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Transient Characteristics of a Gas Pressurizer in an Integral Reactor for an In-surge Flow

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1. Introduction

Pressurizer is an essential component which provides a buffer volume for a reactor system during a transient. There are several types of pressurizers depending on their location and working medium. A gas pressurizer can be used for providing a self-pressurizing capability for a reactor system. In this study, a multi-cavity gas pressurizer (MCGPZR) with a cooler and an insulator is proposed and its transient characteristics for an in-surge flow case are analyzed. Through an evaluation of the analysis results, it was revealed that the concept of a self-pressurizing pressurizer can be embodied with the proposed pressurizer.

2. General Description for the MCGPZR

The MCGPZR concept consists of in-vessel cavities and out-of-vessel gas cylinders for holding the gas supply/vent system (Fig. 1). In-vessel cavities consist of an end cavity (EC), intermediate cavity (IC), and an upper annular cavity (UAC). The gas cylinders are connected to one of the in-vessel cavities via piping. Nitrogen gas is used as a pressure-absorbing medium for the MCGPZR. The in-vessel cavities located in the reactor vessel are separated from the flowing primary coolant by special thermal insulators. This maintains a primary system pressure of about 15 MPa. The in-vessel cavities of the MCGPZR are sized to accommodate normal volume surges from load changes and large volume surges during a heatup operation. The total gas volume of the MCGPZR at a power operation is composed of the gas cylinders and the EC.

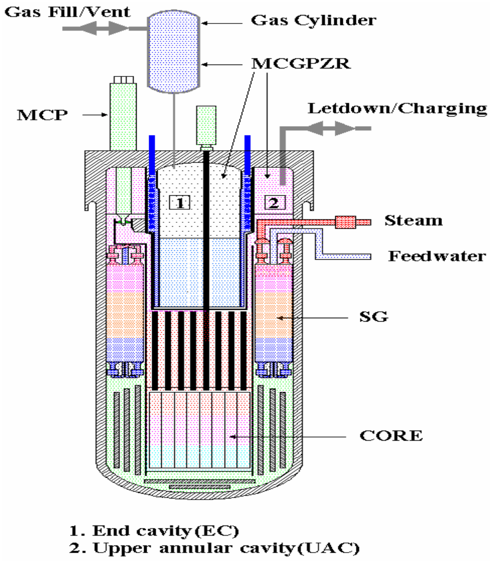

Fig. 1 Schematic view of the MCGPZR

3. Mathematical Models

Mathematical models for the MCGPZR are derived by considering all the important thermal hydraulic processes of the fluid mediums occurring in the MCGPZR. A mathematical model is used for an analysis of the slow processes in the MCGPZR. The model calculates the variations of the pressure in the MCGPZR during the changes of the reactor coolant surge flow rate. Ideal operation of the control system has been assumed for the analysis and therefore the rate of the temperature change of the reactor coolant is taken to be preset.

3.1 Water Temperature of the MCGPZR

During the changes of the reactor power, some portion of the reactor coolant is insurged/outsurged to/from the MCGPZR because of a density change of the reactor coolant. As a consequence, the steam-gas mixture volume is reduced/expanded, while the system pressure rises/drops.

All the cavities exchange a heat with each other and a hot part of the reactor system. In addition, the coolant displaced from the reactor system contributes some amount of heat to each cavity.

When the EC is partially filled, the EC will be filled with water displaced from the IC.

$$\begin{cases} \dfrac{dH_U}{dt} = \left[G_{HP-U}\left(H_{HP} - H_U\right) + G_U\left(H_{HP} - H_U\right) + Q_{HP-U} - Q_{U-I}\right]\dfrac{v_U}{V_{WU}} \\ \dfrac{dH_I}{dt} = \left[G_{HP-U}\left(H_U - H_I\right) + Q_{HP-I} + Q_{U-I} + Q_{E-I} - Q_{I-HX}\right]\dfrac{v_I}{V_{WI}} \\ \dfrac{dH_E}{dt} = \left[G_{HP-U}\left(H_I - H_E\right) + Q_{HP-E} - Q_{E-I}\right]\dfrac{v_E}{V_{WE}} \end{cases}$$

Net heat transfer through wet thermal insulations is written as follows:

$Q=U\Delta T\ A$

$$U = \frac{1}{\dfrac{1}{h_1} + \dfrac{\delta_{ins}}{k_{ins}} + \dfrac{\delta_m}{k_m} + \dfrac{1}{h_2}}$$

3.2 Gas Temperature of the MCGPZR

$$\frac{dE_j}{dt} = G_{jin} h_{in} - G_{jout} h_{out} + Q_j + W_j$$

3.3 Heat Structure of the Gas Cylinder

$$\frac{dE}{dt} = Q_{in} - Q_{out}$$

where Q_{in} and Q_{out} means a heat to the metal from the gas medium and a heat to the environment from the metal, respectively.

