releasing the submersible device in to the pool at a certain position on the pool top. The accuracy of the RTD sensors and the depth sensor are about ± 0.1℃ and ± 0.01 m.

3.2 CFD Calculation Method

For the CFD, the geometries and meshes for the reactor pool and the service pool are produced by the Geometry and the Mesh in the ANSYS Workbench 13.0. The patch conforming tetrahedrons method and the multi-zone method are used for the mesh generation. The tetrahedrons mesh is adopted for the hot water layer region and the multi-zone method is adopted below the hot water layer where the thermal stratification develops. Mesh sizing functions which consider the proximity and curvature of the geometry is used and the maximum cell size is restricted to 0.1m. Number of generated mesh cells is about 1.8 million. The calculation is done using a transient solver. RNG k-e model is adopted for the viscous model. For the pressure-velocity coupling, SIMPLE scheme is adopted with the spatial discretization of second order upwind for momentum, turbulence, and energy. A user-defined function is used to set the discharge temperature considering the suction temperature and the actual heater capacity. In the function, the information of suction temperature is taken and the discharge temperature is set by adding the temperature difference produced by the heater for each time-step.

4. Results and Discussion

Fig. 1 shows a time history of the temperature measured from each RTD sensor. The time history results from the CFD calculations are also presented. The discharge temperature is controlled by the heater internal control logic to maintain the temperature at a desired temperature. The heater works with 100% power at the initial stage and then the heater power is automatically adjusted as the discharge temperature reaches to the desired temperature. The suction and hot water layer temperatures are almost same because the RTD sensors are located at the same height. After the discharge temperature reaches to a desired temperature, the hot water layer temperature begins to converge to a certain temperature. The calculated temperature histories show quite good agreement with the measured values. However, there exists a little error for the suction temperatures between the measured and calculated values. The calculation estimates quite higher temperature than the measurement. This can be resulted from the adiabatic boundary condition assumed for the pool walls in the calculation. In real situation, there can be a significant heat loss through the pool wall which decreases the hot water layer temperature. Another possibility is the turbulence model in the calculation. If the turbulence model underestimates the heat transfer at the bottom part of the hot water layer, the hot water layer temperature can be estimated to be higher than the real situation.

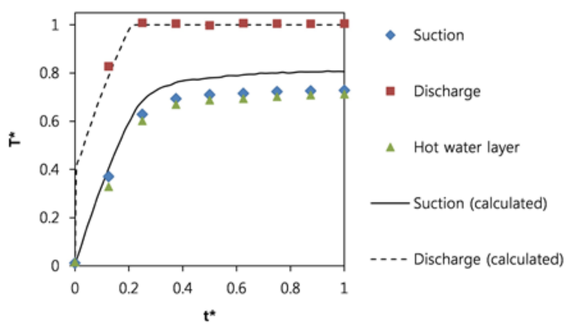

Fig. 1. Measured and calculated temperatures according to the time. The values are normalized.

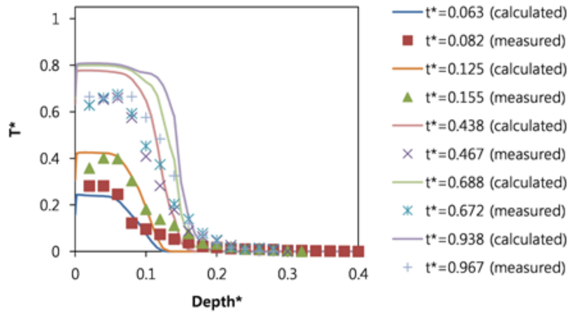

Fig. 2. Depth-wise temperature distribution at the center of reactor pool. The values are normalized.

Fig. 2 shows depth-wise temperature distributions at the center of reactor pool measured by the submersible RTD sensor at different times. The calculation results obtained at the similar times are also presented in the figure. As time goes by, a convergence trend can be seen in the temperature distributions. Although there exists a deviation between the measured and calculated hot water layer temperatures, the thicknesses agree quite well with each other.

5. Conclusion

In this study, the characteristics in the initial hot water layer formation are investigated. Several temperature information are obtained during the performance test of the hot water layer system and the results are used to validate the CFD calculation results. Although there exists a small deviation between the measurement and the calculation, the calculation method predicts the results within an acceptable accuracy. By developing the boundary condition or the turbulence model for the calculation, the CFD method can be expected to produce more exact solutions for this kind of calculation.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. NRF-2012M2C1A1026909).

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