Attachment 4

CHLE-008: Debris Bed Preparation and Formation Test Results

PROJECT DOCUMENTATION COVER PAGE

Document No: CHLE-008	Revision: 3	Page 1 of 22
Title: Debris Bed Preparation and Formation Test Results		
Project: Corrosion/Head Loss Experiment (CHLE) Program		Date: 12 June 2012
Client: South Texas Project Nuclear Operating Company		

Summary/Purpose of Analysis or Calculation:

Fiberglass debris will be added to the head loss modules in the CHLE tests to form a debris bed that will act as a substrate for the capture of corrosion products if they form in the corrosion tank. Capture of corrosion products will be manifested as an increase of head loss through the debris bed. This document describes the results of a series of tests that were conducted to determine the procedures to form the debris beds in the head loss modules.

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Revision	Date	Description
1	6/3/2012	Describes results from Debris Tests 1 through 6.
2	6/9/2012	Adds a summary and the results from Tests 7 to 14.
3	6/12/2012	Addresses internal comments, adds TOC, introduction, and summary.

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Introduction

One key objective of the 30-day chemical effects testing is to determine whether or not chemical precipitates can form or collect on prototypical fiberglass media that are present in the post LOCA environment. Two primary chemical formation mechanisms are postulated that might affect the pressure drop across a sump-strainer debris bed: (1) formation and/or agglomeration of precipitates in the bulk solution that migrate to the strainer and incur some degree of filtration (by various mechanisms), and (2) direct precipitation of chemical products on fiber surfaces and interstitial contact points. Formation mechanism 1 could be monitored using commercial water quality filter media and microscopic examination of periodic grab samples. However, formation mechanism 2 requires the presence of real debris constituents in at least a prototypical physical configuration. Since both mechanisms can lead to measurable pressure drop across a debris bed, it is desirable to monitor pressure at constant flow through a fiber mat for the duration of the 30 days as an indicator of possible chemical product formation. If chemically induced pressure drop is observed, a more complete study of debris combinations and bed morphologies will be needed to develop a descriptive (if not predictive) head-loss correlation.

Diagnostic debris beds used in the 30-day CHLE tests should have the following attributes: (1) long-term mechanical stability, (2) reproducible formation and head-loss response to the same flow and chemical conditions, (3) internal complexity necessary to stimulate and respond to the presence of the two postulated chemical formation mechanisms. It has long been recognized that debris preparation protocol has important effects on fiber bed head-loss behavior including changes to characteristics such as compressibility, compaction, filtration efficiency, porosity, specific surface area, etc. The most recent debris formulation advocated by NEI for strainer testing involves baking fiber blankets on one side at 300 °C for 6 to 8 hours, followed by disaggregation with a commercial pressure-washer. The combination of a relatively new debris preparation method, a very low approach velocity of 0.01 ft/s across the STP strainers, and high-temperature chemically buffered water justify the time devoted to the short series of preliminary tests described in this report.

The primary objective of this CHLE preliminary test series was to select a bed preparation protocol suitable for initiating the 30-day baseline performance tests (to be conducted under plant conditions, but without corrosion materials). Careful consideration was given to the bed attributes of mechanical integrity, reproducibility, chemical detection threshold sensitivity, and time-response sensitivity. A series of preliminary debris generation and head loss tests were conducted between May 14 and 18 to evaluate procedures for creating reproducible and reliable debris beds for the CHLE program. These preliminary tests revealed great difficulty filtering silicon carbide particulates with a nominal diameter of 10 μm using the NEI debris preparation method. NEI prepared fiber is only slightly more compact than the manufactured blanket and retains up to 98 percent porosity. After these preliminary results were obtained, a more systematic testing program was instituted to evaluate trends and patterns associated with debris bed formation. Test instrumentation included flow meters accurate to 1 percent and differential pressure transducers accurate to 0.08 percent. The systematic testing program was conducted from 22 May 2012 to 07 June 2012 and included 14 tests that evaluated the following:

- 3 different fiber preparation methods: (1) the NEI pressure-washing method, (2) the Alion double-leaf-shredded and boiled method, and (3) chopping in a blender for 25 seconds.
- Incremental additions of quantities of fiber.
- 3 different solutions: (1) deionized water, (2) deionized water with boric acid and trisodium phosphate (TSP), and (3) deionized water with boric acid and sodium tetraborate.
- 2 approach velocities: (1) 0.1 ft/s and (2) 0.01 ft/s.
- 2 temperatures: (1) room temperature, and (2) 174 °F.
- With or without silicon carbide particles.
- With or without WCAP aluminum-based precipitates (AlOOH).
- WCAP precipitates added directly in the head loss columns or added in the CHLE corrosion tank.

The results of this series of tests are summarized in the next section, and detailed results of the tests are presented after that.

Summary of Results

The following conclusions can be drawn from this test series:

	Conclusion	**Basis**
1	The NEI pressure-washing fiber preparation method is not effective at preparing a debris bed that will capture silicon carbide (SiC) particles. The double-shredded method is more effective at doing so but was not completely effective in these tests.	Test 2 with 140 g of NEI-prepared fiber and 70 g of SiC (η = 0.5) remained turbid (turbidity 417 NTU after 10 minutes of circulation). The results were qualitatively similar to multiple tests the previous week. Test 3 (double-shredded) achieved turbidity of 54 NTU (94 percent removal of turbidity) at η = 1.0 but turbidity increased to 512 NTU at η = 3.0.
2	Fiber beds appeared to be better at capturing silicon carbide particles when sodium tetraborate (NaTB) was the buffer instead of TSP in fiber beds prepared by the double-shredded method, possibly because TSP also has properties that result in it being used as a surfactant and a detergent.	Test 3 (NaTB) achieved turbidity of 54 NTU at η = 1.0 and 512 NTU at η = 3.0, whereas Test 4 (TSP) achieved turbidity of 93 NTU at η = 1.0 and 901 NTU at η = 3.0. All conditions other than buffer chemical were identical.
3	Fiber debris beds with Nukon are highly porous. Based on the densities of silica and the debris beds, the porosity of fiber debris beds ranges from 95 to 98.5 percent.	Based on measured bed thickness in numerous tests.
4	The NEI fiber preparation method results in very consistent debris beds. Incremental additions of fiber result in a linear increase in bed thickness and head loss. Repeated tests resulted in similar increases in bed thickness and head loss.	Fiber was added in increments in Tests 2 and 5. Not only did the tests individually display linear results, but the data matched well between tests. See Figures 6, 7, and 8. Addition of WCAP precipitates in Tests 6 and 8 also matched well. See Figure 11.

5	The blender method results in less consistent debris beds. The increase in head loss with additions of debris was non-linear. In addition, changing the approach velocity and returning it to the original velocity resulted in significant increases in head loss.	After a threshold quantity of fiber was introduced into the column, the head loss through the fiber-only bed increased rapidly to over 50 inches at both 0.1 and 0.01 ft/s, see Figures 14 and 15. The increase in head loss caused by cycling the velocity low and high was as much as 80 percent, see Figure 16.
6	The NEI and blender fiber preparation methods are both highly effective at capturing WCAP precipitates. The blender method generates high head loss with lower quantities of WCAP precipitates when they are introduced directly into the head loss column.	See Tests 6 and 8 for WCAP addition to the NEI preparation and Tests 11 and 12 for WCAP addition to the blender preparation. The head loss spiked after 4 grams of addition for the NEI preparation, whereas the head loss spiked after only 1 gram for the blender preparation.
7	The addition of WCAP precipitate in small increments results in non-linear head loss behavior. The first additions, if small, can result in small increases in head loss. Once a threshold quantity that coats the leading surface of the bed is reached, however, head loss increases rapidly until the test must be terminated.	See Figures 9 and 10.
8	The addition of WCAP precipitate into the CHLE corrosion tank at high temperature results in head loss at the head loss columns. Rapid head loss increase was observed after a threshold amount of WCAP precipitate was present in the tank. The threshold amount was lower when the blender preparation method was used than it was when the NEI procedure was used, but the difference was less substantial than in the column tests. Furthermore, the behavior of the 3 columns was more consistent when the NEI debris preparation was used than when the blender method was used.	See Test 13 for WCAP addition to the tank for the NEI preparation and Test 14 for WCAP addition to the tank for the blender preparation. 90 g of WCAP was added to the NEI prepared tests and 50 g of WCAP was added to the blender prepared tests before head loss spiked.

Conclusions and Plans for Debris-Bed Formation for 30-Day Tests

Numerous tests demonstrated that the NEI-prepared fiber beds were ineffective at retaining silicon carbide particles. Because of the importance of having a debris bed that is stable over a long period of time (30 days), it was decided to conduct the 30 day tests with fiber-only beds. This decision was reviewed with NRC staff during a telephone conference on May 30, 2012.

Alternative bed preparations that were studied for retention of WCAP precipitates included the NEI-protocal (pressure-washer) and 25-s blended fiber suspended in a water slurry. The blended material exhibited significant visual size uniformity when viewed on a light table and very regular bed thickness when introduced to the columns. However, the increased fraction of shards (broken glass fibers) created by mechanical blending destroys the tensile strength of the fiber bed and introduces somewhat erratic sensitivity to small perturbations in flow. The 3 replicate blended beds exhibited somewhat greater variation in head loss response compared to the 3 NEI-prepared beds. This is attributed to random variations in the configuration of glass shards between the beds. It is conjectured that glass shards easily compact (spatially reconfigure) in response to minor changes in flow leading to both variation in initial conditioning and variation in the response times under product accumulation. Blended material exhibits rapid head loss rises as the beds compress. Spatial reconfiguration (compaction) cannot be recovered after reducing the flow.

