Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 10-11, 2007

Experiment for Plant Specific Head Loss Induced by LOCA-generated Debris at Containment Sump of PWR

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1. Introduction

In pressurized water reactor (PWR), the emergency core cooling system (ECCS) containment sumps collect the reactor coolant and chemically reactive spray solutions following a loss-of-coolant accident (LOCA). The LOCA in PWR would generate debris from thermal insulation and other materials in the vicinity of the break. A fraction of the LOCA-generated debris and pre-LOCA debris will be transported into the sump and accumulated on the sump screens resulting in adverse blockage effects that are degradation or loss of NPSH (Net Positive Suction Head) available for the ECCS pumps.[1] In Korea, the sump blockage issue has been addressed as a result of the periodic safety review (PSR). To resolve this, a sump performance analysis has been initiated since early 2006.

An assessment of the head loss across debris bed accumulated on the sump screen has been experimentally studied since the sump blockage has been issued. Nuclear Regulatory Commission (NRC) in U.S.A. sought a semi-theoretical approach for correlating the experimental data that is known as NUREG/CR-6224 correlation used to estimate the debris-induced head loss for PWR sump performance evaluation.[2]

NUREG/CR-6224 correlation was validated for the theoretical thickness of the debris bed from 1/8 inch to 4 inch [3]. In Westinghouse two loop plant, a scoping analysis of the containment sump for the sump performance evaluation has suggested the theoretical thickness of the debris bed greater than 4 inch. To apply NUREG/CR-6224 correlation to estimating the head loss across debris bed that is formed at the containment sump screen, experimental validation has to be conducted for the theoretical thickness greater than 4 inch. Therefore, the purpose of the research is to measure head loss against plant specific debris condition of Westinghouse two loop plant with a test facility and to estimate head loss parameters for NUREG/CR-6224 correlation.

2. Methods and Results

2.1 Description of Test Facility

The head loss test facility has been developed for the evaluation of plant specific head loss across the containment sump screen of Westinghouse two loop plant in Korea. Based on past experiments on the head loss test [1,4,5], the test facility was designed as a closed loop type with a vertical test section. A ratio of length to diameter (L/D) of the vertical test section was about 30.

In transparent section, the inner diameter of the clear PVC pipe is 165 mm, which results in a screen area of 0.196 ft2. The test screen is a perforated metal plate that supports the debris bed and has been located at the middle of the transparent section. The perforated metal screen is located at the position of 20 L/D upstream and 10 L/D downstream in the vertical section. The perforated metal screen with holes of 3 mm diameter was used to simulate the sump screen

The flow rate in the test facility was controlled by a 15 HP variable speed motor-pump and measured with Coriolis-type flow meter. And the test facility has been operated at higher water temperature than ambient temperature. The steel piping of the loop was insulated to minimize heat loss and a resistance heater on the pipe wall was wound to maintain water at temperature as high as 60 °C.

2.2 Test Conditions

The types and quantities of debris of the Westinghouse two loop plant has been obtained from the walkdown process and scoping analysis on debris generation and sump screen sizing calculation. Table 1 shows the debris quantities of Westinghouse two loop plant.

Table 1 Debris quantities for head loss test

Debris Type	Westinghouse two loop plant	Test Facility
NUKON™	417.6 kg	96.4 g
Calcium Silicate	122.5 kg	28.3 g
Qualified Coating	317.6 kg	73.3 g
Unqualified Coating		
Particulate	32.2 kg	7.4 g
Chip	101.6 kg	23.4 g
Latent Debris	115.7 kg	26.7 g

The surrogates for the debris in the Westinghouse two loop plant are selected based on the characteristic size and microscopic density of the debris. And the water temperature for testing is selected as 50 °C to estimate head loss conservatively.

