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SCE&G®
A SCANA COMPANY

December 17, 2010

U. S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555

Dear Sir / Madam:

Subject: VIRGIL C. SUMMER NUCLEAR STATION (VCSNS) UNIT 1
DOCKET NO. 50-395
OPERATING LICENSE NO. NPF-12
FOLLOW-UP RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION FOR GENERIC LETTER 2004-02

References:

1. SCE&G Letter RC-09-0134 (ADAMS Accession No. ML093360336) from Jeffrey B. Archie to Document Control Desk dated November 29, 2009, "Response to Request for Additional Information for Generic Letter 2004-02"
2. NRC Meeting Notes- "Summary of September 14, 2009 Public Conference Call to Discuss Responses to Generic Letter 2004-02 Requests for Additional Information (TAC No. MC4721) (ADAMS Accession No.ML093000573)
3. NRC Letter (ADAMS Accession No. ML090270927) to Jeffrey B. Archie dated February 3, 2009, "V. C. Summer Nuclear Station - Request for Additional Information for Generic Letter 2004-02 (TAC NO. MC4721)"
4. SCE&G Letter RC-08-0031 (ADAMS Accession No. ML080640545) from Jeffrey B. Archie to Document Control Desk dated February 29, 2008, "Supplemental Response to NRC Generic Letter 2004-02: Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors"

South Carolina Electric & Gas Company (SCE&G) hereby submits a response to address the commitments made in Reference 1 for the remaining open Requests For Additional Information (RAIs) related to Generic Letter 2004-02 with the exception of RAI No. 23. SCE&G provided a supplemental response to this generic letter per Reference 4 and the NRC issued a letter with a Request for Additional Information per Reference 3. A number of teleconferences were held over the ensuing months with resolution to most of the RAIs agreed upon. A draft of the RAIs resolution was provided for NRC staff review in August 2009 followed by a public teleconference on September 14, 2009 which is summarized in Reference 2. Follow-up telephone conversations were also held between the NRC and SCE&G to provide additional details on some of the RAIs. The draft RAI resolutions were then updated to reflect the NRC concerns and formally submitted on November 29, 2009 per Reference 1. The commitments made were to perform additional fiber loading testing, support NRC review of a Westinghouse WCAP and to perform chemical effects head loss testing. The attachments to this letter discuss each commitment and provide a response.

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With the submittal of this information, RAI No. 23 remains the only RAI without a response. As noted in previous letters, SCE&G plans to demonstrate for RAI No. 23 that the in-vessel downstream stream effects are addressed by the application of WCAP-16793-NP, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous, and Chemical Debris in Recirculating Fluid". However, this WCAP is still under NRC review. Therefore, within 90 days of issuance of the final NRC safety evaluation on this WCAP, SCE&G will respond to RAI No. 23.

There are no new commitments made in this letter.

Should you have questions, please call Bruce Thompson at (803) 931-5042.

I certify under penalty of perjury that the information contained herein is true and correct.

12/17/2010
Executed On

Robert M. Bulko for
Thomas D. Gatlin

GAR/TDG/jg
Attachments

c. K. B. Marsh
S. A. Byrne
J. B. Archie
N. S. Carns
J. H. Hamilton
R. J. White
W. M. Cherry
L. A. Reyes
R. E. Martin
NRC Resident Inspector
K. M. Sutton
NSRC
RTS (CR-04-02911)
FILE (815.14)
PRSF (RC-10-0165)

## SCE&G Commitments - Response to RAIs in Letter RC-09-0134

1. VCSNS will perform comparison testing between Marinite and TempMat to verify fiber loading and submit the tests results to the NRC. This commitment was to resolve concerns with RAI #6b.

2. VCSNS will meet with the NRC Staff at Westinghouse to review and discuss WCAP-16571-P, "Test of Pump and Valve Surface to Assess the Wear from Paint Chip Debris Laden Water for Wolf Creek & Callaway Nuclear Power Plants", July 2006. Schedule to be arranged based on NRC, VCSNS and Westinghouse personnel availability. This commitment was to resolve concerns with RAI #22.

3. VCSNS will perform plant specific chemical effects head loss testing and submit the results to the NRC. This commitment was to resolve concerns with RAIs #24, 25 and 26.

