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Conceptual Design of Air Ingress Measurements Experiment for Downward Forced Flow Cooling System in a Research Reactor

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1. Introduction

An open-pool type research reactor (RR) usually adopts a downward forced core flow by a primary cooling system (PCS). During reactor normal operation, the pressure inside the highest pool penetration pipe of the primary cooling system can be lower than the atmospheric pressure, and the outside air will be come into the pipe in case of a pipe rupture accident. If the air enters into the cooling system, air-water mixture flows in the system, and many troubles such as the cooling pump stop or malfunction and the pump flywheel coast-down time decrease can be caused.

In this study, conceptual design of an experimental facility for the measurement and analysis of the air-water mixture flow phenomena in the primary cooling system is proposed. Air-inflow test section to simulate a pipe rupture accident is designed to measure the air-water mixture behavior in terms of the pipe rupture sizes, shapes, and directions.

2. Methods and Results

2.1 System pressure characteristic of downward forced flow system in a research reactor

RRs are generally divided into a tank-in-pool type and an open-pool type. Open-pool type RRs have a benefit in the points of utilization because the top of the core is opened. In consideration of the advantages for the utilization and operation aspect, a downward forced flow system can be usually applied to the primary cooling system.[1]

Fig. 1 shows a schematic of a typical downward cooling system which is composed of the reactor pool, core, a cooling pump, and piping. The reactor pool penetration pipe of the primary cooling system should be installed at higher elevation than the pool water minimum height for natural convection cooling of the core decay heat during a loss of coolant accident (LOCA). During the normal operation, the pressure inside the highest pipe of the primary cooling system can be lower than the atmospheric pressure due to a large core pressure drop, and the outside air can enter into the pipe in case of a pipe rupture accident as shown on Fig. 1.[2]

Therefore, it is necessary to accurately predict the air ingress phenomena for the safety-to-design against such pipe rupture accident in the primary cooling system. In other words, if air ingress flow rate by pressure difference between inside and outside the pipe and the ingress air bubble size as the pipe rupture sizes can be quantitatively and accurately measured, the safety facility, such as an air trap tank for collecting the ingress air at the outlet of the rupture pipe, can be designed in the primary cooling system.

In general, the calculation of the system pressure distribution in the primary cooling system is possible. However, little studies have experimented and quantitatively estimated the air ingress flow rate and air bubble size by the pipe rupture. In this study, the parameters used for the system design and accident analysis will be measured through the experiment at the negative (gauge) pressure condition inside the pipe.

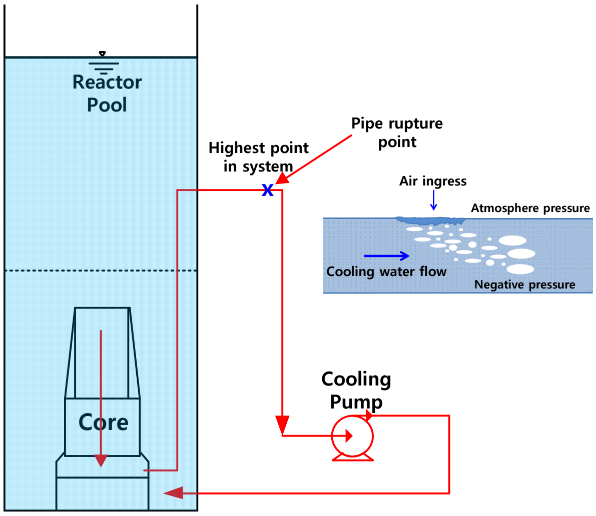

Fig. 1. Schematic of downward forced flow cooling system.

2.2 Measurement parameters for air-water mixture analysis

In order to quantitatively estimate the air ingress flow rate and air bubble size by the pipe rupture at the negative (gauge) pressure condition inside the system pipe, the experimental condition and measurement parameters are decided. First of all, the negative (gauge) pressure conditions inside the pipe will be made through the installation of an orifice to decrease the inside pressure at the inlet of the air ingress test part. Independent variables can be pipe rupture sizes, shapes, and directions. Since there is little experiment studies related to the air ingress at the negative (gauge) pressure condition inside the pipe, the range of the experimental conditions and measurement variables may be extensive. Therefore, in this study, the reference data will be limitedly measured first, and the extensive data will be continuously measured and accumulated. Main experimental measurement variables are the air ingress flow rate and the pressure variation inside the system. All data will be measured at the transient condition.

An air void fraction and air bubble size at the inlet pipe of the air trap tank will be measured by using the special two phase measurement instruments. If the air is not collected in the air trap tank, the air will flow to the outlet pipe of the air trap tank. In this case, the air void fraction and air bubble size at the outlet pipe of the air trap tank will be measured. These data will be used as the reference data for optimizing the air trap tank design by analyzing the air behavior inside the air trap tank. Table I summarizes the experimental condition and measurement parameters.

Table I: Experimental condition and measurement parameters

Experimental condition parameter	Independent variable	Dependent variable
-Cooling water mass flow rate (kg/s) -Negative (gauge) pressure in pipe(kPa)	- Pipe rupture sizes (m^2) - Pipe rupture shapes - Direction of pipe ruptures	- Ingress flow rate of air (m^3/s) - Pressure variation in pipe (kPa) - Air flow velocity (m/s) - Air void fraction - Air bubble size

2.3 Experimental facility design for air ingress measurement

Experimental facility for the measurement and analysis of the air-water mixture flow phenomena is conceptually designed. To apply the experimental results, the experimental facility is designed to model a reduced-volume system of RR primary cooling system. Fig. 2 shows a schematic flow diagram of the experimental facility for air-water mixture flow phenomena measurement.

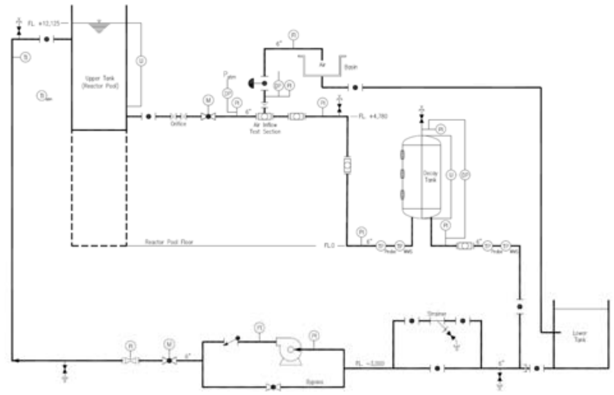

Fig. 2. Flow diagram of the experimental facility for air-water mixture flow phenomena measurement

The experimental facility is composed of an upper tank for maintaining the uniform hydraulic pressure, the air trap tank for trapping the ingress air through the pipe rupture part, and a main pump to provide a cooling water flow rate. And instruments, such as flow meters, pressure transducers, and level transmitters, for flow characteristic measurements are installed. Air inflow test section to simulate a pipe rupture accident is proposed to measure the phenomena on the difference as the pipe rupture sizes, directions, and shapes. The air volume fraction and bubble size by the air inflow after a pipe rupture accident is measured and quantified. Safety tests of the primary cooling pump integrity will also be performed.

3. Conclusions

At the negative (gauge) pressure condition of the downward forced flow cooling system in a RR, the outside air can enter into the pipe in case of a pipe rupture accident. It is necessary to accurately predict the air ingress phenomena for the safety-to-design against a highest pipe rupture accident in the primary cooling system. In this study, the experimental facility for the measurement and analysis of the air-water mixture phenomena by the air ingress is proposed.

ACKNOWLEDGEMENT

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