3.4 System Pressure in the MCGPZR

The system pressure is determined based on the condition of a nitrogen gas mass conservation in the MCGPZR.

$$M_{GU} + M_{GI} + M_{GE} + M_{GCYL} = M_{G\Sigma}$$

where

$$M_{Gi} = \frac{P_{Gi} V_{Gi}}{R Z_{Gi} \left(T_i + 273 \right)}$$

$$P_{Gi} = P - P_S \left(T_i \right)$$

4. Results and Discussions

We selected 6 cases of in-surge flows ranging from 0.5 kg/s ~ 5 kg/s for the transient analysis of the MCGPZR. Normal power operation was chosen as an initial condition. Figures 2 and 3 show the EC pressure and level transient behaviors during an in-surge flow. Slow in-surge results in a slow buildup in the pressure and level as expected.

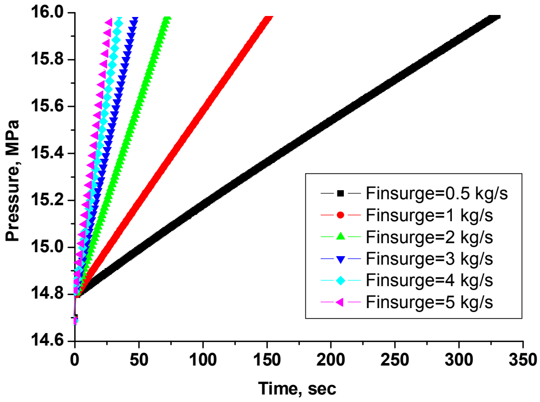

Fig. 2 Gas pressure during in-surge flow

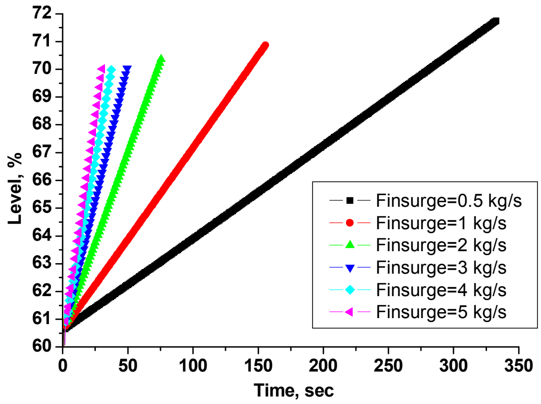

Fig. 3 End cavity water level during in-surge flow

Fig. 4 shows the EC gas temperature. In-surge flow delivers a flow-work to the gas medium, resulting in a gas temperature rise. Final EC gas temperatures are almost the same even though the EC water levels are different, which can be explained by referring to Figures 5 and 6.

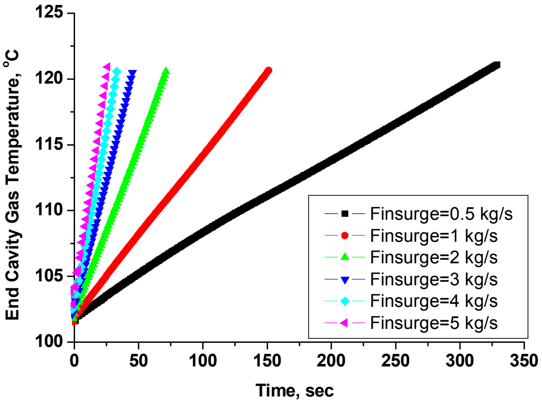

Fig. 4 EC gas temperature during in-surge flow

Gas cylinder gas temperatures are sensitive to the in-surge flow rates. Fast in-surge flow causes adiabatic temperature rise in the gas medium, while a heat loss for the case of a slow in-surge flow is significant, as implied by Fig. 5. The EC gas temperatures are mainly influenced by the in-surge flow rate, EC water temperature, and heat transfer with the environment. The EC gas temperature reduction for the case of a slow in-surge flow is retarded by a relatively higher EC water temperature, which is shown in Fig. 6.

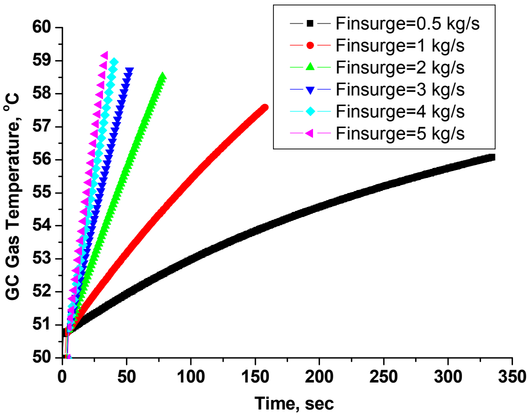

Fig. 5 GC gas temperature during in-surge flow

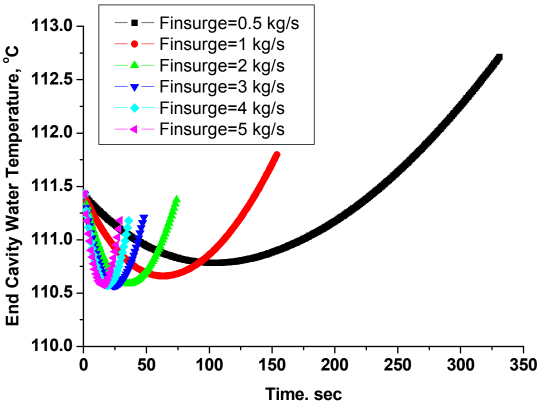

Fig. 6 EC water temperature during in-surge flow