Tests that used direct introduction of WCAP precipitate in the head loss columns and bulk mixing of surrogate in the large-volume CHLE tank exhibited significant head-loss responses after introducing less than 20 percent of the WCAP total prediction for the STP containment. Very small increments of WCAP surrogate were observed to initiate a small increase in head loss, indicating sufficient sensitivity in the NEI fiber bed without particulates for detecting freely migrating chemical products having similar properties. Fully formed beds used in these tests contained 18 g of fiberglass forming a bed thickness of approximately 2 inches.

It was concluded that fiber debris beds formed with the NEI preparation procedure that retain significant internal tensile strength will provide a more stable basis for tracking long-term trends and a more robust substrate for accommodating unforeseen flow perturbations during the course of the 30-day tests, and are therefore recommended for the 30-day tests.

Details of the individual tests that support these conclusions are described in the following sections.

Test 1: Nukon fiber, silicon carbide particles, RO-treated water

Date: 22 May 2012

Conditions: Nukon fiber prepared according to the NEI protocol, added to the head loss column in multiple batches, starting with 60 g of fiber and added in 20 g batches until 140 g was reached. After 140 g of fiber was in the bed, 70 g of silicon carbide (SiC) particles was added. Head loss was measured at a target approach velocity of 0.1 ft/s (actual about 0.093 ft/s) and at 0.010 ft/s. Recirculating water was deionized by reverse osmosis.

Results: Additions of fiber in 20 g increments led to uniform increases in head loss at both 0.093 and 0.01 ft/s, although the intercept did not pass through zero (see Figures 1 and 2 below). Water turbidity declined slightly with each addition of fiber (starting at 2.6 NTU and declining to 2.1 NTU after 140 g of fiber were in the column), indicating that the fiber bed was probably filtering some particles from the water. After SiC was added and the water was allowed to circulate for 10 minutes, the turbidity was measured at 162 NTU. After an additional 20 minutes, the turbidity was measured at 97 NTU, indicating that the fiber bed was removing some of the SiC carbides, but very slowly. After the SiC was added, the head loss stabilized at 30.5 inches, compared to 26.2 inches with fiber only (at a velocity of 0.093 ft/s), an increase in head loss of 16%.

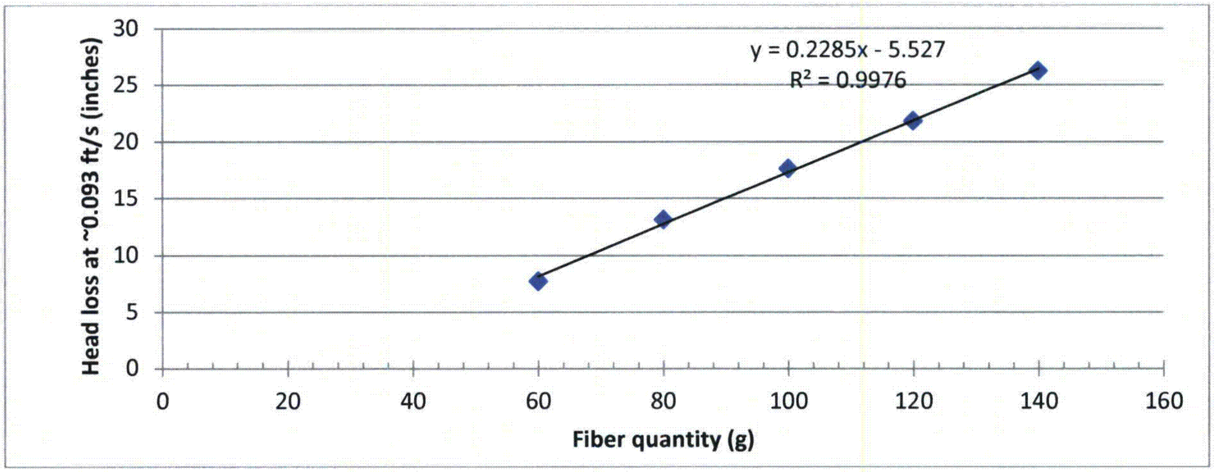

Figure 1: Head loss at approach velocity of about 0.093 ft/s with RO-treated water as the circulating fluid.

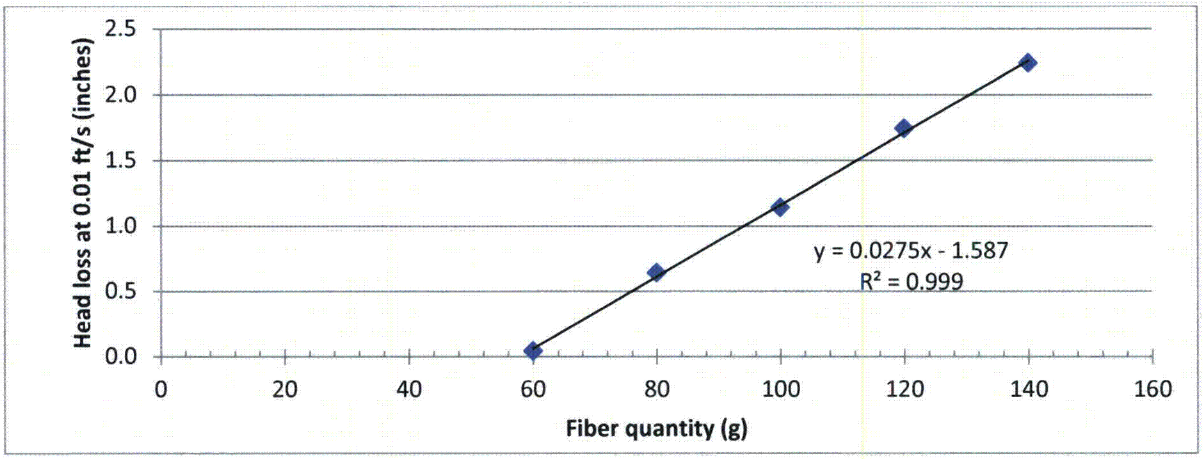

Figure 2: Head loss at approach velocity of 0.010 ft/s with RO-treated water as the circulating fluid.

Test 2: Nukon fiber, silicon carbide particles, water with H_3BO_3/TSP

Date: 23 May 2012

Conditions: Same experimental procedures as Test 1, except that boric acid = 2,680 mg/L as B and TSP = 3,370 mg/L was added to the RO water. The boric acid and TSP were added directly to the water in the column.

Results: Additions of fiber in 20 g increments led to uniform increases in head loss at approach velocities of both 0.093 and 0.01 ft/s, similar to Test 1. Two differences between this test and Test 1, however, were that the overall head loss was lower in this test (with 140 g of fiber, Test 2 had 17.3 inches of head loss compared to 26.2 inches in Test 1), and the intercept of the increasing head loss trend was close to zero (see Figures 3 and 4).

The increase in bed thickness was also relatively linear with additions of fiber, as shown in Figure 5.

The initial turbidity before adding any chemicals to the water was 0.74 NTU. After chemicals were added and the water circulated for a time, the turbidity was 3.0 NTU. The turbidity declined gradually as additional batches of fiber were added, reaching 2.0 NTU after 140 g of fiber was added. After SiC was added and the water was allowed to circulate for 10 minutes, the turbidity was measured at 417 NTU.

Test 3: Double-shredded Nukon fiber, sodium tetraborate as buffer

Date: 25 May 2012

Conditions: Nukon fiber and silicon carbide particles from Alion's facility in Warrenville, IL were used. The fiber was shredded twice with a common leaf shredder by Alion. The fiber was boiled in RO water in a beaker at UNM, the fiber was allowed to settle and the RO water was decanted and replaced with water containing boric acid and sodium tetraborate. 18 g of SiC was placed in the column first, followed by 18 g on Nukon fiber ($\eta = 1$). After 40 minutes of circulation, 36 g of additional SiC was added ($\eta = 3$). The water circulating in the column was deionized by RO with boric acid and sodium tetraborate added.

Results: After 18 g of SiC was added to the column, the turbidity was measured at 845 NTU and no detectible head loss was measured. Shortly after 18 g of Nukon fiber was added, the head loss was 3.27 inches and the turbidity was measured at 179 NTU. After 40 minutes of circulation, the head loss had increased to only 3.48 inches, but the solution in the column was visibly relatively clear and the turbidity was measured at 54.2 NTU. Shortly after 36 g of additional SiC was added, the head loss increased to 3.63 inches and the turbidity increased to 996 NTU. After 45 minutes of additional circulation, the head loss had increased to only 3.75 inches and the turbidity was still 512 NTU.

Test 4: Double-shredded Nukon fiber, TSP as buffer

Date: 25 May 2012

Conditions: The same as Test 3 except with TSP instead of sodium tetraborate as the buffer.

