Head Loss Test for the APR1400 Sump Strainer

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1. Introduction

If a loss of coolant accident (LOCA) were to occur, it is postulated that this LOCA could generate and transport debris to the emergency core cooling suction strainer. The debris that could accumulate on the strainer may form a debris bed and increase the head loss across the strainer. The purpose of this test is to develop data to validate the sump strainer performance using conservative conditions. Flow sweeps were also conducted to adjust the head loss over the range of fluid temperatures required for the strainer operation [1].

Test results of the head loss across an APR1400 sump strainer are presented, and compared with the allowable head loss to confirm net positive suction head (NPSH) margin.

2. Description of the Tests

2.1 Test Facility

The test facility consists of an approximately 4.5 m diameter tank that is 2.1 m deep. The flow returns into the tank from a 6 inch pipe with a tee that is pointed at the floor in the center of the tank. The exit of the tee is approximately 0.05 m above the floor so that the return flow sweeps along the floor then up the tank walls to help suspend debris. The tank can hold approximately 35,961 liters of water.

The test strainer is located next to the return pipe with the strainer plenum mounted 0.15 m above the tank floor. The top of the strainer elements are 1.2 m above the tank floor. Six agitators (trolling motors) are located at approximately every 60 degrees at an approximately 3.7 m diameter, see Figure 1.

The suction pipe is attached to the strainer and runs to the pump. The discharge of the pump goes to a flow meter, flow control valve, and then back into the tank.

Head loss across the strainer was measured by two independent differential pressure transducers. The flow meter was installed on the discharge side of the pump more than 50 diameters upstream of the pump with a straight section of pipe upstream and downstream of the flow meter. A flow control valve was installed downstream of the straight section of piping. Water temperature was measured with a type T thermocouple installed in the tank near the water surface.

2.2 Debris Description

Four types of debris were used in the test. Aged

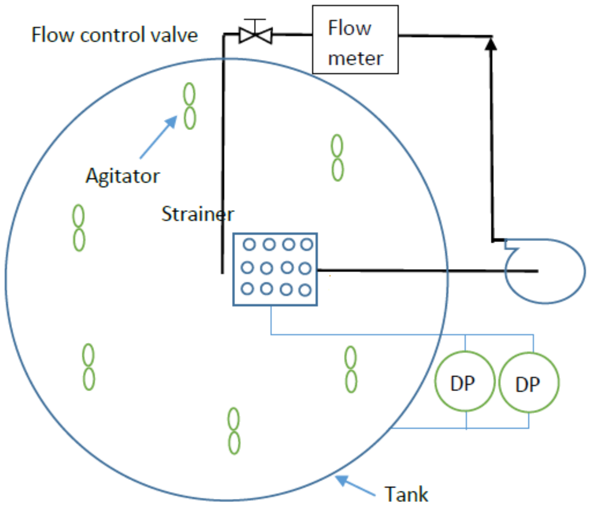

Fig. 1. Flow schematic of the test loop

Nukon fiberglass prepared as fines to simulate latent fiber, silicon carbide to simulate epoxy paint, sand mixture to simulate latent particulate, and aluminum oxy-hydroxide to simulate chemical debris.

- Latent Fiber

The use of fiberglass insulation, such as Nukon is recommended as a surrogate for dry latent debris [2]. The fiber was processed into fines. For the test, the fibers were triple shredded, separated by a pressure washer, and stirred by a mixer in a more dilute fiber water mixture. The end results of the suspended fibers are nearly all class 1 and 2 as defined in Reference 3.

- Silicon Carbide

Silicon carbide particles have an average diameter of approximately 10 microns as measured by the manufacturer.

