Experimental Study for the Water Pool Type Reactor Cavity Cooling System in the High Temperature Gas Cooled Reactor

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1. Introduction

The hydrogen production system coupled with a High Temperature Gas Cooled Reactor (HTGR) is considered as one of the most promising application to allow new processes of massive hydrogen production with economy and emission free [1]. In the cavity of the HTGR which is the space between the reactor vessel and containment, a reactor cavity cooling system (RCCS) is equipped to remove the heat transferred from the reactor vessel to the structure of the containment. In the present study, a new concept of the RCCS for the HTGR named water pool type RCCS was proposed which is expected to have better cooling capability than air cooled type and simpler system configuration than water cooled type. Also the experimental results for the new RCCS were presented, which were performed to evaluate its cooling capability and understand the heat transfer phenomena in the system.

2. The Concept of Water Pool Type RCCS

We proposed a new concept of the RCCS, named water pool type RCCS to overcome the disadvantage of both the weak cooling ability of air-cooled RCCS and the complex structures of water-cooled RCCS. As different from the common water cooling RCCSs which use natural circulation of water [2], it uses water pools as a heat sink of the heat loss during normal operation and the afterheat during the accident conditions. The schematic diagram of the water pool type RCCS is presented in Figure 1. In normal operations, the heat loss from the reactor vessel is transferred into the water pools via cavity. The heat is rejected to the atmosphere by forced convection of air flowing through cooling pipes. Ambient air is utilized for the forced convection. In the case of the LOFC accident with accompanying failure of all active cooling systems, the afterheat is passively absorbed by heating up and then boiling off the water in the water pools. We would like to design the capacity of the water pool to provide sufficient cooling capability of the passive afterheat removal for three days.

This new concept of the RCCS is similar to the common water cooling systems but it is expected to be easier to design and analyze because of the simple geometry of the cavity cooling surface. It uses ambient air to reject the afterheat to the atmosphere so additional cooling systems are not necessary. Also it is expected to have less uncertainty and complexity in the boiling situation than other water cooling systems since typical pool boiling occurs in the water pool of the system. Poor cooling capability of air, however, may result in undesirably large capacity of the air supply system. Also the size of the water pool should be optimized due to the limited space of the cavity.

For this reason, we have performed a series of experiments to evaluate the feasibility of the water pool type RCCS and assess the cooling capability of the device.

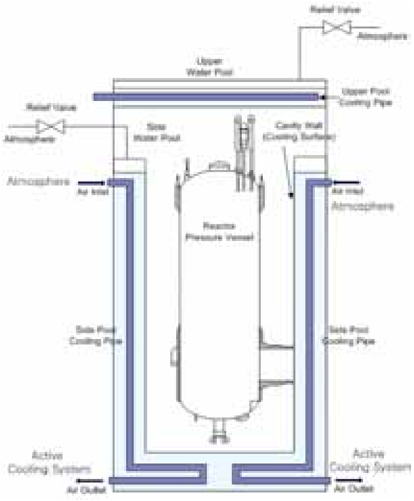

Figure 1. Concept of the Water Pool Type RCCS

3. Experimental Facility

The experimental apparatus mainly consists of a reactor vessel, side water pool surrounding the vessel, upper water pool, cooling pipes in the water pools and air supply system. The reactor vessel of the test facility is 1/10 linear scaled model [3] of the PBMR (265 MW). In the reactor vessel, six cartridges of heaters were installed to simulate the heat loss during normal operation and the afterheat during the LOFC accident. Thirteen cooling pipes are installed in the side pool and the upper pool (12 in the side pool, 1 in the upper pool) to remove the released heat from the vessel.

The major measuring parameters are the air flow rates, pressure drops along the cooling pipes, water level in the side pool, pressures at the water pools, reactor vessel and cavity and temperatures.

In the present study, two categories of experiments, the normal operation tests and the LOFC accident test with accompanying failure of all active cooling systems were performed.

4. Experimental Results

4.1 Normal operation test

Temperature distributions at the reactor vessel wall and cavity wall during normal operation were measured in the experiments as shown in Figures 2.