2.3 Test Results

Head loss test was conducted with debris bed that has the debris composition of the Westinghouse two loop plant as listed in Table 1. Debris beds of NUKON™ with surrogate latent debris or surrogate coating chip show similar head loss data. Debris bed of NUKON™ with coating particulate surrogate showed the same head loss by the debris bed of NUKON™ with coating particulate surrogate, coating chip surrogate, and latent debris surrogate. This indicates that coating particulate surrogate is a significant debris type to determine head loss in debris bed. In the test, coating particulate surrogate has a characteristic size of 10 μm. Coating chip surrogate has a characteristic size greater than 125 μm. Latent debris has a distribution with 37.04 % for the size less than 75 μm, 35% for the size between 75 μm and 500 μm, and 28% for the size between 500 μm and 2000 μm. Theses features of coating particulate surrogate, coating chip surrogate, and latent debris indicate that the smaller size of debris with about 10 μm has a great effect on head loss. Figure 1 also shows that debris bed of NUKON™ with calcium silicate showed a higher head loss compared with that of other debris composition except debris bed with all composition. The result of head loss by debris bed with all types of debris is shown in Figure 9. As approach velocity increases slightly in debris bed, the head loss by debris bed increases steeply.

The measured head loss is compared with head loss predicted with NUREG/CR-6224 correlation, as shown in Figure 2. Application limits on head loss of NUREG/CR-6224 correlation is from 0 to 20 ft-water and application limits on approach velocity is 0 to 2 ft/sec. [3] Approach velocity to debris bed of the containment sump screen in Westinghouse two loop plant was estimated to about 0.023 ft/sec by scoping analysis of sump performance evaluation.

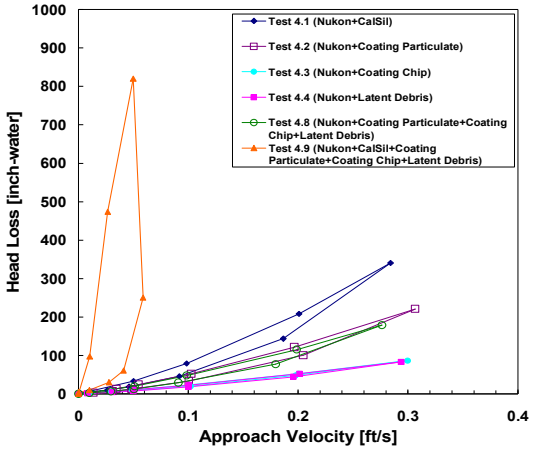

Fig. 1 Head loss by debris bed of a similar composition with Westinghouse two loop plant as a function of approach velocity at water temperature of 50 °C

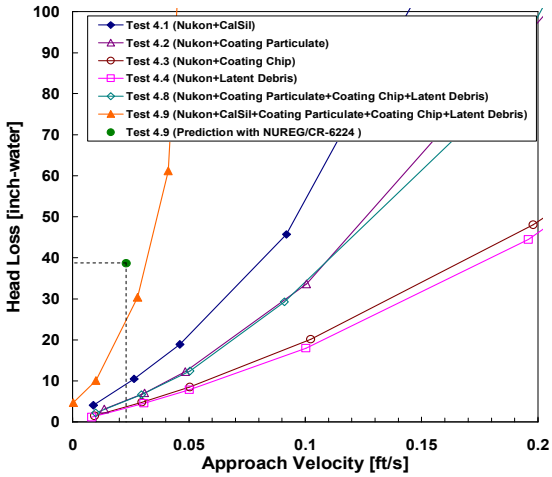

Fig. 2 Comparison of experimental data with head loss predicted with NUREG/CR-6224.

The predicted head loss with NUREG/CR-6224 was 3.22 ft-water. Figure 10 exhibits that the head loss predicted with NUREG/CR-6224 correlation is higher than the measured data at same approach velocity. This indicates that the head loss predictions with NUREG/CR-6224 correlation are much conservative.

3. Conclusion

Closed-loop test facility was devised and fabricated to estimate plant specific debris-induced head loss. Experimental results exhibited that NUREG/CR-6224 correlation could be applied to NUKON™ debris bed with theoretical thickness greater than 4 inch. Head loss test with debris composition of Westinghouse two loop plant showed that NUREG/CR-6224 correlation could predict conservatively head loss across debris bed. The experiment showed that the debris bed with calcium silicate and/or the particulate of about 10 μm size in NUKON™ debris had a significant effect on the head loss.

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