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Experimental Study of Head Loss Induced by Accumulation of LOCA-generated Debris at Containment Sumps of PWR

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1. Introduction

In PWRs, the containment emergency sumps provide for the collection of reactor coolant and chemically reactive spray solutions following a loss-of-coolant accident (LOCA). The LOCA in PWRs would generate debris from thermal insulator 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) margin.[1] In KORI unit 1, the sump blockage has been issued 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 debris-induced head loss in the sump performance analysis has been experimentally studied since the sump blockage has been issued. Experimental results have exhibited that head loss depends on amount of debris, specific surface area, mixture porosity of debris bed, debris types, and so on. Based on the experimental results, empirical correlations have been developed. NUREG/CR-6224 head loss correlation among them has been widely used to estimate the debris-induced head loss for PWR sump performance evaluation. However, in order to apply this correlation for estimating head loss in specific PWR plant, plant-specific head loss parameters for NUREG/CR-6224 correlation are required because of a different composition of debris sources between PWR plants.[1,2,3]

The purpose of the research is to measure head loss against plant-specific debris in KORI unit 1 in the closed-loop test facility and to estimate head loss parameters for NUREG/CR-6224 correlation. To do this, the closed-loop test facility is developed.

2. Experimental

2.1 Head loss correlation

In order to estimate debris-induced head loss, USNRC sought a semi-theoretical approach for correlating the experimental data that is known as NUREG/CR-6224 head loss correlation. This correlation is of a form containing two terms that account for head loss in the laminar and turbulent flow regimes, derived from the Kozeny-Carman and Ergun Equations as follows;

$$\frac{\Delta P}{\Delta L_O} = \left[\begin{array}{l} 3.55 S_V^2 (1-\varepsilon_m)^{1.5} \left[1 + 57(1-\varepsilon_m)^3 \right] \mu V \\ + 0.66 S_V \dfrac{(1-\varepsilon_m)}{\varepsilon_m} \rho_W V^2 \end{array} \right] \left(\frac{\Delta L_m}{\Delta L_O} \right) \quad (1)$$

where ΔP [dynes/cm^2] is a pressure drop due to flow across the debris bed, S_V [cm^2/cm^3] is a specific surface area of the porous bed, ε is a porosity of debris bed, ΔL_0 [cm] is a fiber bed theoretical thickness, ΔL_m [cm] is a actual bed thickness, ρ_W [g/cm^3] is the water density, μ [poise] is the fluid dynamic viscosity, and V [cm/s] is the fluid velocity. $\Delta L_m / \Delta L_0$ is defined as a compaction ratio.[2]

In the equation (1), the specific surface area, the porosity of debris bed, and the compaction ratio is dependent on the characteristics of debris bed formed on the screen. Theses parameters are plant-specific and have to be usually determined using experimental methods.

2.1 Closed-loop test facility

A head loss test facility has been developed for the evaluation of plant specific head loss across the containment sump screen in KORI unit 1. Based on past experiments on the head loss test [1,4,5], a closed test loop was selected as the head loss test facility. The test facility was designed as a closed loop with a vertical test section as shown in Figure 1. The vertical test section was fabricated with 6 inch schedule 80 CPVC. The vertical test section had a 20L/D approach upstream and 10L/D downstream of a perforated mesh screen. The long approach section was needed to achieve a relatively flat velocity profile at the screen.

The screen that is perforated plate was located at the middle of a transparent section that was inserted into the vertical test section. The perforated metal screen with holes of 3 mm diameter was used to simulate the sump screen as shown in Figure 2. Transparent section was fabricated with 6 inch schedule 40 Clear PVC or polycarbonate piping. It will be used to observe a formation of debris bed and to measure the bed thickness. The return path of the loop needs to keep the flow velocities high enough to minimize settling of

sludge particles in the loop and was fabricated with 2 inch schedule 10 stainless steel piping.

