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Effect of heater material and coolant additives on CHF for a downward facing curved surface

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HIGHLIGHTS

- Critical heat flux experiment for a downward facing curved surface was conducted.
- We investigate the effect of heater material and coolant additives.
- Critical heat flux is affected by the steel oxidation.

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ABSTRACT

The critical heat flux (CHF) in the vicinity of an inclination angle of 90° for the reactor vessel lower head external wall was measured on a downward facing curved surface. Two test sections having radii of curvature 0.15 m and 0.5 m were used. The objective was to investigate the effect of heater material and the combined effect of the heater material and additives on flow boiling CHF to assess the CHF enhancement under accident conditions. The heater material SA508 (low alloy steel) and the additive solutions of boric acid and tri-sodium phosphate (TSP, $Na_3PO_4{\cdot}12H_2O$) were used. An enhancement of CHF with the SA508 heater was confirmed in comparison with stainless steel reference heaters, which have negligible steel oxidation. As a result of the combined effect tests, the CHF with a TSP solution was reduced and the CHFs with a boric acid and a mixed solution (boric acid and TSP) were enhanced in comparison with the deionized water reference case. The CHF results are discussed in terms of steel oxidation according to the pH of the working fluid. Steel oxidation is also affected by local flow conditions as shown in the $R = 0.5$ m tests in which the boric acid and mixed solution had negligible effects on CHF enhancement. Under a relatively high concentration of boric acid (2.5 wt%), additive deposition as well as steel oxidation were observed and resulted in CHF enhancement.

1. Introduction

For severe accident mitigation, a number of nuclear power plants use the in-vessel retention through external reactor vessel cooling (IVR-ERVC) strategy which removes the decay heat of the molten corium by boiling on the reactor vessel outer surface. The coolability limit, i.e., the critical heat flux (CHF), is one of the most important criteria by which to judge the success of the IVR-ERVC strategy. The CHF is affected by the properties of cooling water and the conditions of heated surface as described in previous experimental works (Jeong et al., 2005, 2008; Lee et al., 2010; Park et al., 2013; Theofanous et al., 1994; Theofanous and Syri, 2001). In advanced power reactor 1400 (APR1400), the cooling water of the in-containment refueling water storage tank (IRWST), which contains boric acid (H_3BO_3), is injected into the reactor cavity by an external reactor vessel cooling (ERVC) system (an active feature) and a cavity flooding system (CFS, a passive feature) to manage severe accidents (Fig. 1). As the CFS begins to operate, IRWST water flows through the hold-up volume tank (HVT), which contains tri-sodium phosphate (TSP, $Na_3PO_4{\cdot}12H_2O$), and the TSP is dissolved into the cooling water. The reactor vessel is made of SA508 Grade 3 Class 1 (SA508, low alloy carbon steel). Corrosion of the steel surface is affected by the environment under accident conditions: the composition of the water and the degree of contact with the water.

In several studies, it has been demonstrated that the effect of CHF enhancement is associated with each additive of boric acid and TSP due to their better wettability than that of pure water.

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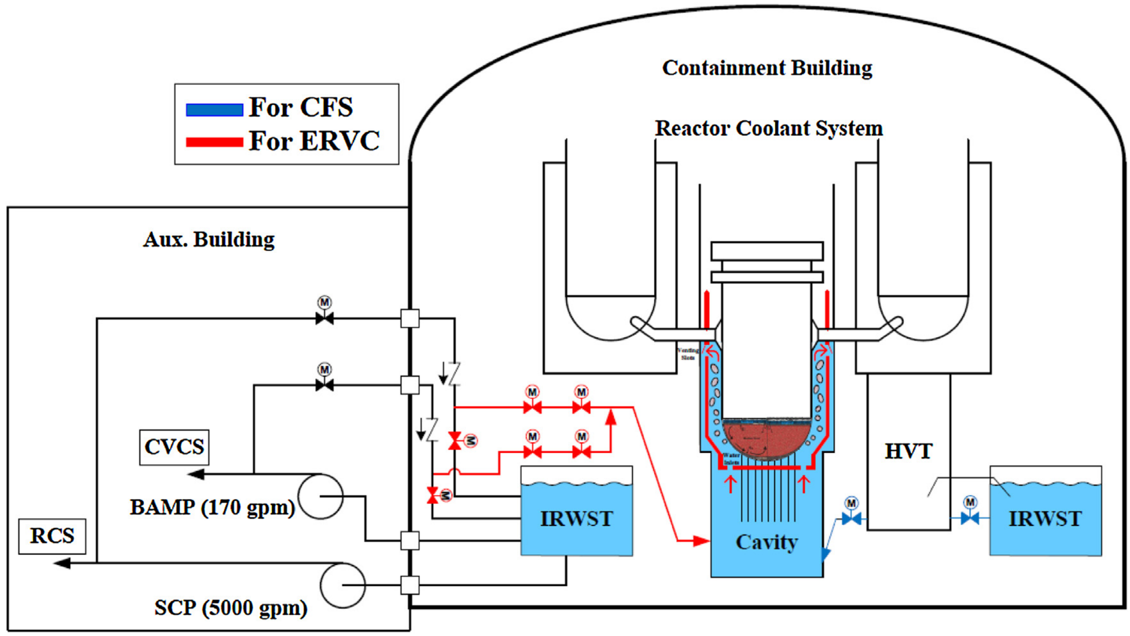