# Commitment #1

## Commitment #1 Response – Comparison Test between TempMat Loading and Marinite XL Loading

In resolving RAI #6B, SCE&G's position was the Marinite debris loading case would be limiting since it had more fiber mass, shorter fibers and calcium silicate. The NRC concern was that the Marinite fibers were small and may act more like particulate. The longer TempMat fibers could be limiting. SCE&G committed to perform confirmatory tests comparing Marinite and TempMat debris loads as a part of the scoping test program prior to the Chemical Effects test.

The comparison tests were completed on the AECL Rig 89 small scale chemical effects test rigs. The Rig 89 test facility consisted of 6 independent test loops. Each loop included a 16 in. × 16 in. × 36 in. strainer box (approximately 40 US gal) and a 12 in. diameter × 18 in. long cylindrical debris addition tank (approximately 9 US gal). Test modules were installed inside the strainer box. Installation is shown in Figure 1.

Fibrous and particulate debris were added through the debris-addition tank. The debris-addition tank was equipped with a paddle-type stirrer to keep the debris suspended, and mixed debris was slowly metered out through a manual valve on the pipe leading to the tank. The tank was bypassed during or after the debris addition.

Marinite debris load and testing conditions are listed in Table 1. TempMat debris load and testing conditions are listed in Table 2. Common debris loading for both Marinite and TempMat cases is listed in Table 3. The approach velocity used on the comparison tests was selected to match previous large scale tests. This provided a direct comparison with the prototypical test early in the scoping test program for scaling evaluations.

The test scaling factor was the ratio of the test module area to the available installed strainer area, and it applied to the test materials as well as the test flow rate. The scaling factor for the Marinite and TempMat scoping tests was based on a 1701 $ft^2$ (from Tables 1 and 2) available installed area and the test module area of 5.08 $ft^2$. The scaling factor for this case was 0.002986 (5.08/1701).

The paint chip loading was modeled as a reduction in strainer surface area. This was discussed with NRC staff and described in the RAI response letter RC-09-0134. Prototypical loading of paint chips on to the strainer surface could not be achieved in the small scale Rig 89 tests. The reduction in strainer surface area is a conservative test approach to bound actual plant debris loading conditions.

The Marinite debris load scoping test was started on April 12, 2010. The particulate and fibrous debris was added in one addition. The pressure drop quickly peaked at 2.3 psi. The pressure drop trace is shown in Figure 2. The TempMat debris load scoping test was run twice. In the first test, the pressure drop increased to 0.05 psi. Fiber was found wrapped around the debris mixing tank stirrer at 19 hours and reintroduced with little effect on pressure drop. In the second test, the pressure drop increased to 0.20 psi. Fiber was found wrapped around the debris mixing tank stirrer at 2 hours and reintroduced with little change. The pressure drop traces are provided in Figures 3 and 4.

## Commitment #1

The Marinite bed was consistent and resembled a filter cake with particulate build up as shown in Figure 5. The calcium silicate particulate collected on the strainer. The TempMat bed was consistent across the strainer surface, but had less particulate build up as shown in Figure 6. The longer, firm TempMat fibers developed a thin, more porous fiber bed. It held less particulate.

The test data clearly shows the Marinite debris loading is limiting. Examination of the debris beds is consistent with the pressure drop results. The TempMat debris loading case was run twice to confirm the results.

**Table 1**
**Marinite XL Debris Loading on Strainer B for Comparison Test**

| | |
|---|---|
| Screen size (Train B) | 2379 $ft^2$ |
| Sacrificial Area (75% of 220 $ft^2$) | 165 $ft^2$ |
| Paint Chip Allowance (75% of 684 $ft^2$) | 513 $ft^2$ |
| Available Surface Area | 1701 $ft^2$ |
| Velocity | 0.0075 ft/sec |
| Marinite Load | 8.58 $ft^3$ (395 lbs) |

**Table 2**
**TempMat Debris Loading on Strainer B for Comparison Test**

| | |
|---|---|
| Screen size (Train B) | 2379 $ft^2$ |
| Sacrificial Area (75% of 220 $ft^2$) | 165 $ft^2$ |
| Paint Chip Allowance (75% of 684 $ft^2$) | 513 $ft^2$ |
| Available Surface Area | 1701 $ft^2$ |
| Velocity | 0.0075 ft/sec |
| TempMat Load | 1.76 $ft^3$ (20.8 lbs) |