- PWR Sand Mix

The PWR mix was made by combining three types of sand. Paver leveling sand was used for the coarse sand. It was passed through a 2000 micron sieve and no material passed through a 500 micron sieve. Glass bead blasting media was obtained in two different size ranges. The size labeled 40-60 mesh was all medium classification, all the sand passed through a 500 micron sieve and did not pass through a 75 micron sieve. The second size was labeled 170-325 mesh, and was a combination of fine and medium sizes. 75.94% of the sand passed through a 75 micron sieve (fine) and 24.06% passed through a 500 micron sieve but was captured on the 75 micron sieve (medium). To create the sand mixture 28% of the total amount was weighed out from the paver sand. To create the fine sand 48.7% of the total amount was weighed out of the 170-325 mesh, which produced 37% fines and 11.7% medium. The rest of the medium sand, 23.3% of the total, was weighed from the 40-60 mesh sand.

- Aluminum Oxy-hydroxide

Aluminum oxy-hydroxide was fabricated following WCAP-16530-NP-A [4]. The chemicals to make the aluminum oxy-hydroxide, aluminum nitrate and sodium hydroxide were used. The aluminum oxy-hydroxide was made at a concentration of 11g/l immediately prior to the test and a settling test was performed to ensure the chemical surrogate met the requirements [4].

2.3 Test Procedure

- Debris Preparation

The particulate, sand mixture and silicon carbide, were split into buckets with approximately 4,536 g in each bucket. About 11.36 liter of water was carefully added to each bucket and the mixture was agitated with a propeller agitator attached to a drill motor. The particulate and water was mixed to suspend the debris to facilitate pouring the mixture into the tank.

Fiber fines were prepared based on NEI guidance [5]. For the test, aged Nukon fiberglass insulation was cut into approximately 7.62 cm by 7.62 cm pieces. The cut pieces were then shredded in a leaf shredder/chipper, separated by a pressure washer, put into buckets, agitated by a mixer, and then poured into the tank.

The shred fiber was weighed into 2 batches of 521.6 g. A batch was split into three approximately equal portions and each third was placed into plastic container (approximately 121.1 liters) with approximately 7.57 liters of water. The fiber was thoroughly wet. The fiber was then separated using a pressure washer with a fan nozzle for 4 minutes. The water fiber mixture was then further diluted into 8 buckets with a total of 11.35 liters of water in each bucket. Immediately prior to adding the fiber, the fiber was agitated with a propeller mixer on high for one minute. A sample of this fiber water mixture was taken to ensure the process produced fines that were nearly all class 1 and 2 fines [3]. The fiber mixture was added to the tank and there were no fiber clumps as the fiber was poured into the tank.

Aluminum oxy-hydroxide (ALOOH) is made following the WCAP-16350 recipe [4]. Given the volume of ALOOH required the amount of water is determined from the concentration (11g/l). Water is added to a clean plastic tank. Aluminum nitrate is added slowly to the water at 2,835 g/g of ALOOH. The water is mixed by a stirrer. After the aluminum nitrate has all dissolved, sodium hydroxide is added at 907 g/g of ALOOH. The suspension must be mixed for at least one hour.

A sample is taken and placed undisturbed in a graduated cylinder for an hour to perform a settling test. After one hour, greater than 60% of the volume must remain cloudy.

The ALOOH is mixed in a plastic tank. The required amount of volume is weighed out into plastic containers and poured into the tank around the perimeter.

- Debris Addition

After the clean flow sweeps were completed, particulate was added to the tank. Particulate was distributed into 18.9 liter buckets and mixed with water. The particulate was added as a slurry to make it easier to add the particulate in the tank. The buckets were poured around the perimeter of the tank. Several buckets were added at consecutively to complete the addition.

After the particulate was allowed to circulate for a minimum of 2 pool turnover times (PTOs), the first of two batches of fiber was added. Fiber was added as a slurry around the perimeter of the tank. Several buckets were added at consecutively to complete the addition. The second batch of fiber was added after 10 PTOs and the head loss reached its stability criterion (<1% head loss change in one hour). The head loss was so low that a 1% change in one hour was difficult to determine, but the head loss essentially remained constant to meet this criterion.

Chemical debris was then added from plastic 113 liter containers and poured around the perimeter of the tank. The measured head loss increased slightly for the first three chemical additions so the total load of chemicals was added in five batches.

