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Evaluation of Effect of N_2 Gas on the Cooling Capability of Passive Auxiliary Feedwater System

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1. Introduction

Advanced Power Reactor Plus (APR+), a next generation nuclear power plant in Korea, adopts Passive Auxiliary Feedwater System (PAFS) to replace the conventional active auxiliary feedwater system [1]. Because PAFS removes decay heat from the reactor core, it is required to verify the performance of PAFS in postulated accidents cases. In addition, an effect of non-condensable gas such as N_2 gas on the heat removal capability of PAFS should be evaluated since the non-condensable gas may deteriorate a condensation heat transfer through the condensation heat exchanger in PAFS. In this study, MARS code is used to evaluate the effect of N_2 gas.

2. Analysis for N_2 Effect

2.1. Design and Operating Condition of PAFS

PAFS is designed to be separately installed in two loops of the secondary side instead of conventional active auxiliary feedwater system. PAFS consists of the steam supply line, the condensation heat exchanger, and return water line, and passively removes decay heats by a natural circulation. The condensation heat exchanger submerged in Passive Condensate Cooling Tank (PCCT) consists of 4 tube bundles wit 240 horizontal condensate tubes. The condensation tubes are designed to have the inclination of 3 degrees for prevention of water hammer effect. Also, the flow regimes in the condensate tubes are restricted to a horizontal stratified flow and an annular-mist flow [2].

2.2. Assumption on Non-condensable Gas Generation

It is assumed that a kind of non-condensable gas generated in PAFS is N_2, and its source is total volume of feedwater in steam generators, main steam line, and other pipe lines in PAFS. Therefore, generated mass of N_2 gas can be calculated by multiplying the solubility of N_2 gas to total mass of feedwater.

For the calculation of N_2 gas generation, the solubility is calculated at the operating temperature of feedwater. For conservatism, an additional calculation is performed using the solubility at a room temperature.

2.3. Development of MARS Model

In order to evaluate the effect of N_2 gas, LOss of Condenser Vacuum (LOCV) accident is simulated. PAFS model is developed by simulating one secondary loop in APR1400 with PAFS as shown in Fig. 1. For a steady state calculation, a main feedwater flow, turbines, and condenser are modeled as a boundary condition.

N_2 gas generated from feedwater in pipe lines of PAFS is injected through the inlet header with operation of PAFS. N_2 gas generated from feedwater in SGs is injected to a steam dome in SG before a transient calculation. In addition, comparative case is simulated by injecting N_2 gas into the steam dome after close of MSSVs. Because, N_2 gas injected to steam dome can be released through main steam safety valves (MSSVs), injecting after close of MSSVs may show more conservative result.

As shown in Table I, four cases are compared with varying the feedwater temperature for solubility and release of N_2 gas via MSSVs.

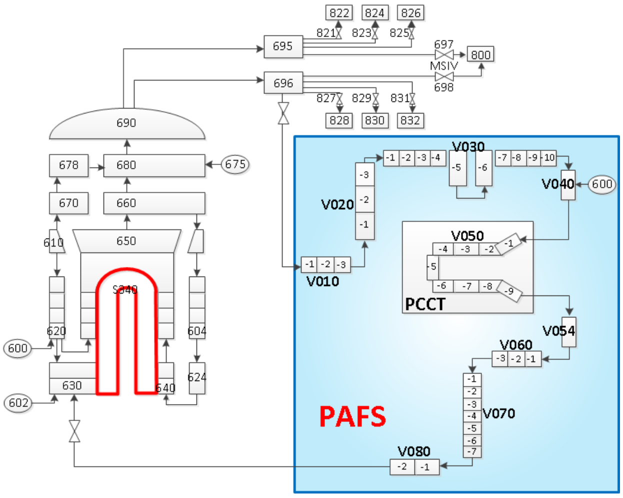

Fig. 1. MARS model for PAFS in APR1400

TABLE I: Calculation matrix

	Solubility (g-N_2/kg-H_2O)		Release via MSSVs
Case 1	Room temperature	1.43	O
Case 2	Room temperature	1.43	X
Case 3	Operating temperature	1.357(SG)/ 1.292(PAFS)	O
Case 4	Operating temperature	1.357(SG)/ 1.292(PAFS)	X

2.4. Calculation Results

Mass quality of N_2 gas at inlet of condensate tube is shown in Fig. 1. Mass quality shows maximum value at the early phase of transient when the N_2 gas is injected. Then, the mass qualities in four cases are conversed to 0.260 – 0.286 % after 5,000 seconds. Because the case 2 shows the most conservative result, a reference case without non-condensable gas is compared with the case 2.

