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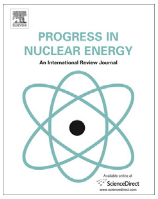

Simulating and evaluating the pressurizer dynamic behavior in various sizes

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ABSTRACT

In a pressurized water reactor, overpressure necessary to limit the bulk boiling is maintained by a pressurizer. Therefore, evaluation of this component is very important. In this paper, a simple numerical model based on the non-equilibrium, multi-region model is employed to simulate the pressurizer behavior during transient conditions. Because of the important role of the scale, this model should be able to predict the behavior of a real power plant pressurizer precisely. In the present study, it is shown that if all of the phenomena occur in a pressurizer are coupled with an appropriate computation model, a good prediction could be acquired. Accordingly, the basic balances equations of mass and energy together with appropriate constitutive models are used to describe all the important phenomena inside the pressurizer. Furthermore, a pressurizer model is built using the TRACE thermal-hydraulic code. The developed model are then assessed against the different data from separate experiment tests conducted on MIT, PACTEL as well as a full-scale pressurizer. For all the cases, TRACE simulation results are also reported. It is shown that the agreement between the results is rather good for different sets of conditions. This confirms that the scale would not affect the accuracy of the model and that it can be successfully applied for analyzing a full-scale pressurizer.

1. Introduction

The importance of safety in nuclear facilities necessitates the continuous improvement of the accurate models for analyzing the dynamic behavior of all components specifically those, which are responsible for controlling the plant normal operation. In this respect, pressurizer has two major roles of maintaining a prescribed system pressure and a constant coolant mass inventory in the primary loop of a pressurized water reactor (PWR). Therefore, accurate investigation of the pressurizer behavior is crucial in safety evaluation of a PWR reactor. There are different commercial thermal-hydraulic codes such as RELAP5 and TRACE, which can be used to simulate the pressurizer behavior. However, an accurate simulation model in these codes requires users to have high professional knowledge and experience (Takasuo, 2010, 2006).

Besides using thermal-hydraulic codes for analyzing the pressurizer behavior, some numerical models based on the control volume approach have been developed. Early methods of analyzing a pressurizer utilized a simple formulation in which the entire vessel was represented as a single region at equilibrium conditions (Gajewski, 1955). However, because of restrictions associated with the equilibrium model specifically in fast transients, non-equilibrium, multi-region approaches were proposed (Abdallah et al., 1982; Nahavandi, 1969; Baron, 1973; Kuridan and Beynon, 1998; Bake et al., 1986; Kim and Griffith, 1987). In general, the upper portion of the pressurizer is a continuous vapor region through which liquid drops fall, and the lower portion is a continuous liquid region through which vapor bubbles rise (Todreas, and Kazimi, 1990). This description leads to the identification of four regions to describe this fluid-vapor configuration. However, the four-region model is so complicated that development of a practical computation model is very difficult unless one consider many simplification assumptions. In this respect, two-region model in which two separated volumes of liquid and steam exist in the pressurizer were proposed. The two-region model can take into account most of the practical

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transients in reactor analysis (Botelho et al., 2008; Todreas, and Kazimi, 1990).

It is well known that the scale has a remarkable effect on the phenomena occur in a pressurizer. Consequently, it is of prime importance to ensure the model capability for predicting the accurate response of the system. Pressurizer models are better verified through comparing the output results with the experimental data. There are some widely known experimental test data, which are used to verify the developed pressurizer models. Since these experimental tests have been conducted in facilities with different scales and conditions it is important to consider this aspect in applying a developed model to full-scale pressurizer analysis. There are some articles, which have studied full-scale pressurizes' dynamic behavior (Botelho et al., 2008; Yi-Hsiang et al., 2009; Zarghami et al., 2005; Moghanaki and Rahgoshay, 2014). Due to the important role of the pressurizer, some articles have considered it in conjunction with the other reactor components to analyze the behavior of the systems specifically the new generation of the PWRs more thoroughly (Porhemmat et al., 2016; Lee and Park, 2013; Wang et al., 2012). Furthermore, Takasuo considered a thermal hydraulic modeling of the PWR pressurizer using both APROS simulation software package and the TRACE code and showed that these models need more improvements. The results obtained by Takasuo showed unphysical behavior in some situations (Takasuo, 2006). Therefore, the main objective of this paper is to simulate and evaluate a pressurizer model and show the important role of the accurate modeling of the phenomena in predicting the pressurizer behavior with different scales and conditions. In fact, it is justified that the obtained results do not depend on the scale and an appropriate simulating method is capable of acquiring accurate results for different conditions. To show these features, results are assessed using different experimental test data. Additionally, in order to complete the comparisons, pressurizer is simulated using the TRACE thermal hydraulic code. On the other hand, codes models, which their development is based mainly on the results of downscaled experiments, must have the ability to describe the thermal-hydraulic processes expected in the full-scale reactor plant.

