Dryout on Outer Spherical Vessel Lower Head with Streamlined Gap

Sang W. Noh, Kyoung M. Kang, Kune Y. Suh*
Department of Energy Systems Engineering, Seoul National University
599 Gwanak-Ro, Gwanak-Gu, Seoul, 151-744, Korea
**Corresponding author: kysuh@snu.ac.kr*

1. Introduction

The recent Shin-Gori Units 3 and 4 of the APR1400 (Advanced Power Reactor 1400 MWe) under construction have adopted the concept of in-vessel retention through external reactor vessel cooling (IVR-ERVC) by reactor cavity flooding as major severe accident management strategy. The ERVC in the APR1400 design resorts to active flooding system using thermal insulator. [1-6] The CASA SC (Corium Attack Stopper Apparatus Spherical Channel) tests are conducted to measure the critical power on a downward hemispherical vessel scaled down from the APR1400 lower head by 1/10.

2. Experiment

The CASA SC test section comprises three main parts: the pure copper vessel, copper blocks and scale-down thermal insulator. Fig. 1 illustrates the copper vessel with an outside diameter of 0.5 m and a wall thickness of 0.02 m. The hemispherical copper block is divided into eight pieces of the same shape, four of which are heated. The four heated copper blocks having twenty four holes on the upper surface for vertical insertion of cartridge-type heaters with a total power of 256 kW are inserted into the copper vessel. Four rectifiers in two control panels allow eighty-four cartridge heaters in the four copper blocks to be heated and then the hemispherical copper vessel is heated by conduction. The heater power simulates the decay heat of molten core relocated in the reactor vessel lower head.

Fifty-five thermocouples of K-type are installed at 0o, 10^o, 20^o, 30^o, 40^o, 50^o, 60^o, 70^o, 80^o and 90^o within the hemispherical copper vessel. Three T-type thermocouples are located in the pipes of the primary loop to control the constant inlet sub-cooling. These thermocouples are calibrated for a maximum uncertainty of $\pm 1^oC$ and inserted at an interval of 10^o inside surface of copper vessel as presented in Fig. 1. The uniform gap size between the vessel and the thermal insulator is 0.05 m.

Demineralized water is used as working fluid and filtered prior to entering the test section. A booster pump having a maximum mass flow rate of 16.5 kg/s is used for forced convection and two motorized two-way control valves are installed to maintain a constant mass flow rate. The primary coolant is injected into the primary loop and test section by the booster pump and control valves. The working pressure in the primary loop is 0.17 MPa. The surface temperatures of the copper vessel from the fifty-five thermocouples are recorded using the LabVIEW program and data acquisition system of National Instruments, Inc. Additionally, the heat flux values are measured by the WT-130 instrument.

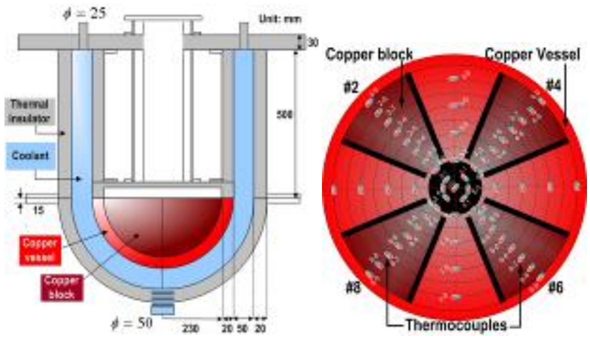

Fig. 1 Configuration of CASA SC test section.

3. Results

Fig. 2 shows the temperature profiles at 60^o and 90^o of copper block #6. Two temperature histories were observed to be much higher than others. The maximum temperature at 60^o was about 373^oC, which signifies that dryout had occurred at this region under low heat flux. The involved thermohydrodynamic phenomenon could be explained by the local lack of coolant leading to dryout. Fig. 3 presents the analysis results of flow path in the gap through a computational fluid dynamics (CFD) code. Flow depletion was predicted to occur at 0.1 kg/s or higher in a random, irregular fashion. It is considered that the coolant shot by the booster pump induced the eddy flow in the gap in the forced convection. The eddy flow gave rise to vapor stagnation in copper block #6.

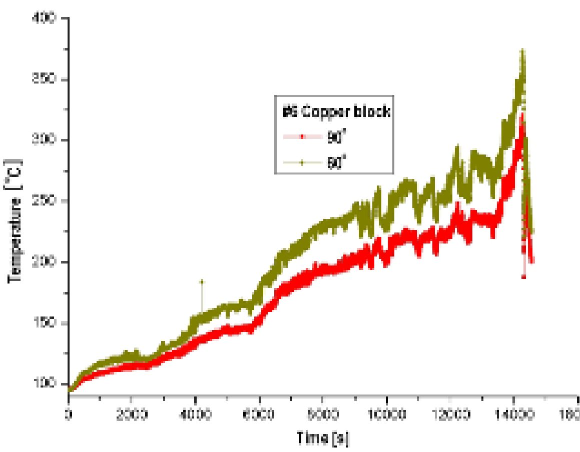

Fig. 2 Temperature history of copper block #6.

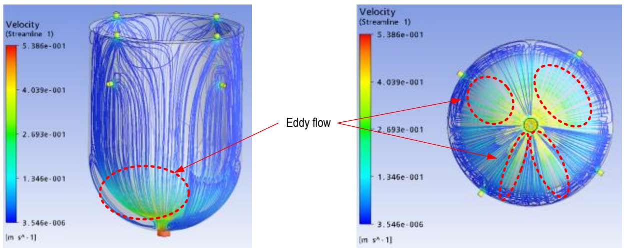

Fig. 3 Analysis of flow path in gap using ANSYS® CFX®.

4. Conclusions

The dryout resulted from the vapor stagnation due to eddy flow in spite of the low heat flux. In other words the heat of copper block #6 could not be removed sufficiently due to flow starvation. Notwithstanding the local dryout and hot spot, the critical heat flux (CHF) did not take place. It is concluded that the three-dimensional effect affected the CHF mechanism owing to the spherical channel in CASA.

REFERENCES

[1] J.L. Rempe, K.Y. Suh, F.B. Cheung, S.B. Kim, In-Vessel Retention of Molten Corium- Lessons Learned and Outstanding Issues, Nuclear Technology, Vol.161, p. 210, 2008.

[2] J. Yang, F.B. Cheung, J.L. Rempe, K.Y. Suh, S.B. Kim, Critical Heat Flux for Downward-Facing Boiling on a Coated Hemispherical Vessel Surrounded by an Insulation Structure, Nuclear Engineering, Technology, Vol. 38, No. 2, p. 139, 2006.

[3] F.B. Cheung, Y.C. Liu, S. Additon, CHF Experiments to Support In-Vessel Retention Feasibility Study for an Evolutionary ALWR Design, EPRI WO# 5491-01, University Park, PA, USA, 1999.

[4] T.G. Theofanous, C. Liu, S. Additon, In-Vessel Coolability and Retention of a Core Melt, DOE/ID-10460, Santa Barbara, CA, USA, 1996.

[5] C.S. Kim and K.Y. Suh, Sensitivity Studies on Thermal Margin of Reactor Vessel Lower Head during a Core Melt Accident, Journal of Korean Nuclear Society, Vol. 32, No. 4, p. 376, 2000.

[6] Y.H. Kim, K.Y. Suh, Sensitivity Analyses for Maximum Heat Removal from Debris in the Lower Head, Journal of Korean Nuclear Society, Vol. 32, No. 4, p. 392, 2000.