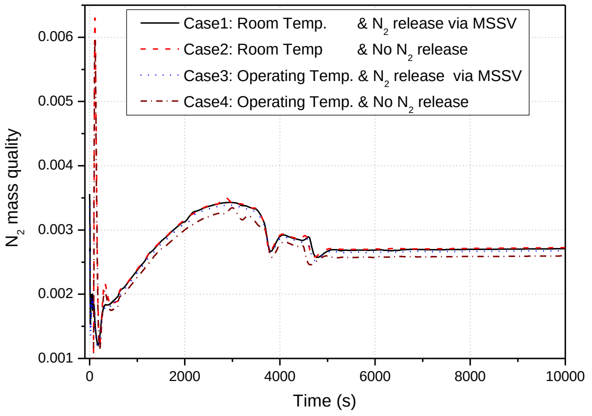

Fig. 2. Mass quality of N_2 gas at inlet of condensate tube

Figure 3 shows distribution of mass fraction of N_2 gas at 300, 4000, 7000, and 10000 seconds. N_2 gas is accumulated at the outlet region of condensate tube and return water line according to the transient time. Due to the accumulation of N_2 gas, the heat transfer coefficients in the condensate tube deteriorate with time as shown in Fig. 4. Thus, the system pressure increases in the case with N_2 gas injection to remove the decay heat from U-tubes in SGs. The system pressures show 1.15 and 2.24 MPa in the cases with and without N_2 gas, respectively.

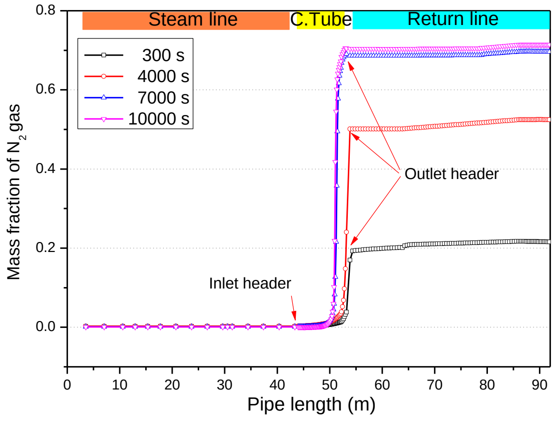

Fig. 3. Distribution of mass fraction of N_2 gas

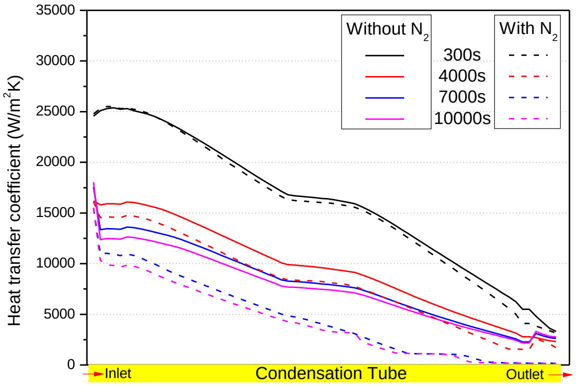

Fig. 4. Distribution of heat transfer coefficient

4. Conclusions

In this paper, the effect of N_2 gas on the condensation heat transfer in PAFS was evaluated for LOCV accident case by using MARS code. The analysis result showed that the condensation heat transfer coefficient decreases as N_2 gas is accumulated in the condensate tube. Consequently, the system pressure increases in the case with N_2 gas in order to remove the decay heat by increase of steam temperature at the inlet of condensate tube.

Although the conservative assumptions were applied in this analysis, it was shown that the existence of non-condensable gas affect the heat removal capability of PAFS. Therefore, it is necessary to evaluate the accurate mass of non-condensable gas that may be generated in SGs and PAFS.

ACKNOWLEDGEMENT

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