# Commitment #1

**Table 3**
**Common Debris Loading for Comparison Test**

| Debris Type | Quantity |
|---|---|
| Latent Fiber | 16 lb |
| Latent Particulate | 89 lb |
| Qualified Coatings | |
| Ameron 89 (epoxy) | 126 lb |
| Nu-Klad (epoxy) | 54 lb |
| Amercoat 66 (epoxy) | 6 lb |
| MobilZinc 7 (Inorganic zinc) | 352 lb |
| Nu-Klad (epoxy) | 343 lb |
| Unqualified Coatings | |
| Alkyd | 410 lb |
| Epoxy – Particulate | 24 lb |
| Inorganic Zinc | 233 lb |
| Cold Galvanizing Zinc | 17.4 lb |

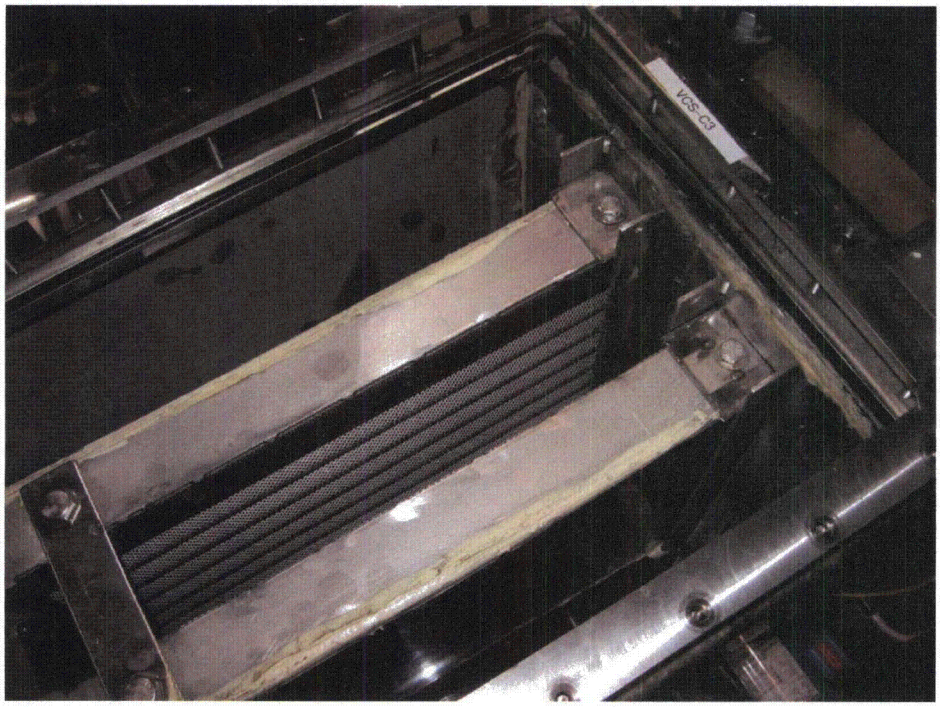


**Figure 1**
**Photo of Test Strainer Fins installed in Rig 89**

# Commitment #1

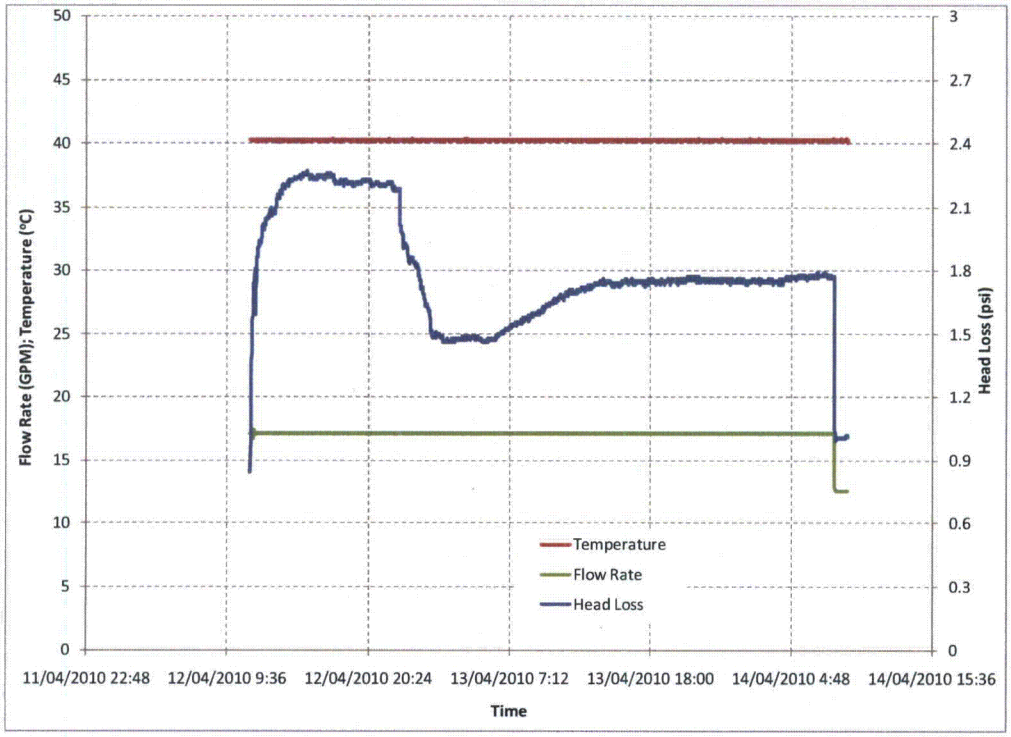


**Figure 2**
**VCS Marinite Debris Load Scoping Test 1 Head Loss vs. Time Curve.**

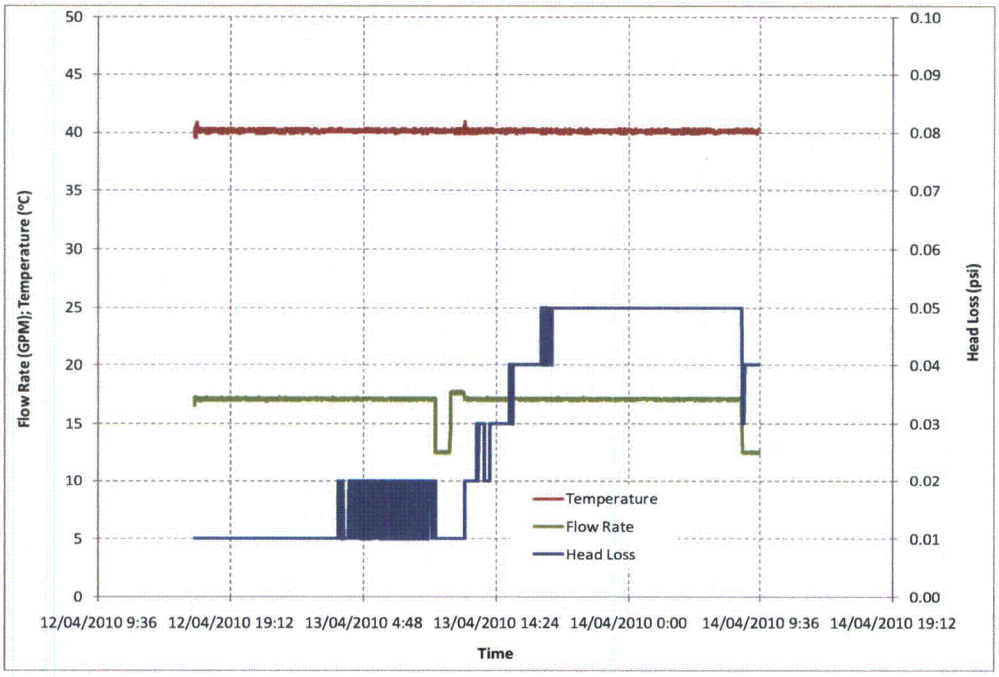


**Figure 3**

**TempMat Debris Load VCS Scoping Test 2 Head Loss vs. Time Curve**

## Commitment #1

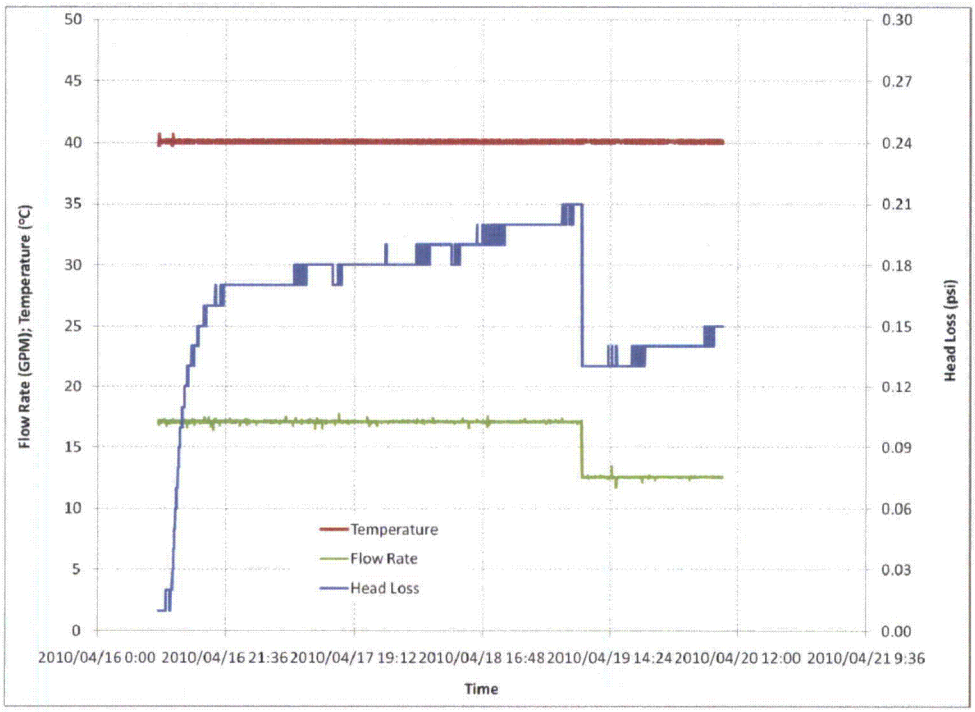


**Figure 4**
**TempMat Debris Load VCS Scoping Test 3 Head Loss vs. Time Curve**

**Figure 5**

**Marinite Debris Bed from Scope Test 1**

## Commitment #1

**Figure 6**

**TempMat Debris Bed from Scope Test 3**

# Commitment #2

## Commitment #2 Response – NRC review of Westinghouse Proprietary WCAP-16571-P

SCE&G applied WCAP-16406 methodology for downstream effects augmented by