Natural Circulation Phenomena on the Cooling Channel of an Ex-vessel Core Catcher

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1. Introduction

Versatile measures have been suggested and applied to mitigate severe accidents in nuclear power plants. The newly engineered corium cooling system, that is, an ex-vessel core catcher, has been considered as one of severe accident mitigation measures for an APR1400 [1]. The ex-vessel core catcher in an APR1400 is a passive corium cooling system consisting of an inclined engineered cooling channel made of a single channel between the body of the core catcher and the inside wall of the reactor cavity. If the severe accident in a nuclear power plant occurs and the reactor vessel fails, the molten corium ejected from the reactor vessel is relocated in the body of the ex-vessel core catcher. The water from the IRWST is supplied to the engineered cooling channel between the outside of the core catcher body and the reactor cavity wall. The supplied water in the inclined channel should sufficiently remove the decay heat transferred from the corium by boiling off as steam. A buoyancy-driven natural circulation flow through the cooling channel and down-comers is intended to provide effective long-term cooling, and to stabilize thermally the molten corium mixture in the core catcher body. In general, an increase in the natural circulation mass flow rate of the coolant leads to an increase in the critical heat flux (CHF) on the hot wall, thus enhancing the thermal margin [2]. Therefore, it should be ensured and quantified that the water coolant is circulated at a sufficiently high rate through the inclined cooling channel for decay heat removal to maintain the integrity of the ex-vessel core catcher system.

2. Experimental method and results

Boiling-induced natural circulation flow experiments in the cooling channels of the ex-vessel core catcher are investigated. A scaling analysis is applied to design the test facility compared with the prototypic core catcher cooling system [3]. As the geometry and heating wall heat flux of the heating channel of the test facility will be the same as those of the prototypic core catcher cooling system except for a reduced width of the heating channel, assume that the axial distributions of the coolant quality (or void fraction) between the prototype and model facility are expected to resemble each other. Thus, using this fact, the down-comer piping design characteristics of the modeled experimental facility can be determined from the relationship derived from the scaling analysis.

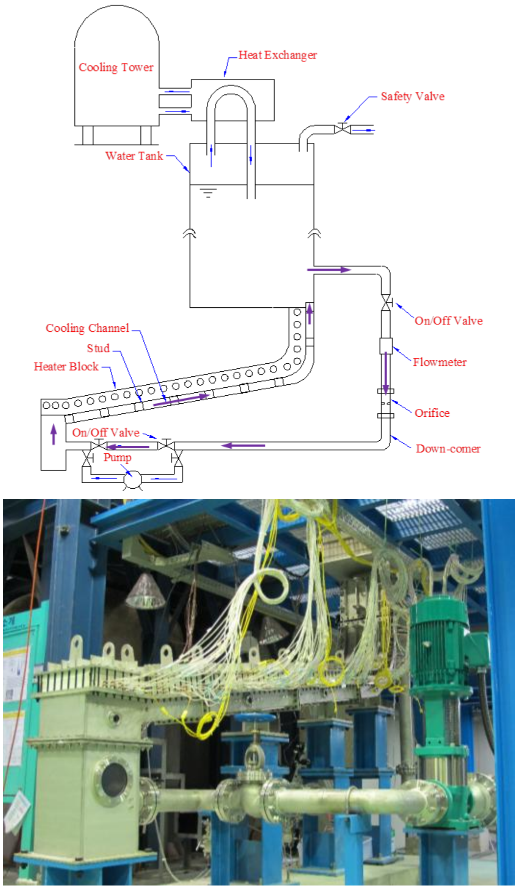

Fig. 1 Schematic and photograph of natural circulation experimental facility.

As shown in Fig. 1, the experimental cooling channel is made of a single channel simulating the actual cooling channel between the core catcher body and inside wall of the reactor cavity. The width of the cooling channel and the heating block is 0.3 m, and the horizontal length is 3 m. The gap size of the cooling channel is 0.1m as is the gap between the core catcher body and concrete body. Seven short columnar structures, called studs, each with dimension of 0.07m×0.1m×0.1m (width× length×height), are placed in the cooling channel gap to support the static and dynamic loading on the core catcher body. The gap of the cooling channel is determined appropriately such that the cooling channel also has an inclination angle of 10 degrees as is the actual core catcher system to facilitate the steam venting. A down-comer, which has a 0.1 m diameter, is provided to generate the natural circulation flow. A water tank is also installed to supply static pressure to the cooling channel.