The experimental results show that there exists large gradient of the cavity wall temperature across the water level and the uncovered part of the cavity by water may remain uncooled in the system. However, the existence of the uncooled section does not seem to affect the radiative heat transfer from the reactor vessel apparently because the view factor of the uncooled region is relatively very small comparing with the other region of the cavity wall. In spite of the insignificant effect of the uncooled region, it would be recommended that the area of the uncooled region be reduced as small as possible for the optimization of the system. It should be noted that the maximum temperature of the reactor vessel wall was kept less than the design limitation 300^{o}C. The observed maximum temperature was 265^{o}C and it means that the water pool type RCCS removes the heat released from the reactor vessel sufficiently well.

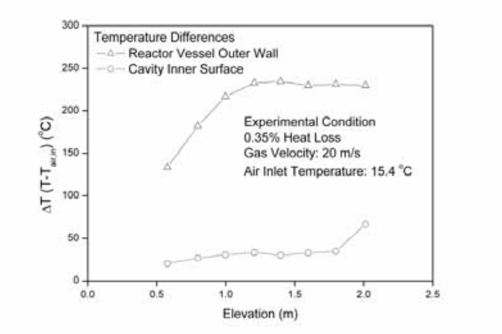

Figure 2 Temperature Profile
during Normal Operation

4.2 LOFC test

An experiment was carried out simulating the LOFC accident of the HTGR, which is the case that the forced convection of the main cooling system of the reactor is failed and the failure of all other active cooling system including the RCCS air coolers is accompanied. With the beginning of the LOFC accident, the water pool temperature increases and then it maintained constantly at the saturation temperature. Because of boiling off, the water level decreases gradually. With the decrease of the water level, the area of the uncovered cavity wall by water is increased. At the dry out region, the cavity wall temperature increased rapidly because incoming heat could not be removed sufficiently as shown in Figure 3. Figure 4 shows the temperature transient of the reactor vessel wall. The upper part temperatures of the reactor vessel began to increase in spite of the constant heating power at about 60,000 second and it means that the area increase of the uncovered cavity wall began to retard the cooling capability of the water pool. At the moment, the water level was reduced by 10% and about 12 % of total cavity wall length was uncovered by water. From this experimental result, we can conclude that 10% of water level reduction by boiling off would be allowed in the water pool type RCCS and this criterion will be applied for the optimization of the system.

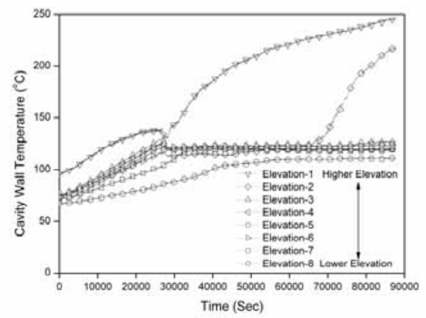

Figure 3 Temperature Transient: Cavity Wall

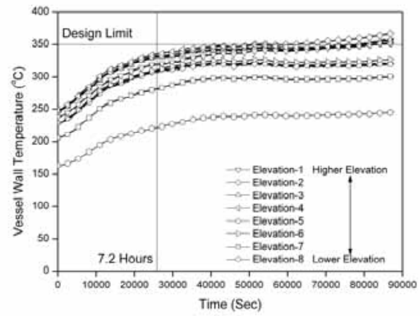

Figure 4 Temperature Transient: Reactor Vessel Wall

5. Conclusion

We proposed a new concept of the RCCS, water pool type RCCS to overcome the disadvantage of both the weak cooling ability of air-cooled RCCS and the complex structures of water-cooled RCCS. To provide the data for the validation of thermal hydraulic reactor safety codes and to evaluate the feasibility of the system, a series of experiments were carried out in the present study simulating the reactor vessel, cavity and RCCS of the HTGR. These experimental results will be used for the design guideline for the optimization and the validation of thermal hydraulic safety analysis codes which will be used for the optimization.

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