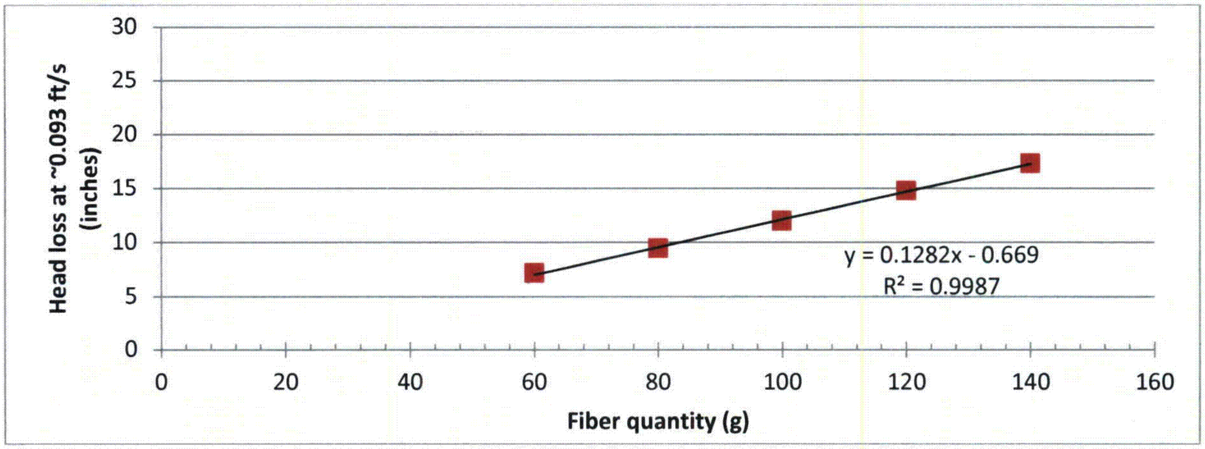

Figure 3: Head loss at approach velocity of about 0.093 ft/s with water containing boric acid and TSP as the circulating fluid.

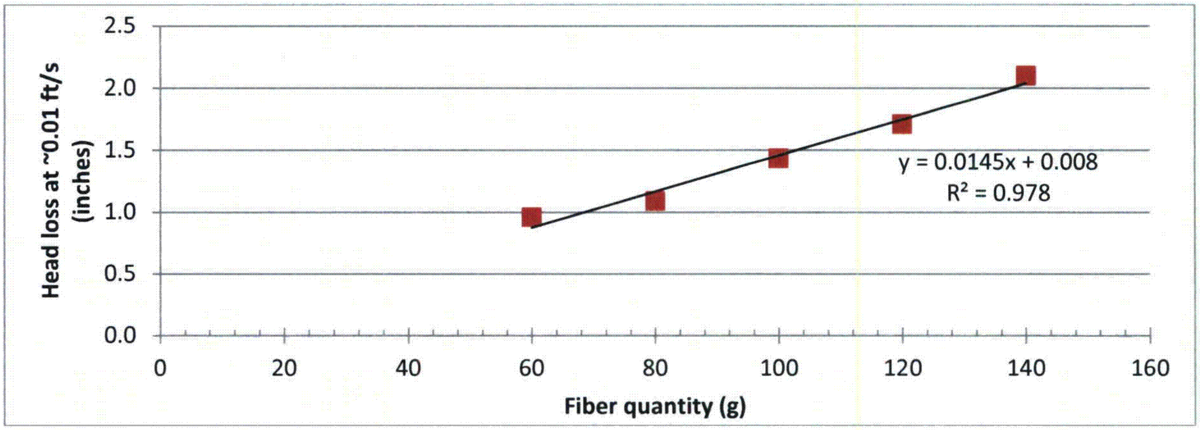

Figure 4: Head loss at approach velocity of 0.010 ft/s with water containing boric acid and TSP as the circulating fluid.

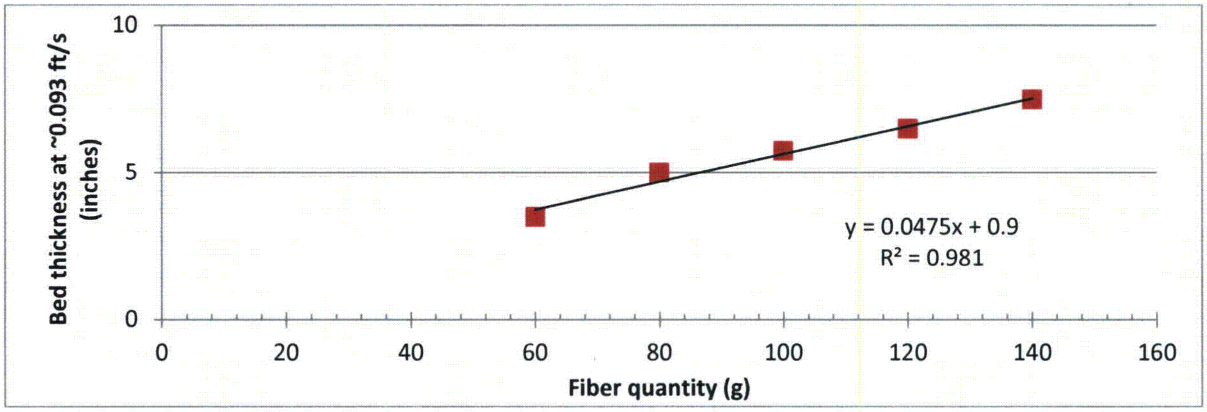

Figure 5: Bed thickness at approach velocity of 0.010 ft/s with water containing boric acid and TSP as the circulating fluid.

Table 1 - Head loss and turbidity in Tests 3 and 4.

	Head loss (inches)		Turbidity (NTU)	
	Test 3	Test 4	Test 3	Test 4
After fiber and 18 g SiC added	3.27	3.37	179	232
40 minutes later	3.48	3.41	54	93
After 36 g additional SiC added	3.63	3.82	996	1073
45 minutes later	3.75	5.84	512	901

Results: Overall, the fiber bed did not remove particles as well when TSP was used as a buffer instead of NaTB. The head loss was nearly the same but the turbidity was higher in Test 4. A comparison of Tests 3 and 4 is shown in Table 1.

Test 5: Nukon fiber, no particles, AlOOH (WCAP) precipitate

Date: 29 May 2012

Conditions: Nukon fiber was prepared with the NEI protocol. No silicon carbide particles were added. Precipitates were prepared according to the instructions for AlOOH in WCAP-16530-NP. The water circulating in the column was deionized by RO with boric acid and TSP added. Fiber was added in 20 g increments until 100 g of fiber was in the column to validate the head loss and bed depth trends from Test 2. During the addition of the fiber, the head loss was recorded at approach velocities of 0.1 and 0.01 ft/s, and the bed thickness was recorded at an approach velocity of 0.1 ft/s.

The amount of AlOOH prepared for this test was 107 g. This amount was based on the total amount of aluminum precipitates calculated to occur in STP containment (by WCAP-16530-NP calculations) times the ratio of the volume of water the STP containment during a LOCA (71,700 ft^3) to the volume of water in the CHLE tank (33.4 ft^3), divided by 3 to account for the fact that the CHLE system has 3 parallel head loss columns. The WCAP precipitate was added slowly while the column was running at an approach velocity of 0.1 ft/s.

Results: The incremental addition of fiber in Test 5 produced head loss and bed thickness results very similar to Test 2. At an approach velocity of 0.1 ft/s, the corresponding head loss in Test 2 was about 85 to 90 percent of the corresponding head loss in Test 5, as shown in Figure 6. However, Test 2 was conducted at an approach velocity of about 0.093 ft/s, whereas Test 5 was conducted at 0.1 ft/s. Considering the difference in approach velocity in the two tests, the results are very similar. Nearly identical head loss results were obtained at an approach velocity of 0.01 ft/s, as shown in Figure 7. The slope of the linear trend of head loss with fiber addition is virtually identical in Tests 2 and 5 at 0.01 ft/s, and the intercept varies by only 0.15 inches. Similarly, nearly identical bed thickness results were obtained in the two tests, as shown in Figure 8.

Bed density can be calculated from the Fiber beds with 60 g or more of fiber have a density nearly identical to that of standard Nukon blankets (2.4 lb/ft^3). Bed density is calculated from

$$\rho_B = \frac{M_S}{V_B}$$

where ρ_B = bed density, M_S is the mass of the substrate (fiberglass), and V_B is the volume of the bed. Fiber beds in Test 5 with less fiber (20 or 40 g of fiber) had less dense beds (1.35 lb/ft^3 for the 20 g bed and 1.80 lb/ft^3 for the 40 g bed), indicating that some head loss was necessary to provide compression to compress the bed to the thickness comparable to the Nukon blankets. The bed porosity is calculated from

$$\varepsilon = \frac{V_v}{V_B} \qquad = 1 - \frac{V_S}{V_B} \qquad = 1 - \frac{\rho_B}{\rho_S}$$

where ε = porosity, V_V = void volume, V_S = substrate volume, and ρ_S = substrate density (M_S/V_S). Assuming that Nukon is primarily silica with a substrate density of 165 lb/ft^3, a bed density of 2.4 lb/ft^3 corresponds to a porosity of 98.5 percent. A fiber bed with that porosity cannot be expected to efficiently remove hard particles like silicon carbide.

The thicker beds in Tests 2 and 5 were observed to expand at the lower approach velocity. The increase in bed thickness ranged from 0.25 to 0.75 inches. In addition, when the approach velocity was returned to the higher value, the bed settled into a more compressed position than it was before the approach velocity was reduced. It was also observed that the head loss increased to a greater value when the approach velocity was returned to 0.1 ft/s after being reduced to 0.01 ft/s, although the head loss only increased by 3 to 5 percent. This trend was observed in both Tests 2 and 5.

