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Study on the Operability of Passive Containment Cooling System

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1. Introduction

The Passive Containment Cooling System (PCCS) is a system that removes the internal energy of the reactor containment to reduce the pressure in the stable condition without electrical power supply. As a part of pre-design of the PCCS, a RELAP5 base model has been developed and the operability and capability are examined in the presence of noncondensable gas.

2. Methods and Results

In this section the composition of the PCCS, the development of the RELAP5 base model, and the pre-test results of operability are described.

2.1 PCCS Pre-design

The PCCS is designed to manage the containment pressure in the design basis events and severe accidents. The design requirements are developed based on the EPRI passive URD and KINS safety review guidelines. The pre-design of the PCCS is consist of four train heat exchanger bundles, two passive condensation cooling tanks, and related connecting pipes. The PCCS operates only with the natural forces of gravity and natural circulation, and does not need operator actions. The minimum operation time of the PCCS is decided as 72 hours without electrical power supply by the capacity of the cooling tanks. Each train has the minimum capacity of 33% to operate in consideration of passive single failure after 72 hours operation. The passive condensation cooling tanks are located at the top of the auxiliary buildings to gain enough gravity force. The heat exchangers are located inside of the reactor containment, and the elevation of the top of heat exchangers is suggested to be lower than the bottom of the cooling tanks to extend the duration of the natural circulation.

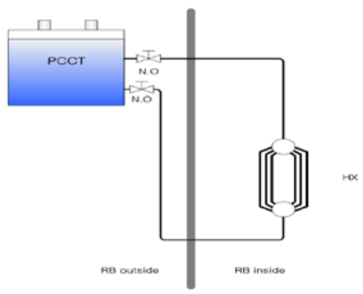

Fig. 1. Pre-design of the PCCS

2.2 RELAP5 Base Model

The preliminary analysis was performed to examine the operability and capability of the PCCS using RELAP5 MOD3.3 system code. Each component is merged in a single model to have the same capacity that the elevation and length are conserved but the flow and heating area are multiplied with the number of the components. The containment is modeled in a single volume to maintain uniform boundary condition of the containment. The analysis is performed with changing noncondensable gas mass quality at the pressure of 4 bar which is assumed to represent the containment condition in the large break loss of coolant accident. The air-steam mixture flow velocity is set to 0.1 m/s to represent the natural convection.

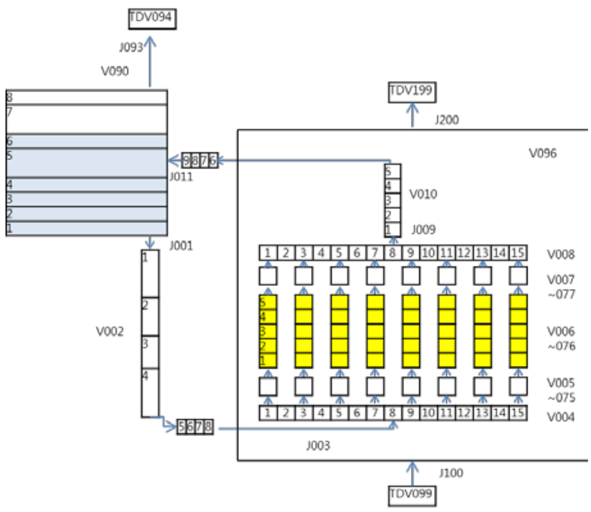

Fig. 2. RELAP5 base model of the PCCS

2.3 Heat Transfer Model

There are two methods available in RELAP5 for calculating the heat transfer coefficients in the condensation mode. The default method uses the maximum value of Nusselt and Shah, but when noncondensible gases are present, Colburn-Hougen model is used for condensation heat transfer model.

$$q''_v = h_m h_{fgb} \rho_{vb} \ln\left(\frac{1-\frac{P_{vi}}{P}}{1-\frac{P_{vb}}{P}}\right)$$

The Colburn-Hougen diffusion calculation involves an iterative process to solve for the temperature at the interface between the steam and water film. The formulation is based on the principle that the amount of heat transferred by condensing vapor to the liquid-vapor interface by diffusing through the noncondensable gas film is equal to the heat transferred through the condensate. From this energy conservation principle, the interface pressure and temperature will be determined by iteration. The heat transfer rate then will be known.

2.4 Test Results

The mass flow distributions in heat exchangers are calculated to confirm the adequacy of the bundle header size. The mass fractions in heat exchanger tubes are calculated by changing header diameter from 12 inch to 20 inch at the containment condition of 4 bar and 0.1~0.5 air mass fraction. The average flow differential rate is decreased from 4.8% to 0.9% as the header size increased.

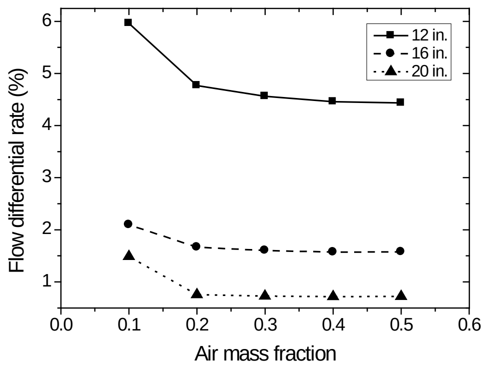

Fig. 3. Flow velocity in the heat exchangers

The heat transfer coefficients are calculated to estimate PCCS capability at the design basis accidents condition. The containment pressure is assumed to be 4 bar which approximately represent a high pressure value during the accidents.

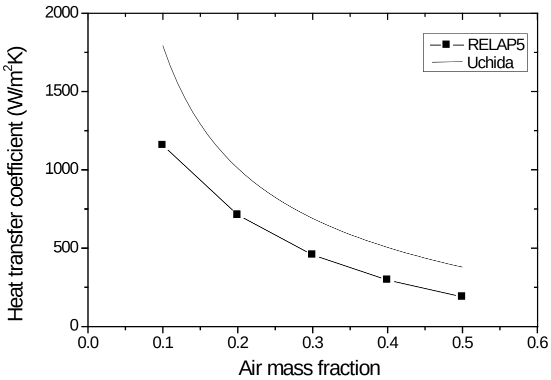

Fig. 4. Condensation heat transfer coefficient

The calculation is performed by changing air mass fraction from 10% to 50%, and compared with the Uchida correlation which is reported to be conservative condensation heat transfer coefficient in accident analysis. The calculated heat transfer coefficient is about 38% lower than the Uchida one. The calculated heat transfer rate per heat exchanger area is estimated 13.3~104 kW/m^2 during the condition.

3. Conclusions

The preliminary analysis was performed to examine the operability and capability of the PCCS using RELAP5 MOD3.3 system code. The pre-size of the header is need to be larger than 20 inch to achieve flow differential rate lower than 1%. The estimated heat transfer capability is 13.3~104 kW/m^2, which is expected to be adoptable, for that the target value is greater than 22.5 kW/m^2.

REFERENCES

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