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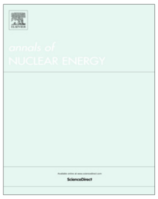

Examination of chemical and physical effects on sump screen clogging of containment materials used in Korean plants

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ABSTRACT

In this study, we have investigated the chemical and physical effects on the mechanism of sump screen clogging of containment materials that are used in most Korean nuclear power plants, such as N-102, N-108 as coating materials, NUKON as insulating materials, and CLP and SSLP as pipe materials. The experimental conditions for dissolution were pH = 8.0 at 88 °C, and those for precipitation were pH = 8.5 at 60 °C. The concentration of both dissolved and precipitated species were evaluated by using an ICP-AES and a particle size analyzer, respectively. From the obtained dissolution/precipitation data, we derived a unique two-step mechanism for the sump screen clogging process. In the first step, the screen was sparsely covered with needle-shaped silicon fiber debris that formed from the insulating materials; in the second step, it was finally clogged with a few micrometer-sized metal hydroxide precipitate particles (predominantly calcium hydroxide) that were generated from the dissolved metal ions. Hence, it can be concluded that the silicon fibers deployed for the insulating materials should be replaced with alternative materials that generate no needle-shaped debris after breakage, and the gypsum component in the coating should be reduced as much as possible.

1. Introduction

In a pressurized water reactor (PWR), it is essential that heat should be rapidly eliminated from a containment building in the event of a loss-of-coolant accident (LOCA) (Park et al., 2011; Whitley et al., 1976). Such a cooling process can be carried out by water discharge from the containment spray that should be collected in a sump for recirculation by the emergency core-cooling system (ECCS) and the containment spray system (CSS). In order to protect such ECCS and CSS systems from contamination by generated debris, one or more screens are usually installed in series at a containment sump (Lee et al., 2011). However, there is a high possibility that such screens can be clogged by the debris generated from the components of the containment building (Sandrine et al., 2008). This situation is very serious, especially for long term cooling, in which the cooling water can be obtained from the recirculation sump alone. Also, the increased pressure drop due to screen clogging can cause critical damage in the pump system. For these reasons, the United States Nuclear Regulatory Commission (USNRC) identified this issue in the document Generic Safety Issue (GSI) 191 and issued Generic Letter (GL) 2004-02, which includes an action plan to address the sump blockage issue (USNRC, 1995; USNRC, 2002a,b; USNRC, 2004a,b). The scope of this plan includes latent debris identification, debris transport, and head loss, and these phenomena were intensively discussed in the NEI 04-07 and OECD workshops of NRC/NEA (NEI, 2004; OECD-NEA, 2004). Recently, several studies have been reported on the origin of precipitation of insulating materials at spacer grids followed by clogging in the strainer at the LOCA event in PWR by using the CFD simulation (Höhne et al., 2011; Kryk et al., 2011; Schaffrath and Weiß, 2011). However, most nuclear power plants in Korea were constructed with little or no consideration for this sump clogging issue, so that an in-depth study that is customized for Korean plants is required. Indeed, although several studies have been reported on debris transport and head loss in Korean plants, they have focused only on the transport phenomena of the debris rather than on the causes of sump screen clogging (Park et al., 2011, 2012). For this reason, a more detailed study on chemical and physical effects is required in order to clearly understand the clogging mechanism.

In this study, we have investigated the physical and chemical effect on the mechanism of sump screen clogging of containment materials that are actually used in most Korean plants, such as

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Table 1
The amounts of samples for dissolution tests.

Sample	Manufacturer	Composition	Note
N-102	Carboline Korea	1st coat = Zinc primer 2nd coat = Epoxy coating 3rd coat = Epoxy finish	Detailed composition cannot be opened owing to the business secret of manufacturer
N-108	Carboline Korea	1st coat = Epoxy primer/sealer 2nd coat = Epoxy surfacer 3rd coat = Epoxy finish	Detailed composition cannot be opened owing to the business secret of manufacturer
NUKON	PCI	Given in parts per million (mg/kg) Sodium = 928 Silicate = 1997 Chloride = 32 Fluoride = 10 pH = 9.8	Based on chemical analysis of Nukon
CLP	POSCO	Carbon steel (SA516 GR.60) Chemical composition (%) C = 0.1117 Si = 0.253 Mn = 0.893 P = 0.0158 S = 0.0028 Cr = 0.02 Ni = 0.01 Cu = 0.011 Nb = 0.001 Ti = 0.001 V = 0.001 Sol-Al = 0.036	Mill sheet
SSLP	Nippon steel	Stainless steel (SA240 Type304) Chemical composition (%) C = 0.05 Si = 0.38 Mn = 0.83 P = 0.03 S = 0.005 Ni = 8.12 Cr = 18.18 N = 0.05	Mill sheet

N-102, N-108 as coating materials, NUKON as insulating materials, and CLP (containment liner plate) and SSLP (stainless steel liner plate) as pipe materials. Dissolution and precipitation tests were performed for all the samples and analysis data for the dissolved chemical species, as well as the concentration and mean sizes of precipitates were obtained with ICP-AES and a particle size analyzer. Finally, we propose a unique two-step mechanism that occurs during sump screen clogging; initially a sparse covering of the screen with needle-shaped silicon fiber debris, formed from insulating materials, occurs followed by dense clogging with micrometer-sized metal hydroxide precipitate particles (predominantly calcium hydroxide) generated from the dissolved metal ions.

2. Methods

2.1. Dissolution tests

N-102, N-108 (Carboline Korea Ltd., Korea), NUKON (PCI, USA), as well as CLP (containment liner plate, POSCO, Korea) and SSLP (stainless steel liner plate, Nippon steel, Japan) were used for these tests. The detailed information for the samples used is presented in Table 1. All the samples were collected from Kori nuclear power plant #1 and used without any further chemical treatment. In the case of N-102, N-108, and NUKON, a simple mechanical pulverization was carried out to increase the reaction area. The dissolution tests were carried out in a custom-built hydrothermal reactor at 88 °C and 130 °C. These conditions were selected by consideration of the actual atmosphere in the containment buildings (KHNP, 2006). The pH used was 8.0 for the steady state where the pH was maintained by trisodium phosphate (TSP, 99.9%, Aldrich). At first, the samples were placed in the hydrothermal reactor and heated until the reactor temperature reached the designated value. The reaction times were 30, 60, and 90 min. After the dissolution, the solution was filtered and cooled. Then, the obtained solution was injected into ICP-AES for the analysis of dissolved chemical species and their concentration. The amounts of samples used are shown in Table 2.

Table 2
The amounts of samples used in the dissolution tests.

Sample	Mass (g)	Water volume (mL)
N-102	26.43	300
N-108	76.65	300
NUKON	11.28	300
CLP	150.68	300
SSLP	150.60	300

2.2. Precipitation tests

The precipitation tests were conducted at room temperature and 60 °C with a solution of metal salt. Indeed, it was difficult to perform the precipitation tests with the obtained solution because the concentration was too low to generate sufficient precipitate and analyze them. In our dissolution tests, because the calcium was the dominant dissolved species, the precipitation tests were carried out with only the calcium species. To this end, we prepared Ca-dissolved solution by using $CaCl_2 \cdot 6H_2O$ (99.9%, Aldrich) and adjusted the pH to 8.5 using TSP to establish a similar condition as