The addition of the WCAP precipitate caused an almost immediate (within one minute) increase of head loss to greater than 90 inches. As the head loss approached that value, the support screen bent and snapped out of place, dumping the debris bed and all the captured precipitates to the bottom of the column. At the time when the support screen collapsed, only a portion of the WCAP precipitate had been added.

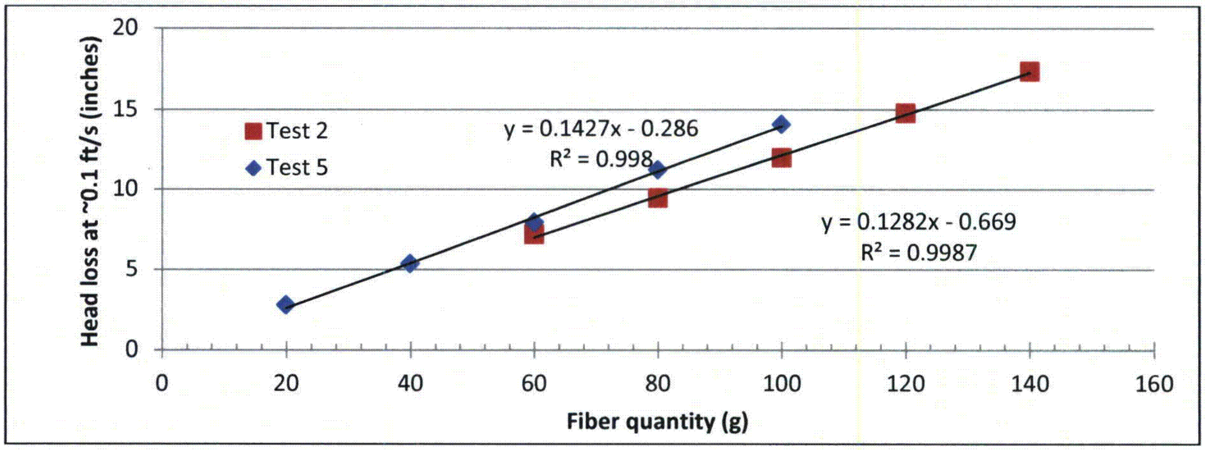

Figure 6: Head loss at approach velocity of 0.093 ft/s in Test 2 and 0.1 ft/s in Test 5.

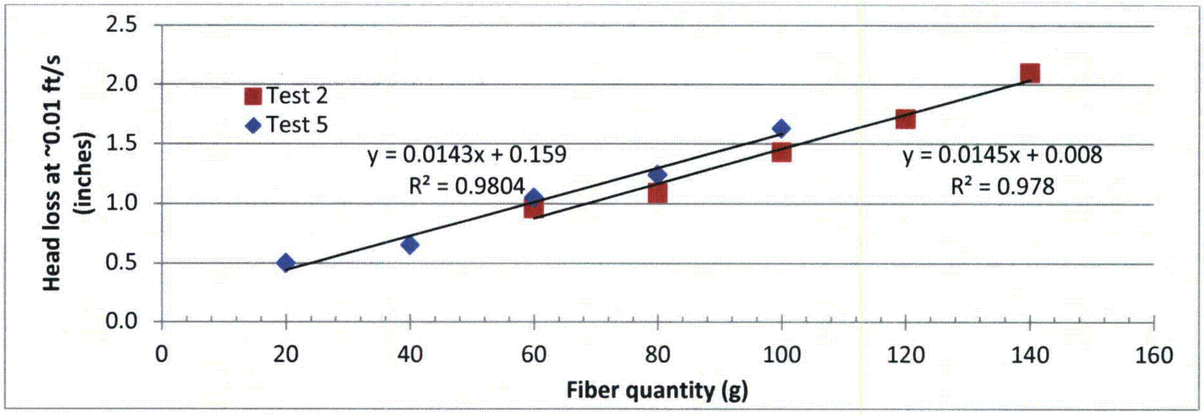

Figure 7: Head loss at approach velocity of 0.01 ft/s in Tests 2 and 5.

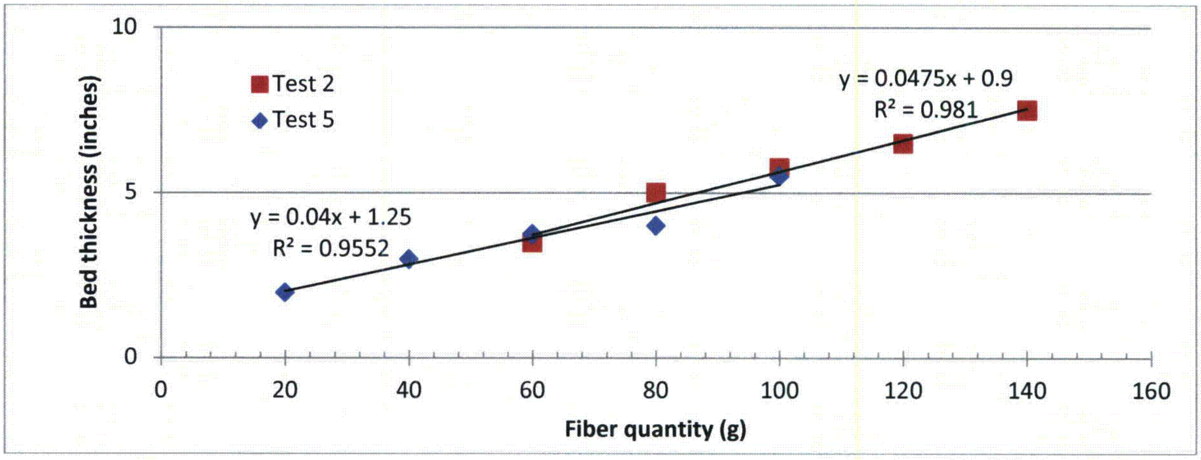

Figure 8: Fiber bed thickness at approach velocity of 0.1 ft/s in Tests 2 and 5.

Test 6: Nukon fiber prepared by NEI protocol, WCAP precipitate

Date: 30 May 2012

Conditions: Because the head loss increased so rapidly and the support screen collapsed within one minute in Test 5, this test was devised to determine the threshold for head loss with smaller additions of WCAP precipitate, with a smaller fiber debris bed, and at a lower approach velocity. The fiber debris bed was prepared with 18 g of Nukon fiber prepared with the NEI protocol. The approach velocity was set to 0.01 ft/s. The water circulating in the column was deionized by RO with boric acid and TSP added. The precipitate was prepared with 10 g of WCAP precipitate (prepared according to the instructions for AlOOH in WCAP-16530-NP) in 1 L of water containing boric acid and TSP. The precipitate was added in 0.1 L increments, corresponding to 1 g of WCAP precipitate in each addition. These 1 g additions each correspond to a loading of

0.0112 lb/ft^2 (lb of precipitate per ft^2 of screen surface area). For comparison, the WCAP calculations for STP predict 1,510 lbs (685.2 kg) of aluminum-based precipitates (AlOOH and $NaAlSi_3O_8$) to be loaded onto 5,450 ft^2 of screens (1815.5 ft^2 x 3), resulting in a total loading of 0.277 lb/ft^2. Thus, each addition of WCAP precipitate in this test is comparable to 1/25th of the precipitate predicted to load the STP screens by the WCAP calculations, assuming 3 trains in operation.

Results: Measured head loss increased only slightly after the first 3 additions of WCAP precipitate. Head loss was more significant after the 4th addition, and the next two additions consisted of only 0.5 g of WCAP precipitate each, but head loss increased rapidly after each. The head loss trend during the test is shown in Figure 9.

Test 7: Nukon fiber prepared by NEI protocol, WCAP precipitate

Date: 31 May 2012

Conditions: This test is a repeat of the same conditions as Test 6.

Results: The test was terminated after 0.5 g of precipitate was added because the head loss stopped rising. The assumption at the time was that the bed developed a borehole that allowed water to bypass the bed, but later (Test 9) it was discovered that the differential pressure cell on the head loss column ceased functioning properly.

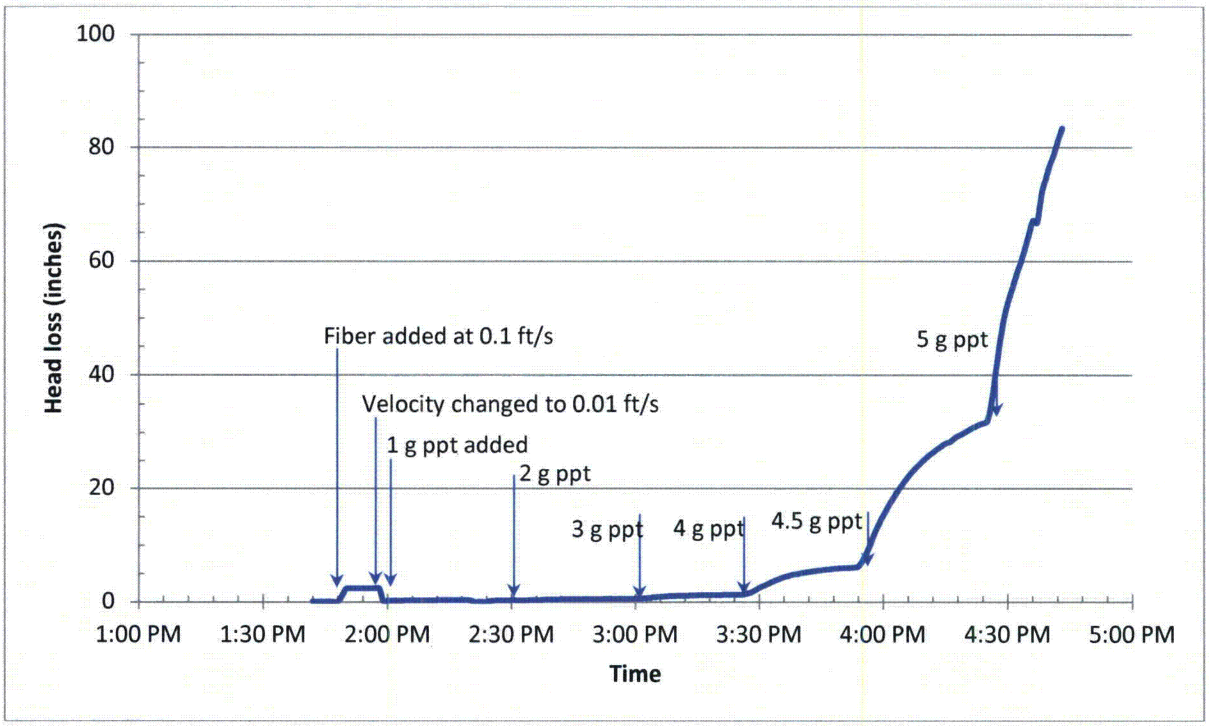

Figure 9: Head loss after addition of 1 g increments of WCAP precipitate (Test 6).