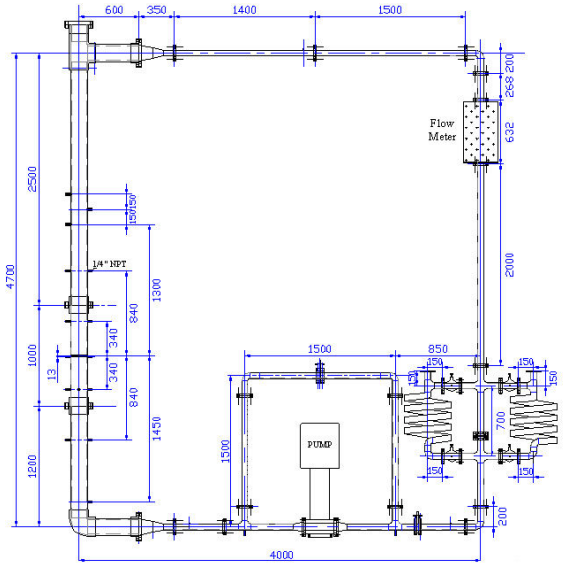

Figure 1. A schematic of the closed loop facility

The test facility will be operated at higher water temperature than ambient temperature. The steel piping of the loop was insulated to minimize heat loss from the loop and a resistance heater on the pipe wall was used to maintain water at temperature as high as 60 °C.

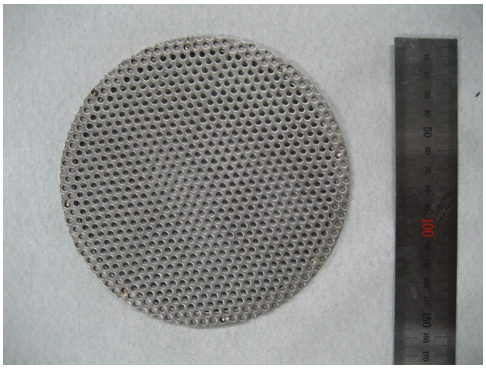

Figure 2. The perforated plate screen

2.2 Debris injection System

Debris injection into test loop will affect the formation of debris bed and mixing pattern of debris. To minimize the effect of debris injection, an on-line debris injection was devised. The debris injection system was designed and fabricated with a couple of twisting 2 inch schedule 10 stainless steel piping as shown in Figure 3. Different debris is inserted into each twisting pipe and then theses are injected into the test section by controlling the mounted valves. With this system, different debris can be introduced into the test loop at once.

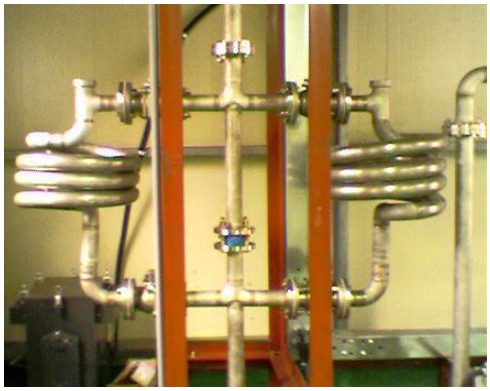

Figure 3. A photo of debris injection system

2.4 Controls and Instrumentation

The flow rate in the test loop was controlled by a 15 HP variable speed motor-pump and measured with Coriolis-type flow meter. The head loss across the screen was measured with pressure transmitter between pressure taps. Pressure taps was perforated at the position of 2L/D and 5L/D from the screen. K-type thermocouples were installed at the test loop to measure water temperature.

3. Conclusion

Closed-loop test facility was devised and fabricated to estimate plant-specific debris-induced head loss and to obtain plant-specific head loss parameters for NUREG/CR-6224 head loss correlation. Debris injection system was developed to minimize the effect of debris injection on head loss and to estimate the effect of debris mixing pattern on head loss. In the test facility, head loss estimation is conducting to obtain head loss parameters for fibrous debris.

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