Analysis of a Hybrid Type Reactor Cavity Cooling System for a VHTR

Nam-il Tak*, Min-Hwan Kim, Hong Sik Lim, and Won Jae Lee
Korea Atomic Energy Research Institute, 1045 Daedeok Street, Yuseong-gu, Daejeon 305-353, Korea
**Corresponding author: takni@kaeri.re.kr*

1. Introduction

When neither the heat transport system (using the intermediate heat exchanger or the power conversion system) nor the shut-down cooling system is available during accident conditions, the core residual heat is removed by the reactor cavity cooling system (RCCS) in a very high temperature reactor (VHTR). It is a safety-related system that ensures the safe states of the reactor components (particularly the nuclear fuel and the reactor vessel) under accident conditions. It also protects the concrete wall of the reactor cavity for all modes of operations.

Two types of the RCCS are available at the recent VHTR designs. For example, GT-MHR [1] and GTHTR300 [2] adopt an air-cooled RCCS that provides a passive means of residual heat removal. On the other hand, PBMR [3] use a water-cooled RCCS which has forced circulating water. Each type has its merits and demerits.

Recently, a hybrid type of these two systems has been proposed by Cho et al. [4]. Although the qualitative features of a hybrid system seem to be good, the feasibility of such a system has not been quantitatively assessed yet. In this work, thermal characteristics of this new concept (i.e., hybrid RCCS) are quantitatively investigated based on the preliminary design parameters of PMR200 [5].

2. Descriptions of Hybrid RCCS

Fig. 1 shows a concept of hybrid RCCS proposed by Cho et al. Both air and water coolant channels are installed in the reactor cavity of a VHTR. Each system is designed for an independent operation. An air-cooled system is designed as a passive heat removal system whereas a water-cooled system has active components such as pumps and valves. Either air-cooled or water-cooled system is operated under normal conditions. Under accident conditions both systems are used at the same time.

3. Thermo-Fluid Analysis

In order to assess the thermo-fluid characteristics of the hybrid RCCS concept, an example calculation has been made using the preliminary design parameters of PMR200. The reference RCCS system of PMR200 is an air-cooled passive system which is the same as that for GT-MHR. In this work, a water cooled system is augmented to the air-cooled system to simulate a hybrid RCCS system. It is assumed that the water-cooled system starts to operate under accident conditions only. Fig. 2 shows the configurations of the cooling channels for the hybrid RCCS. The water-cooled channels are attached to the rear side of air-cooled channels. The heat can be transported by conduction from the air-cooled channels to the water-cooled channels. In this work, radiative heat transfer from the reactor vessel to the water-cooled channels is neglected.

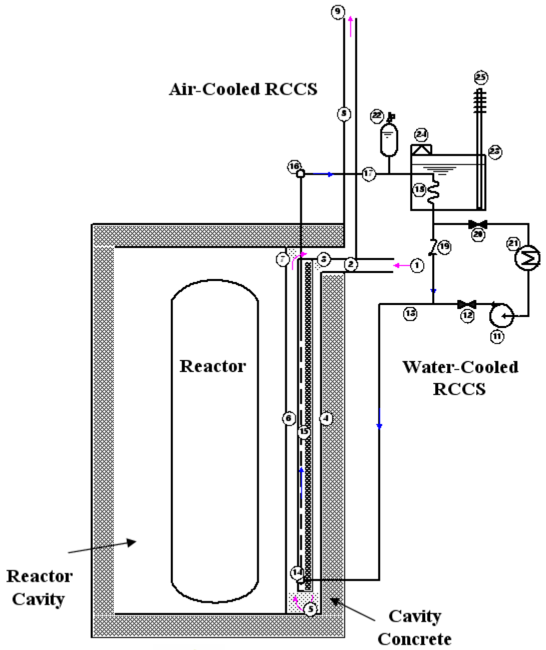

Fig. 1. A concept of hybrid RCCS.

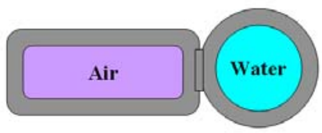

Fig. 2. Cooling channels for hybrid RCCS

A low pressure conduction cooling (LPCC) accident scenario is selected to investigate the thermo-fluid performance of the hybrid RCCS. The GAMMA+ code [6] is applied to simulate the system behavior of PMR200 with the hybrid RCCS. Chemical reaction due to air-ingress is neglected.

4. Results and Discussions

Figs. 3 & 4 show the thermo-fluid performance of the hybrid RCCS under the LPCC event. The results with the reference RCCS system (air-cooled RCCS only) of PMR200 are added for comparisons. As shown in Fig. 3, the peak fuel temperature is not significantly affected by the operation of the water-cooled system. The peak pressure vessel temperature is slightly reduced by the operation of the water-cooled system. It is seen that the cooling capability of the hybrid RCCS is not significantly improved. Such results are from the passive characteristics of the air-cooled system. When the water-cooled RCCS is operated, the heat transfer through the air-cooled RCCS is reduced due to lower temperature of the air cooling channels which result in smaller flow rate of the air as well.