- Test Termination

Each subtest was terminated by completing the required minimum time and reaching the head loss stability requirement, if applicable. Clean flow sweeps were conducted for the time required and then that test was terminated. Particulate additions were conducted for the time required and then that subtest was terminated. Fiber and chemical addition subtests were terminated upon completing at least 10 PTOs and reaching head loss stability of <1%/hour. Final flow sweeps were terminated after completing the required 2 PTOs at each flow rate.

2.4 Test Conditions

Test was run assuming a 46.45 m^2 strainer (assumed blockage by tags and other debris). The flow rate and debris amounts were scaled by the ratio of the test strainer area to the plant strainer area as shown in Table 1.

The test matrix is shown in Table 2. The quantities in the table indicate the amount of debris added during a particular subtest.

Table 1: Head loss test conditions

Quantity	Value
Flow rate (lpm)	3785
Silicon carbide(kg)	42.1
Sand mix (kg)	12.6
Fiber (g)	1043
Chemical (liters)(max)	2528

Table 2: Test Matrix

Sutest	Fiber(g)	Dust(kg)	Coating(kg)	ALOOH(lit)
P1	0	12.6	42.1	0
F1	521.5	0	0	0
F2	521.5	0	0	0
C1	0	0	0	189.3
C2	0	0	0	189.3
C3	0	0	0	378.5
C4	0	0	0	757
C5	0	0	0	1013.9
V1	Water level was reduced to 61 cm above the strainer to check for vortexing			
FS	Flow was reduced in 378.5 lpm increments to 1892.6 lpm			

3. Test Results

3.1 Post Test Observations

After the test the suction and discharge vents were opened very slowly to minimize disturbance of the debris bed. Typically draining with heavy debris beds does disturb the debris bed because debris can easily fall off vertical surfaces, especially when there is little head loss across the debris bed.

Figure 2 show the strainer as the water was being drained from the tank. The debris did not fall off the left cylinder closest to the suction pipe. There is no effect of agitation on the debris build up on the strainer. Figure 3 shows the typical inside of the strainer tubes after drain down, note that debris falls off in an unpredictable manner.

3.2 Debris Head Loss Results

Debris head loss results are plotted in Figure 4 for each of the subtests in Table 2.

Fig. 2. Left side of strainer during drain down

Fig. 3. Typical inside of strainer tubes after drain down

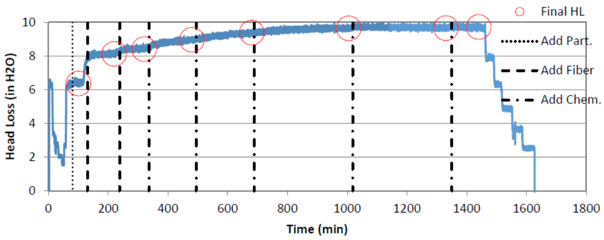

Fig. 4. Head loss results

4. Conclusions

The test results were measured in a fluid approximately 31 ˚C. Therefore it is conservative to use the values at higher temperature since fluid density and viscosity will decrease with increasing temperature. The final head loss value is the sum of the clean strainer head loss(7.62 cm-water) and debris head loss(24.7 cm-water). The strainer produces a final head loss of 32.32 cm-water which is less than the submergence(61 cm) at the full range of In-containment Refueling Water Storage Tank (IRWST) temperature.

REFERENCES

[1] APR1400-E-N-NR-13001-P Rev. 0, “APR1400 Design Features to Address GSI-191,” 2013.

[2] NEI 04-07 Rev. 0, “Safety Evaluation by the Office of Nuclear Reactor Regulation Related to NRC Generic Letter 2004-02,” 2004.

[3] Los Alamos National Laboratory, Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance, NUREG/CR-6808, 2003.

[4] Westinghouse, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191,” WCAP-16530-NP Rev. 0, 2006.

[5] NEI, “ZOI Fibrous Debris Preparation: Processing, Storage, and Handling,” 2012.