2. Mathematical model

2.1. Numerical method

Different regions of water and steam in a pressurizer are described by the control volume approach (Fig. 1). In fact, transient behavior of the pressurizer can be expressed by the following sets of integral-transport equations of mass and energy (Todreas, and Kazimi, 1990)

$$\frac{d}{dt}\iiint_V \rho dV + \oint_S \rho \vec{v_r}\cdot\vec{n}\, dS = 0 \tag{1}$$

$$\frac{dQ}{dt} - \frac{dWO}{dt} = \frac{d}{dt}\iiint_V \rho u dV + \oint_S \rho\left[u + \frac{P}{\rho}\right]\vec{v_r}.\vec{n}\, dS + \oint_S \rho \vec{v_s}\cdot\vec{n}\, dS \tag{2}$$

Two gates of the flow into or out of the control volume (pressurizer tank) are spray nozzle and surge line connection to the hot leg of the primary loop in a nuclear power plant. On the other hand, heat is provided by the electric heaters and is extracted from or conducted to the vessel wall. Other heat and mass transfer rates should be estimated from the constitutive models in the interfaces.

Pressurizer tank is divided into two regions i.e., lower water volume and upper steam volume. Therefore, the discrete form of the governing Equations (1) And (2) for each region is obtained as follow (Todreas, and Kazimi, 1990).

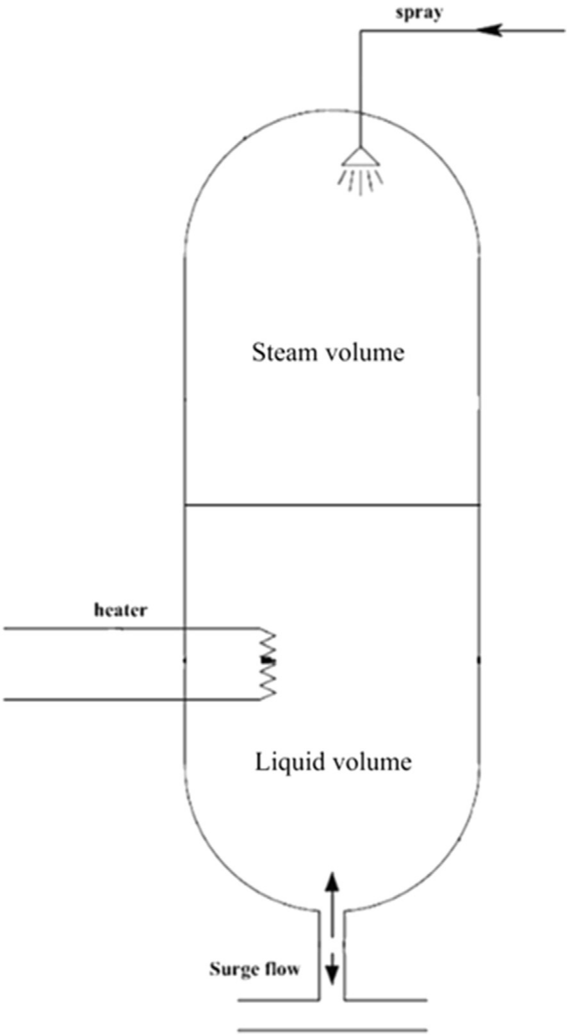

Fig. 1. Two-volume model of the pressurizer.

- Vapor region

$$\frac{d}{dt}(M_v) = W_v \tag{3}$$

$$M_v\frac{d}{dt}h_v = W_v h_g - W_{BC}h_{fg} + v_v M_v \frac{d}{dt}(p) - h_v W_v \tag{4}$$

- Liquid region

$$\frac{d}{dt}(M_l) = W_l \tag{5}$$

$$M_l\frac{d}{dt}(h_l) = -W_v h_f - (W_{BB} + W_{WB} + W_{HB})h_{fg} + W_{SC}h_{fg} + v_l M_l \frac{d}{dt}(p) - h_l W_l + E_l \tag{6}$$

In which:

$$W_v = W_{BB} - W_{BC} - W_{SC} - W_{WC} + W_{WB} + W_{HB} \tag{7}$$

$$W_l = -W_v + \dot{m}_{spray} \pm \dot{m}_{surge} \tag{8}$$