Test 8: Nukon fiber prepared by NEI protocol, WCAP precipitate

Date: 31 May 2012

Conditions: This test is a repeat of the same conditions as Test 6, but using a different column.

Results: The results were similar to Test 6. Measured head loss increased only slightly after the first 3 additions of WCAP precipitate. Head loss started to creep up after the 4th addition, and increased rapidly after the 5th and 6th additions. The head loss trend during the test is shown in Figure 10 and a comparison of the head loss resulting from each addition in Tests 6 and 8 is shown in Figure 11. The results from Tests 6 and 8 demonstrate reproducibility.

Test 9: Nukon fiber prepared in blender

Date: 01 June 2012

Conditions: Nukon fiber prepared by baking one side on a hot plate (NEI protocol), but instead of disaggregating with a pressure washer, the fiber was blended in a blender for 25 seconds on the "chop" setting. Fiber was added to the head loss column in multiple batches, starting with 20 g of fiber and added in 20 g batches until 100 g was reached. Head loss was measured at target approach velocities of 0.10 ft/s and at 0.010 ft/s. The water circulating in the column was deionized by RO with boric acid and TSP added.

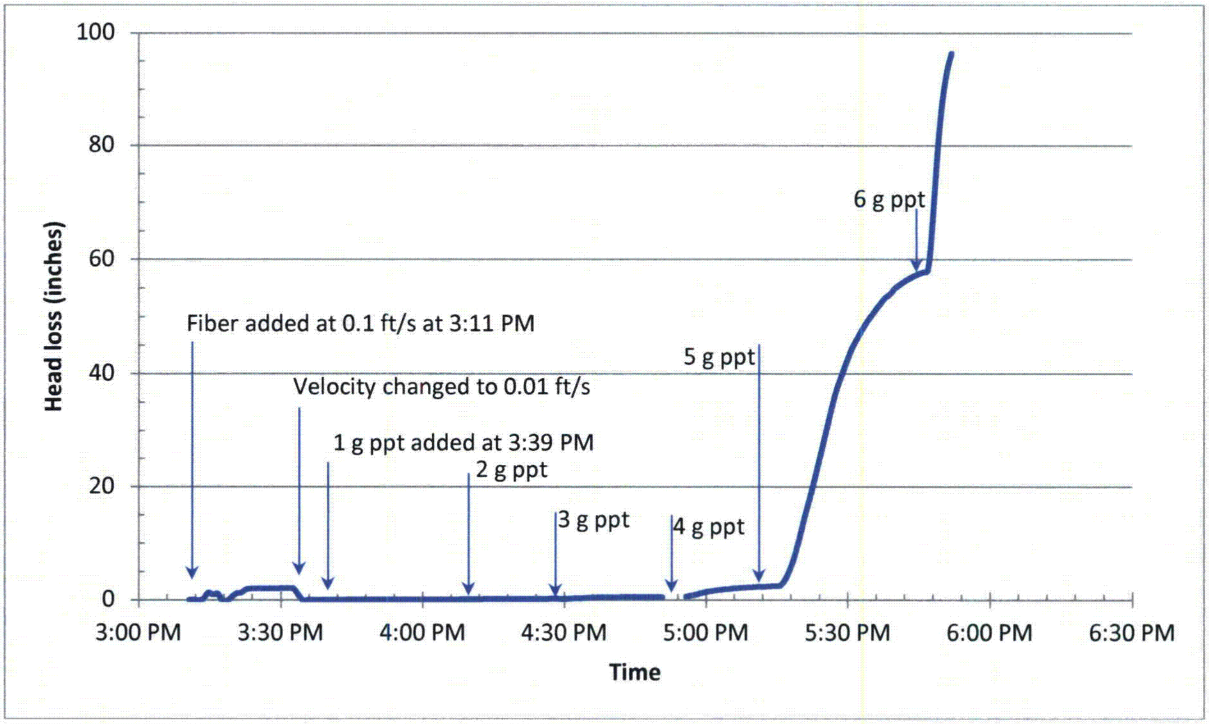

Figure 10: Head loss after addition of 1 g increments of WCAP precipitate (Test 8).

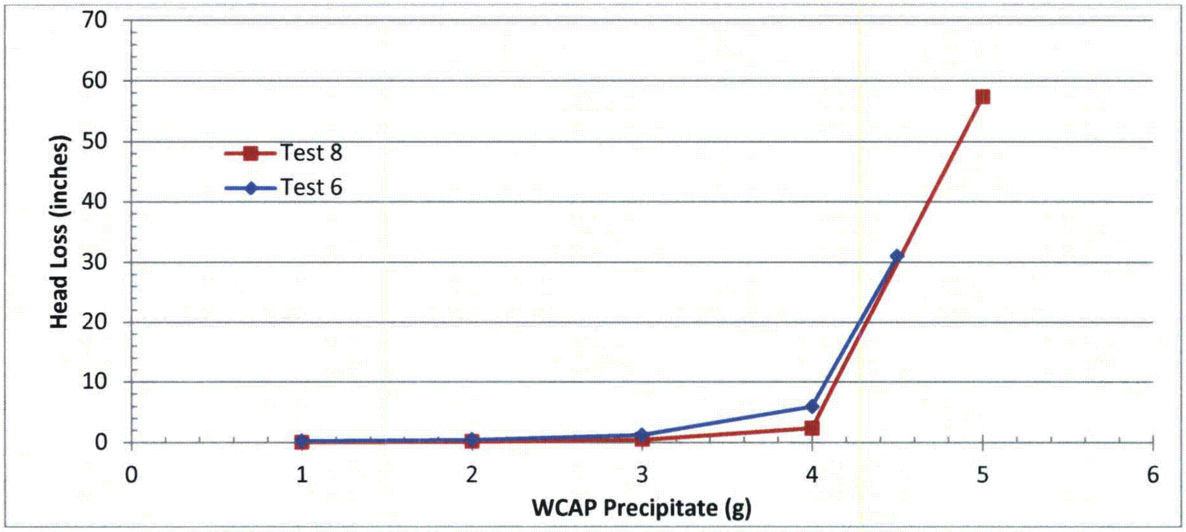

Figure 11: Comparison of head loss after addition of WCAP precipitate in Tests 6 and 8.

Results: Head loss increased with each batch of fiber added. After 60 g of fiber was added however, the head loss stopped increasing at a value of 12.3 inches. Thus, the test was terminated and a new test (Test 10) was started. The results of this test are discussed with the results for Test 10.

Test 10: Nukon fiber prepared in blender

Date: 01 June 2012

Conditions: This test is a repeat of the same conditions as Test 9.

Results: The fiber prepared in a blender resulted in debris beds with substantially more head loss than fiber prepared by pressure washing. The pressure-washed fiber beds were much thicker than the blendered fiber beds, as shown in Figures 12 and 13. The blendered fiber beds were less reproducible and did not result in a linear relationship between fiber amount and head loss (see Figures 14 and 15). The head loss increased rapidly as the fiber amount increased, reaching over 50 inches of head loss with a 60 g fiber bed at 0.1 ft/s approach velocity, and over 50 inches of head loss with a 100 g fiber bed at 0.01 ft/s approach velocity.

The head loss through the beds changed significantly in response to changes in flow. Decreasing the flow from 0.1 ft/s to 0.01 ft/s, and increasing again to 0.1 ft/s caused substantially more head loss, as reflected in Figure 16. This increasing head loss is probably due to a rearrangement of the fibers that decreased bed thickness (a decrease in bed thickness by about 1/8-inch was also noted). While an increase in head after changing flow was observed with NEI pressure-washed beds, the effect was slight compared to blendered beds. The increase in head loss after changing the flow averaged less than 5 percent in both Test 2 and Test 5, but was dramatic in Test 10.

(a) (b)

Figure 12: Photographs of fiber beds with 18 g of fiber at 0.1 ft/s approach velocity (a) prepared with NEI pressure-washer method and (b) prepared in a blender.