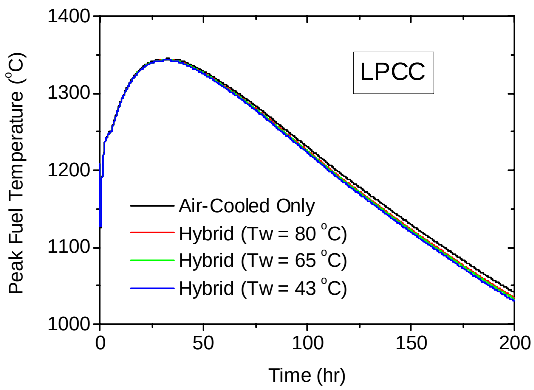

Fig. 3. Peak fuel temperature of PMR200 with hybrid RCCS under LPCC.

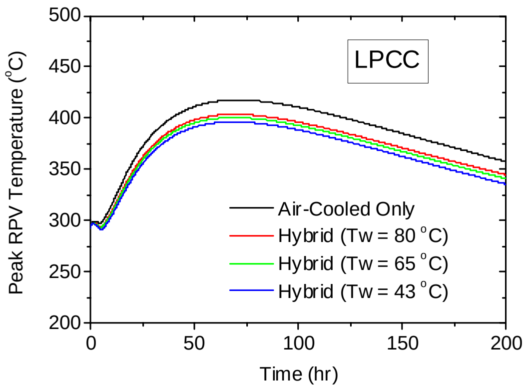

Fig. 4. Peak reactor pressure vessel temperature of PMR200 with hybrid RCCS under LPCC.

However, the hybrid RCCS is found to be useful in terms of the redundancy concept. Figs. 5 & 6 show the thermo-fluid performance of the hybrid RCCS with air-cooled RCCS failure under the LPCC event. Even if the air-cooled RCCS completely fails, the water-cooled RCCS effectively cools down the nuclear fuel as well as the reactor pressure vessel.

5. Conclusions

The GAMMA+ calculations were made to investigate the thermo-fluid characteristics of the hybrid RCCS proposed by KAERI. The results show that the cooling capability of the hybrid RCCS is not significantly improved. However, it plays a crucial role in the case of the air-cooled RCCS failure. It is concluded that more investigations are needed for a practical implementation of the concept of the hybrid RCCS.

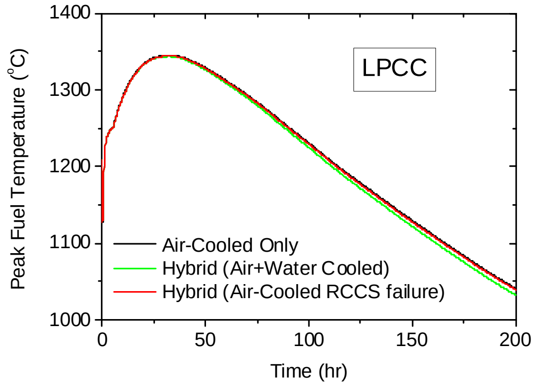

Fig. 5. Peak fuel temperature of PMR200 with hybrid RCCS in case of air-cooled RCCS failure.

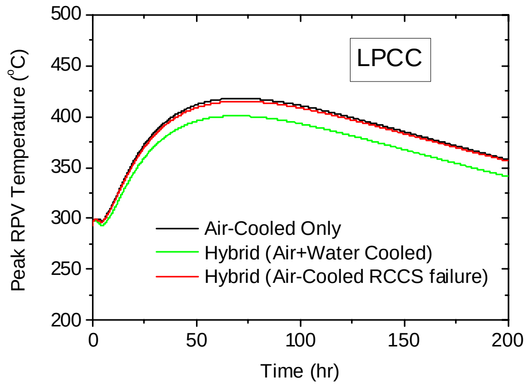

Fig. 6. Peak reactor pressure vessel temperature of PMR200 with hybrid RCCS in case of air-cooled RCCS failure.

ACKNOWLEDGMENTS

This work was financially supported by the Korean Ministry of Education, Science and Technology (MEST).

REFERENCES

[1] General Atomics, GT-MHR Conceptual Design Description Report, San Diego, California, 2002.
[2] K. Kunitomi, et al., Nuclear Engineering and Design, Vol. 233, pp. 309-327, 2004.
[3] M. P. Staden, Analysis of Effectiveness of Cavity Cooling System, HTR2004, Beijing, China, Sep. 22-24, 2004.
[4] B. H. Cho et al. Patent Application No. 2007-0086479, Korea. 2007.
[5] C. K. Cho et al., Preconceptual Designs of the 200MWth Prism and Pebble-bed Type VHTR Cores, PHYSOR2008, Interlaken, Switzerland, Sep., 2008.
[6] H. S. Lim, H. C. No, Nuclear Science and Engineering, Vol. 152, pp. 87-97, Jan. 2006.