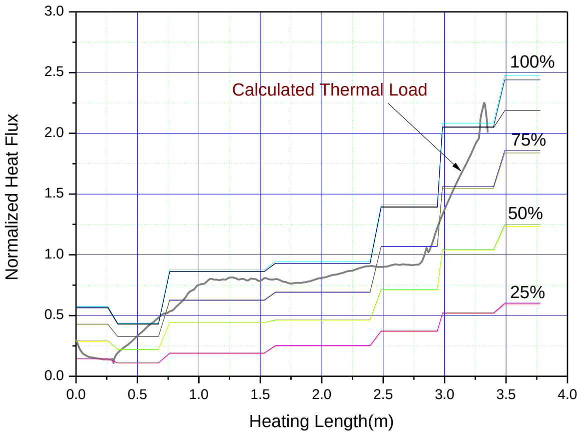

Fig. 2 Normalized heat flux distribution along with the outer wall of the core catcher body.

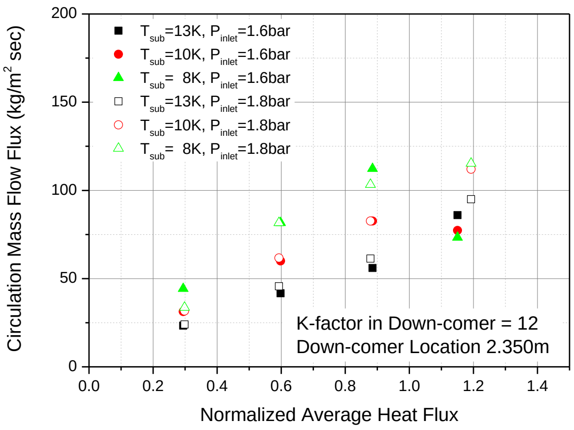

Fig. 3 Circulation mass flux along with heat flux, coolant subcooling, and water head.

The measuring parameters during the test are the input power using a power-meter, the total circulation mass flow rate of the coolant using a flow meter, the local coolant temperature using T-type thermocouples, the local heating wall temperature using K-type thermocouples, the local pressure using pressure transducers, the water level in the coolant tank using a level transmitter, the estimated void fractions using vertical differential pressure transmitters, and a visualization of the flow pattern in the coolant channel using a camera. The experimental parameters are the heat flux from the heating block to the coolant, the inlet coolant subcooling, the elevation of the down-comer, the water level in the coolant tank, and the gap size of the vertical channel of 10 and 15 cm. Two types of experiments, i.e., natural and forced circulation using the pump in the experimental facility, have been performed to determine the two-phase natural circulation mass flow rate for the given heat flux distribution and to evaluate the maximum heat removal rate of the critical heat flux at the given flow rate.

Figure 2 shows the heat flux distribution on the cooling channel imposed by the molten corium in the core catcher. The heat flux distribution was calculated by the CFX code considering the natural convection of the molten corium in the core catcher. Seven heating blocks of the experimental facility simulate the heat flux distribution by controlling the heat powers. The total heating area of the heating blocks in the experimental facility is 1.18m^2.

Figure 3 shows the measured circulation mass flux along with the wall heat flux, coolant subcooling, and water head. As the coolant temperature and heat flux increase, the circulation mass flow rate also increases. It is expected that in the high sub-cooling cases, the boiling point might be retarded in terms of height, and the circulation mass flow rate may then decrease. The water head has a slight effect on the circulation mass flux under the experimental conditions. The experimental results show that the cooling capability of the real core catcher system is sufficient at the given thermal load imposed on the real core catcher body from the corium pool.

3. Conclusion

The cooling capability of a newly engineered corium cooling system, that is, an ex-vessel core catcher system, was quantified experimentally. The scaling analysis was applied to design the test facility compared with the prototypic core catcher cooling system. The natural circulation flow rates were measured experimentally, and the flow characteristics in the inclined channel were investigated. As the coolant temperature and heat flux increase, the circulation mass flow rate also increases. The experimental results show that the cooling capability of the real core catcher system is sufficient at the given thermal load imposed on the real core catcher body from the corium pool.

ACKNOWLEDGMENTS

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