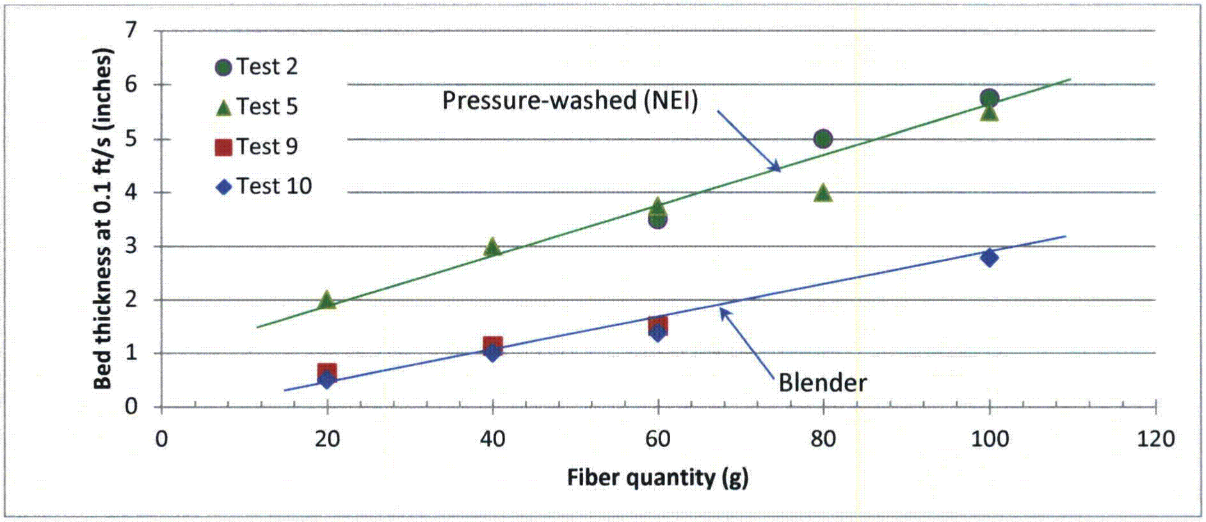

Figure 13: Fiber bed thickness at approach velocity of 0.1 ft/s in NEI pressure-washed fiber beds (Tests 2 and 5) and blendered fiber beds (Tests 9 and 10).

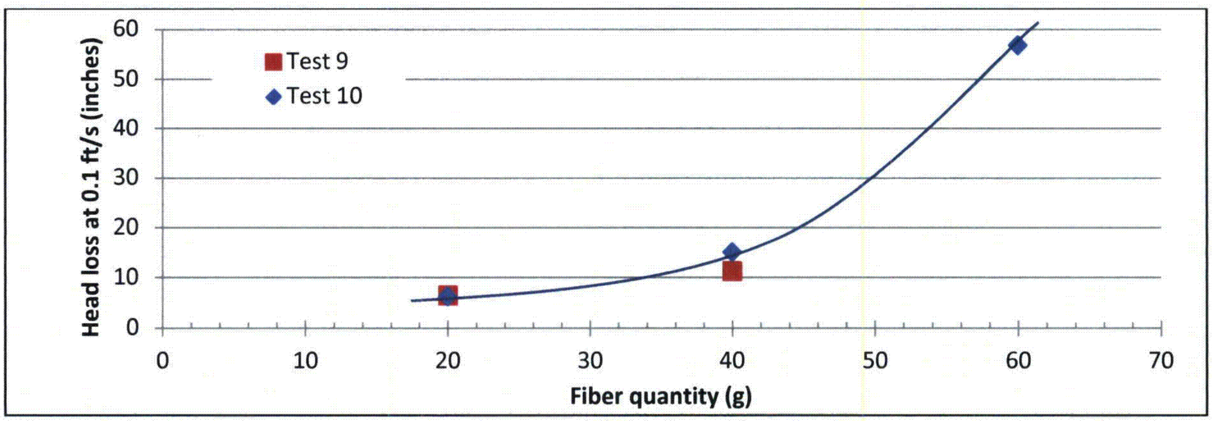

Figure 14: Head loss at approach velocity of 0.1 ft/s in fiber beds prepared with a blender (Tests 9 and 10).

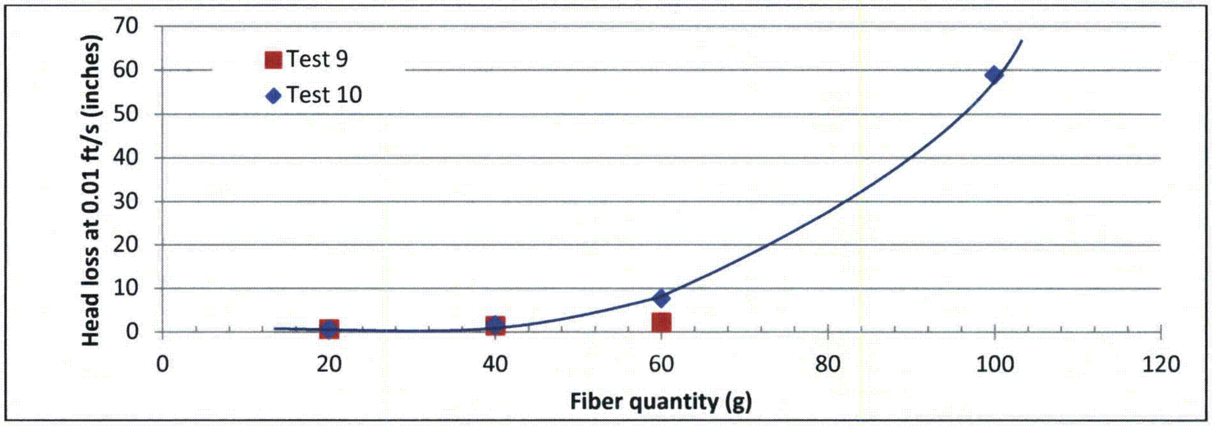

Figure 15: Head loss at approach velocity of 0.01 ft/s in fiber beds prepared with a blender (Tests 9 and 10).

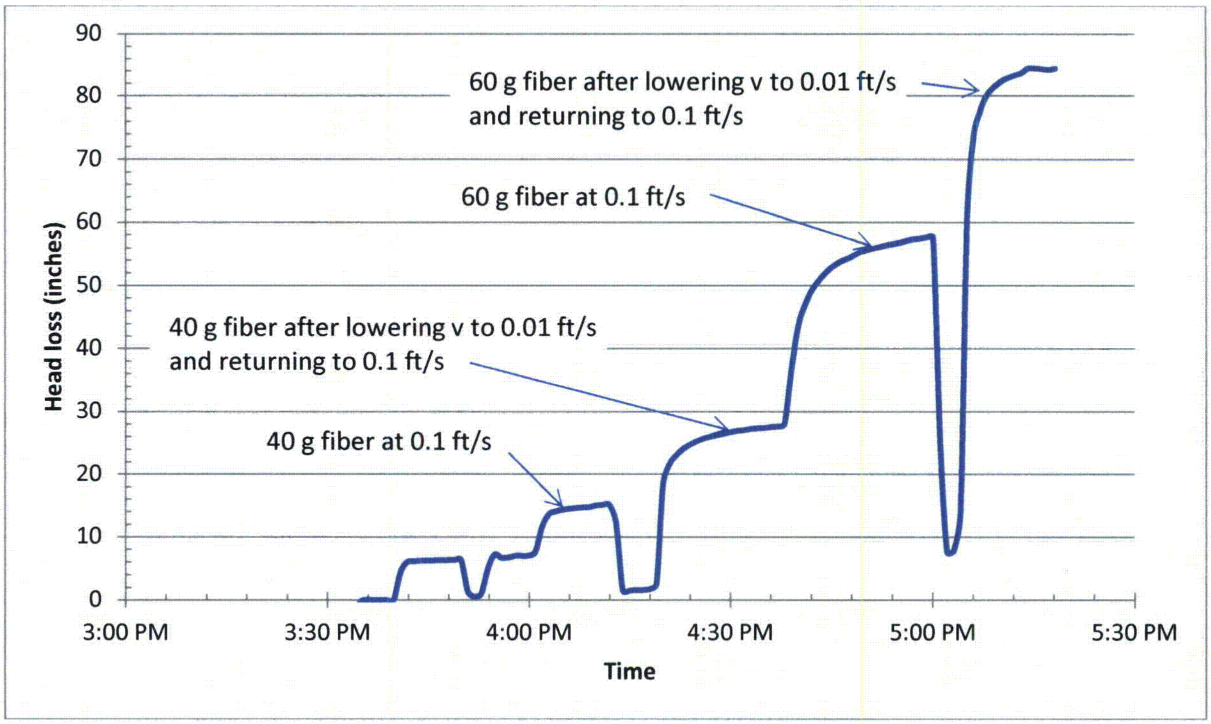

Figure 16: Head loss in Test 10 with fiber bed prepared with a blender.

Test 11: Nukon fiber prepared by blender, exposed to WCAP precipitates

Date: 04 June 2012

Conditions: An 18 g fiber bed prepared in a blender was introduced into a head loss column. WCAP precipitate was added in 1 g batches using identical procedures to Test 8. This test provides a comparison of the NEI and blender fiber preparation methods with WCAP precipitate.

Results: After the first batch (1 g) of WCAP precipitate was added, the head loss rapidly climbed above 100 inches and the test was terminated. As the head loss exceeded 80 inches, a sudden drop in head loss occurred, indicating bypass of water through the bed (often described as a borehole). The head loss is shown in Figure 17. After the test was terminated and the column draining was in progress, water was not observed pouring through any perforations in the bed but was observed running at the wall of the column. Thus, the bypass through the column appears to have occurred at the interface between the bed and the column wall.