WCAP-16571-P. WCAP-16571-P was based on testing run with paint particulate which resulted in lower wear rates. Since WCAP-16571-P had not been reviewed by the NRC staff, a request was made to make the proprietary WCAP available for review.

WCAP-16571-P was provided for NRC review in March 2010 at the Westinghouse office in Bethesda, Maryland. Mr. Ervin Geiger reviewed WCAP-16571-P and issued a report (ML100920035) approving the application of WCAP-16571-P for the V.C. Summer downstream effects.

# Commitment #3

## Commitment #3 Response – Chemical Effects Test

The Chemical Effects Test was run on the AECL Rig 89 loop. This is the same test loop used for the Dominion Generation plants reviewed by the NRC staff (ML090410618). The test protocol was informally provided for review prior to the test. Comments from the staff were incorporated (for example, test flow rate was controlled at 19.74 gpm instead of 19.7 gpm to properly scale the flow to 7500 gpm). Pertinent details of the non-chemical debris load, chemical (aluminum) debris load, test protocol, test results and impact on analysis are covered in the following sections.

**Debris Loading**

The Marinite XL debris and latent debris is the same as provided in the supplemental response letter RC-08-0031 in February 2008. The debris loading for qualified and unqualified coating has been updated.

The update to the qualified coating debris generation was a shift in the operating margin for degraded qualified coating. The debris generation includes an operating margin of 500 $ft^2$ of degraded Level 1 epoxy coating. In the supplemental response (RC-08-0031), this was assumed to be on a concrete wall with an epoxy surfacer and epoxy top coat. This has been revised to 300 $ft^2$ on a concrete wall with an epoxy surfacer and epoxy top coat and 200 $ft^2$ on a metal surface with a zinc undercoat and epoxy top coat. The change was made to better reflect outage experience with degraded coatings.

The unqualified coatings debris load has been reduced. Documentation was located to confirm Level 1 coatings application on the internals lift rig. The internals lift rig was supplied by Westinghouse with an unqualified epoxy coating. The lift rig was removed from the reactor building and inspected in 1986. During this time, the coatings were stripped off and a new Level 1 coating was applied. The Quality Control paperwork to document the application was recovered during the scoping tests, prior to the Chemical Effect test. The unqualified epoxy top coat debris generation is reduced from 7363 $ft^2$ to 5918 $ft^2$. The unqualified zinc changes from 233 lbs to 68 lbs.