Fig. 1. System configuration for the IVR-ERVC strategy in APR1400.

Jeong et al. (2008) and Lee et al. (2010) conducted CHF experiments using a vertical tube of stainless steel that had a length of 230 mm and an inner diameter of 10.9 mm, and they studied the effect of relatively low concentrations of boric acid (0.2–0.8 wt%) and TSP (0.05–0.8 wt%). They confirmed that the CHF was enhanced under low mass flux conditions (100–500 kg/(m^2 s)). Jeong et al. (2005) found that TSP solution (0.5 wt%) had an effect on CHF enhancement in a two-dimensional slice test section of 2.5 m radius.

To test the heater material effect, Jeong et al. (2005) and Park et al. (2013) at the Korea Advanced Institute of Science and Technology (KAIST), and Theofanous et al. (1994) and Theofanous and Syri (2001) at the University of California at Santa Barbara (UCSB) used two-dimensional slice test sections to identify the CHF characteristics of type 304 stainless steel (SUS304) and SA508, respectively. The CHF data with SA508 were relatively higher than those with SUS304. However, it was not clear whether the CHF difference

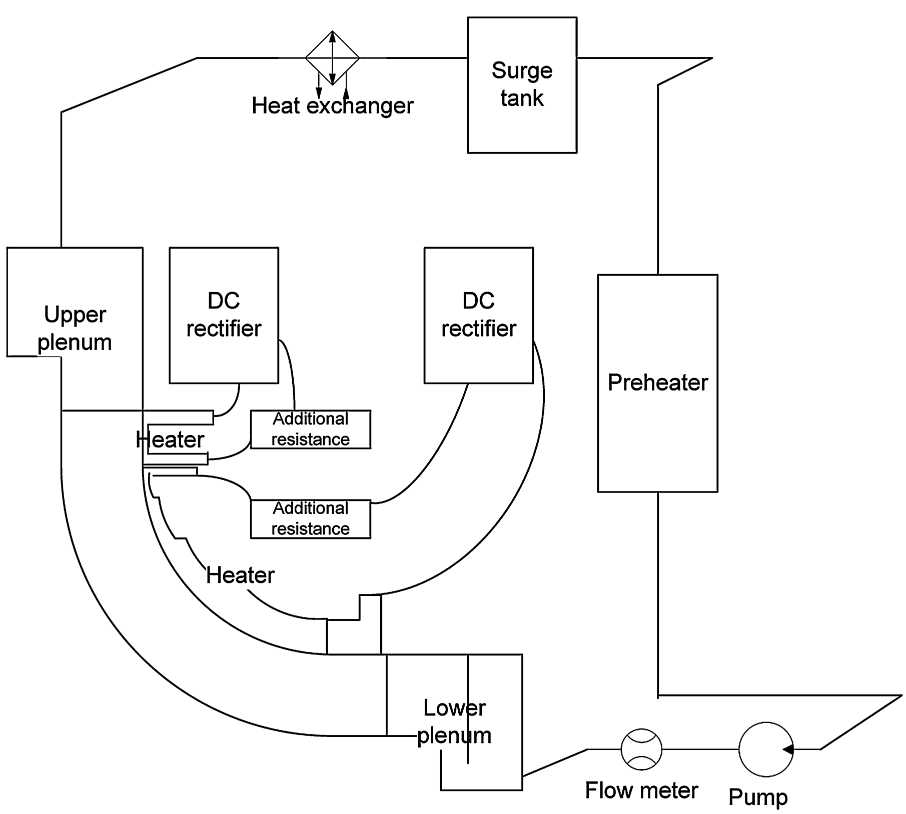

Fig. 2. Experimental water loop.