Test 12: Nukon fiber prepared by blender, exposed to WCAP precipitates

Date: 04 June 2012

Conditions: Test 12 was a repeat of Test 11.

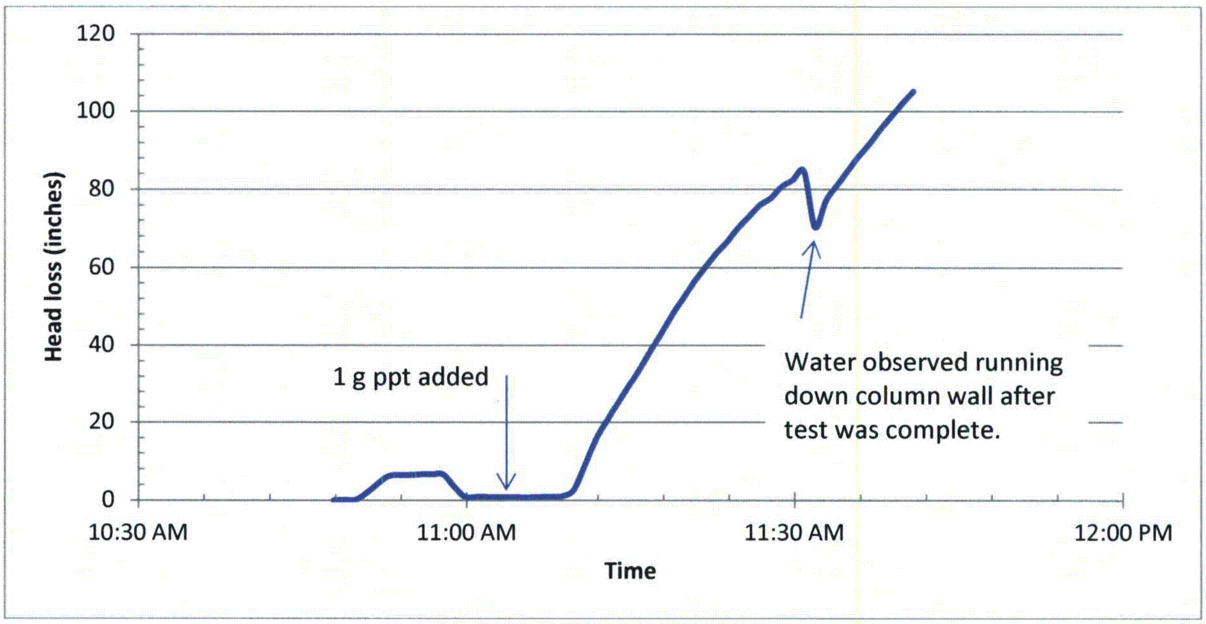

Figure 17: Head loss in Test 11 with fiber bed prepared with a blender and addition of WCAP precipitate.

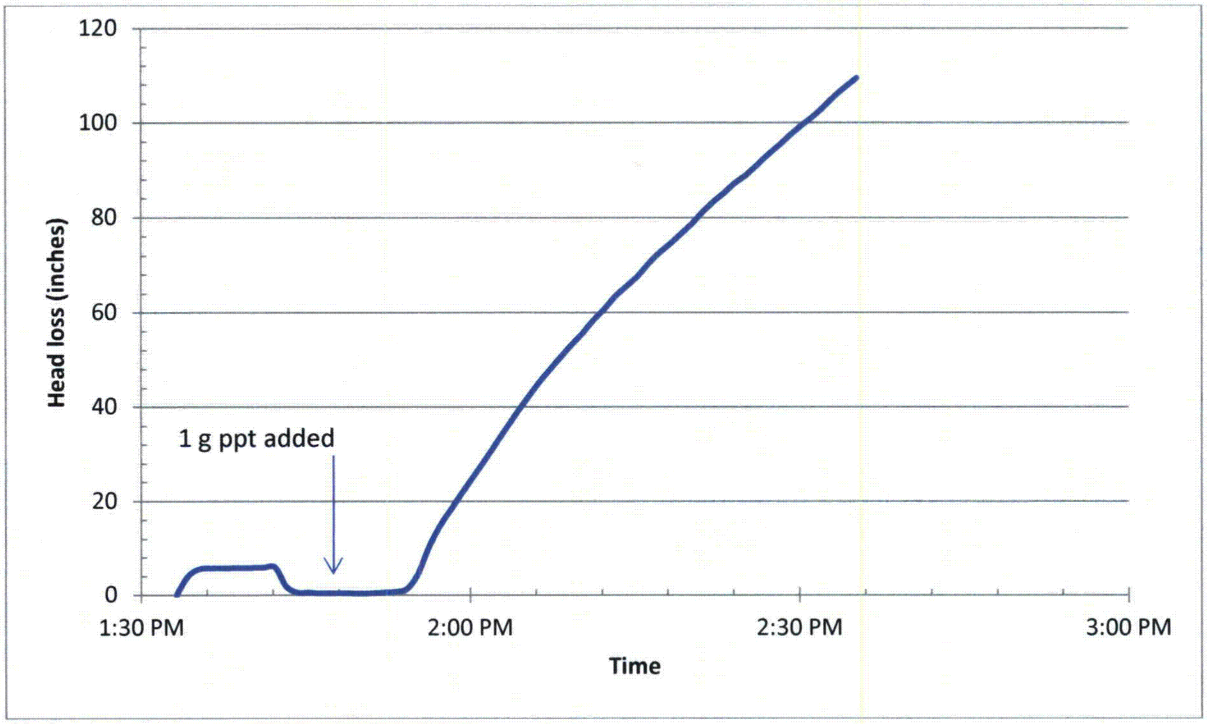

Figure 18: Head loss in Test 12 with fiber bed prepared with a blender and addition of WCAP precipitate.

Results: The results were essentially a repetition of Test 11, except that the fiber bed bypass did not occur. The head loss is shown in Figure 18. The results of Tests 11 and 12 demonstrate that the blendered bed is more sensitive to the presence of WCAP precipitates than the NEI preparation under these conditions.

Test 13: Nukon fiber prepared by NEI procedure, exposed to WCAP precipitates at high temperature from the corrosion tank

Date: 04 to 05 June 2012

Conditions: An 18 g fiber bed prepared with the NEI protocol was introduced into each of the 3 head loss columns. The approach velocity was set to 0.01 ft/s using a gear pump at each column. The flow to each column was recirculated at that velocity and room temperature overnight (about 16 hours). The corrosion tank was filled with water deionized by RO with boric acid and TSP added and heated to 165 °F (74 °C). This temperature was selected because it corresponds to the temperature at the first possible point of precipitation at the STP plant based on the WCAP calculations. Since the WCAP is a conservative procedure, it was determined to be the highest possible temperature at which precipitation can occur. The heated water from the tank was then directed to the three head loss columns by opening valves. After the heated water was allowed to circulate through the head loss column for an hour, batches of WCAP precipitate were introduced into the corrosion tank and allowed to mix thoroughly into the corrosion tank water. The corrosion tank has a pump that withdraws water, pumps it through external piping, and reintroduces it through a distribution header to keep the liquid in the corrosion tank well mixed. The supply piping for the head loss column is connected to the corrosion tank external piping. The WCAP precipitate was added in 30 g increments. The tank and columns contained 1,030 L of water, so each addition of WCAP precipitate corresponded to an addition concentration of 29 mg/L of precipitate.

Results: Between 7:00 PM on 4 June and 8:00 AM on 5 June (13 hours), the head loss through each of the 3 debris bed changed by less than 0.2 inches, indicating debris beds that were stable over time. It should be noted, however, that the head loss through an 18-g NEI-prepared fiber bed at 0.01 ft/s approach velocity is virtually zero.

After the hot, borated, buffered water was introduced into the head loss columns, the dP signal for the head loss columns became more variable. One of the dP cells was replaced and the signal became more reliable. After that, the high-side pressure line was purged on the other dP cells and they became more stable. It appears that the introduction of hot water into the columns may entrap air in the dP cell lines that cause instrument noise, but that purging the lines solves the issue.

WCAP precipitates were introduced in 3 batches, at 10:05 AM, 10:44 AM, and 11:52 AM. No increase in head loss was evident after the first two batches. The head loss started increasing in all three columns shortly after the third batch was introduced, as shown in Figure 19. Three batches of WCAP precipitate corresponds to a concentration of 57 mg/L of AlOOH in the CHLE corrosion tank, which would form from 25 mg/L of aluminum ions in solution. For comparison, the WCAP calculations for the STP plant predict the formation of 337 mg/L of precipitates (AlOOH and $NaAlSi_3O_8$ combined). Thus, the NEI bed formation procedure is able to detect WCAP precipitates in the CHLE corrosion tank at concentrations considerably lower than the levels predicted to occur in the STP plant by the WCAP calculation procedure.

The head loss in the 3 columns followed the same trend in terms of increasing head loss, but column 3 increased earlier than the other two (by about 20 minutes). This difference in response time could be because of natural variability in bed formation and capture of precipitates, or it could be because of minor hydraulic differences in the supply piping. A piping modification is going to be implemented to ensure that all three columns receive the same flow. Regardless of the slight difference in response time, the similarity in the response by all 3 columns demonstrates that the debris beds are reproducible and reliable for detecting WCAP precipitates.