The particulate for epoxy topcoat, zinc undercoat and epoxy surfacer, is 100% transportable. The transport of epoxy paint chips is based on the detailed information supplied to resolve RAI #4 in letter RC-09-0134. The debris loading for the chemical effects test is provided in Table 4.

An appropriate means to prototypically test actual paint chip loading could not be developed using the small scale Rig 89 test loops. As discussed in the RAI response (RC-09-0134), a conservative modeling approach was taken. Similar to latent debris such as tape, the area of the sump strainer was decreased by 75% of the total paint chip surface area. The strainer surface area was scaled as follows (note the B train strainer is limiting).

| | |
|---|---|
| Train B Strainer Surface Area | 2379 $ft^2$ |
| Sacrificial Area (75% of 200 $ft^2$) | -150 $ft^2$ |
| Paint Chips (75% of 398 $ft^2$) | -299 $ft^2$ |
| Total Available Surface Area | 1930 $ft^2$ |

# Commitment #3

| Table 4<br>Chemical Effects Test Debris Loading | |
|---|---|
| Debris Type | Debris Quantity |
| Latent Debris | |
| Latent Fiber | 16 lb |
| Latent Particulate | 89 lb |
| Sacrificial Area (75% of 200 $ft^2$) | 150 $ft^2$ |
| Marinite XL | 8.58 $ft^3$ |
| Paint Chips | 398 $ft^2$ |
| Qualified Coatings (particulate) | |
| Ameron 89 (epoxy) | 126 lb |
| Nu-Klad (epoxy) | 54 lb |
| Amercoat 66 (epoxy) | 6 lb |
| MobilZinc 7 (Inorganic zinc) | 384 lb |
| Nu-Klad (epoxy) | 206 lb |
| Unqualified Coatings | |
| Alkyd | 410 lb |
| Epoxy – Particulate | 20 lb |
| Inorganic Zinc | 68 lb |
| Cold Galvanizing Zinc | 17.4 lb |
| Total Epoxy Particulate | 412 lb |
| Total Alkyd Particulate | 410 lb |
| Total Zinc Particulate | 469.4 lb |

**Chemical Debris Load**

The chemical debris loading (aluminum) was calculated by AECL. The sump aluminum release was calculated using aluminum inventory and the corresponding aluminum release contributions developed by AECL. The aluminum inventory includes 100 $ft^2$ surface area margin for future operation. The calculation below uses maximum long-term sump pH of 8.5 and maximum short-term spray pH of 10.5.

| Location | Duration | Surface Area | pH | Aluminum Load |
|---|---|---|---|---|
| Submerged | 40 days | 6.3 $ft^2$ | 8.5 | 161 g |
| Sprayed | 2 hours | 320 $ft^2$ | 10.5 | 5138 g |
| Sprayed | 40 days | 320 $ft^2$ | 8.5 | 6884 g |
| Total Aluminum Load | | | | 13,183 grams |

This total is slightly higher than reported in the test protocol (13.0 kg). The temperature profile for the aluminum corrosion rates is based on the maximum temperature profile for the EQ program. This profile includes a 10°F operating margin above the analytical maximum for future operating margin. The calculation conservatively uses the containment atmosphere temperature for the submerged aluminum even though the sump fluid temperatures are lower.

# Commitment #3

The strainer surface area is 1930 $ft^2$ (179.3 $m^2$). The total loading per square foot of strainer surface area is:

Strainer Aluminum Loading = 13,183 grams / 1930 $ft^2$
= 6.83 grams / $ft^2$ (73.5 grams / $m^2$)

**Test Protocol**

Prior to running the chemical effects tests, several scoping tests were run to support development of the test protocol. Three scoping tests were run to confirm the Marinite debris load case was limiting as previously discussed in this letter. Scoping tests 4, 5 and 6 were also run to evaluate repeatability, the potential for adding paint chips for prototypical testing and evaluating Rig 89 pressure drops relative to the large scale (Rig 85) prototypical tests previously completed.