The first batch of WCAP precipitate resulted in a concentration below the solubility limit for aluminum hydroxide at the temperature of the test, so it was not known whether the precipitates would dissolve upon being added to the hot water. The turbidity was measured periodically and confirmed that the precipitates did not dissolve after they were formed within the timeframe of the experiment. The turbidity during the test is shown in Figure 20. A separate bench test after the experiment also confirmed that the WCAP precipitates do not rapidly (within the time frame of interest in these tests) dissolve in hot water after they are formed.

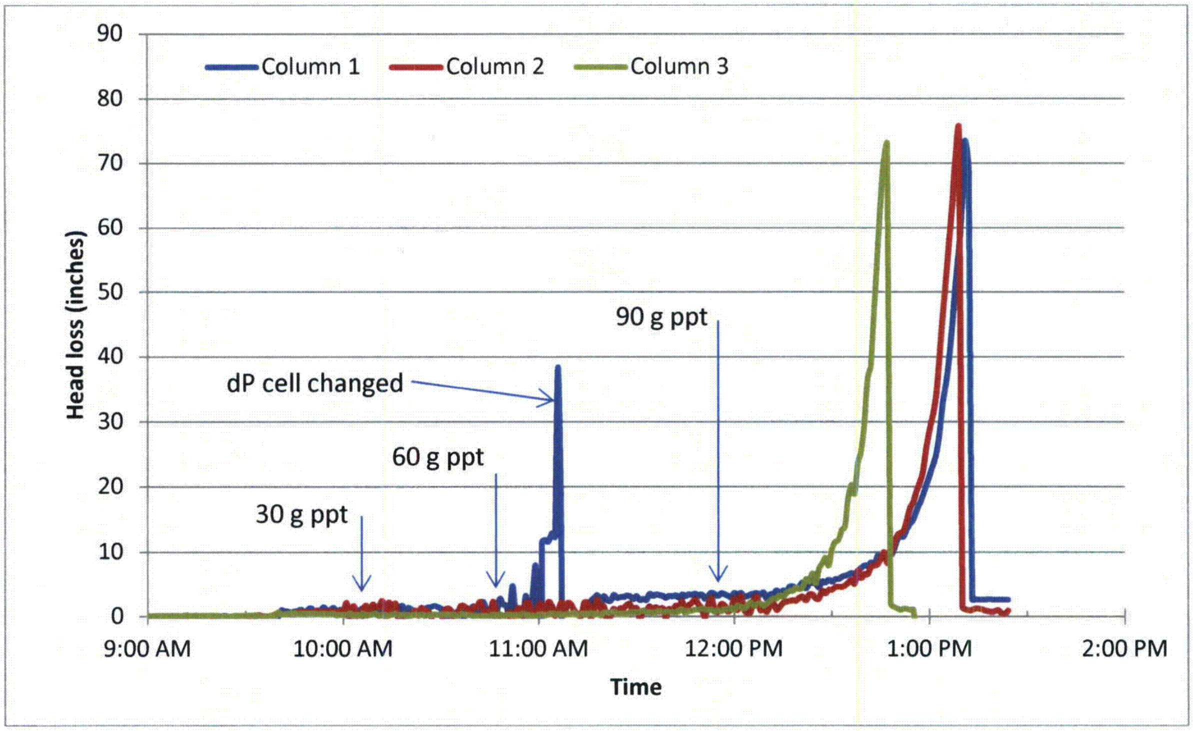

Figure 19: Head loss in Test 13 with 3 fiber beds prepared with the NEI procedure and WCAP precipitates added to the CHLE corrosion tank at 174 °F.

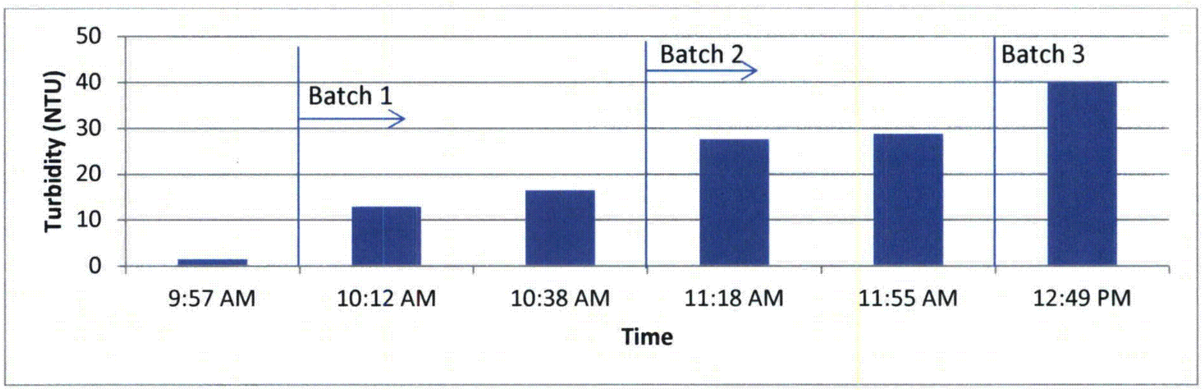

Figure 20: Turbidity in Test 13 with 3 fiber beds prepared with the NEI procedure and WCAP precipitates added to the CHLE corrosion tank at 174 °F.

Test 14: Nukon fiber prepared by blender, exposed to WCAP precipitates at high temperature from the corrosion tank

Date: 06 to 07 June 2012

Conditions: Test 14 was essentially a repeat of Test 13, except that the fiber beds were prepared by blender instead of the NEI protocol. Therefore, Tests 13 and 14 provide a comparison of fiber preparation methods for detecting WCAP precipitates in the CHLE corrosion tank. Because of problems with leaking head loss columns, the debris beds were prepared the morning of testing instead of the night before.

Results: Based on the expectation that the WCAP precipitate would cause a more rapid increase in head loss with the blended fiber bed than the NEI fiber bed (see Tests 11 and 12 compared to Tests 6 and 8), the WCAP precipitate was added in smaller batches than in Test 13. The first 4 batches were added in 7.5 g quantities and no significant increase in head loss was observed. The next batch added 20 g to the CHLE corrosion tank and a rapid increase in head loss was observed, as shown in Figure 21. The increase in head loss occurred when 50 g of WCAP precipitate had been added to the CHLE corrosion tank, which was less than when the NEI fiber preparation procedure was used, but not as significant as when the WCAP precipitates were added directly to the head loss columns at room temperature. In addition, the performance of the 3 columns was not as consistent as it was for the NEI fiber beds. In the NEI fiber bed test, the head loss increased in a very similar fashion in all 3 columns, whereas in this test, one of the columns (Column 2) appeared to develop a "bore hole" that cause the head loss to level off at about 45 inches of head, whereas the head continued to increase in the other two columns.

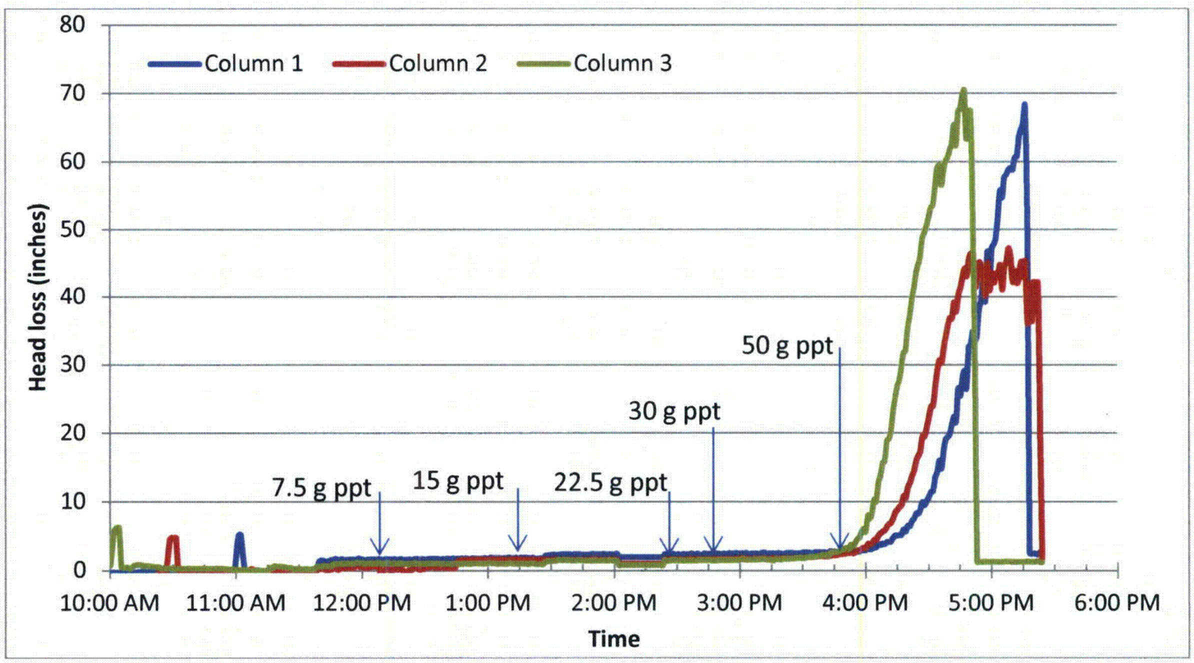

Figure 21: Head loss in Test 14 with 3 fiber beds prepared in a blender and WCAP precipitates added to the CHLE corrosion tank at 174 °F.