Scoping Tests 4, 5 and 6 were performed based on the debris load listed in Table 4. Paint chip allowance (75% of total chip surface area) area was deducted from the effective strainer area for Scope Tests 4 and 6, while real paint chips were used in Scope Test 5. The flow rate was set at 19.74 USGPM for Scope Tests 4 and 6 to simulate fluid approach velocity of 0.0087 ft/sec. For Scope Test 6, the fluid approach velocity was 0.0075 ft/sec because real paint chips were added to the test rig. All tests were run at 40°C (~104°F).

The peak pressure drop reached 1.4 psi for Scope Test 4. At the end of the test, it was measured that approximately 85% of debris had settled on the test section. The head loss versus time curve is shown in Figure 7.

For Scope Test 5 (which used paint chips), the peak head loss was 1.1 psi. At the end of the test, it was measured that approximately 64% of debris settled on the test section. All of the paint chips were observed settled on the floor, which was not prototypical as compared to the large-scale test where some paint chips were found attached to the strainer surface as well as on the floor. The head loss versus time curve is shown in Figure 8.

The initial phase of Scope Test 6 was a repeat of Scope Test 4. The peak pressure with the same debris load, flow rate and temperature was 1.25 psi. This demonstrates repeatability within approximately 10%. After the initial phase to confirm repeatability, the flow rate was reduced to 17.1 gpm to simulate an approach velocity of 0.0075 ft/sec. This is the same velocity as the large scale prototypical tests. An additional 0.5 lb of Marinite debris was added and the pressure drop increased to 1.6 psi. A second 0.5 lb of Marinite debris was added and the head loss increased to 2.1 psi. After the second Marinite addition, the total Marinite debris load for Scope Test 6 was 2.18 lbs (1.18 lbs + 2 x 0.5 lbs) which is 0.43 lb/$ft^2$. The large scale prototypical all particulate Test 2 has a Marinite load of 30.2 $ft^3$ (1389 lb) for 2229 $ft^2$ of surface area which is 0.62 lb/$ft^2$. The large scale Test 2 also had higher coating particulate load. The pressure drop was 1.92 psi. This demonstrated that the reduced-scale test protocol yields a conservatively high pressure drop as compared to the large-scale Rig 85 test. The head loss vs. time curve is shown in Figure 9.

# Commitment #3

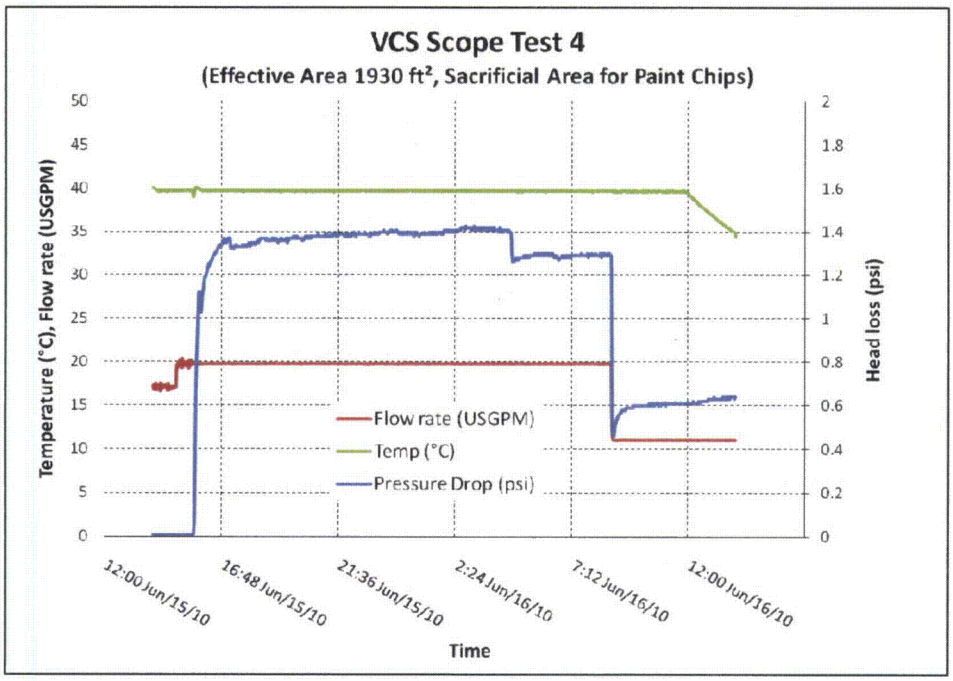


**Figure 7**
**Scope Test 4 Pressure Drop Versus Time**

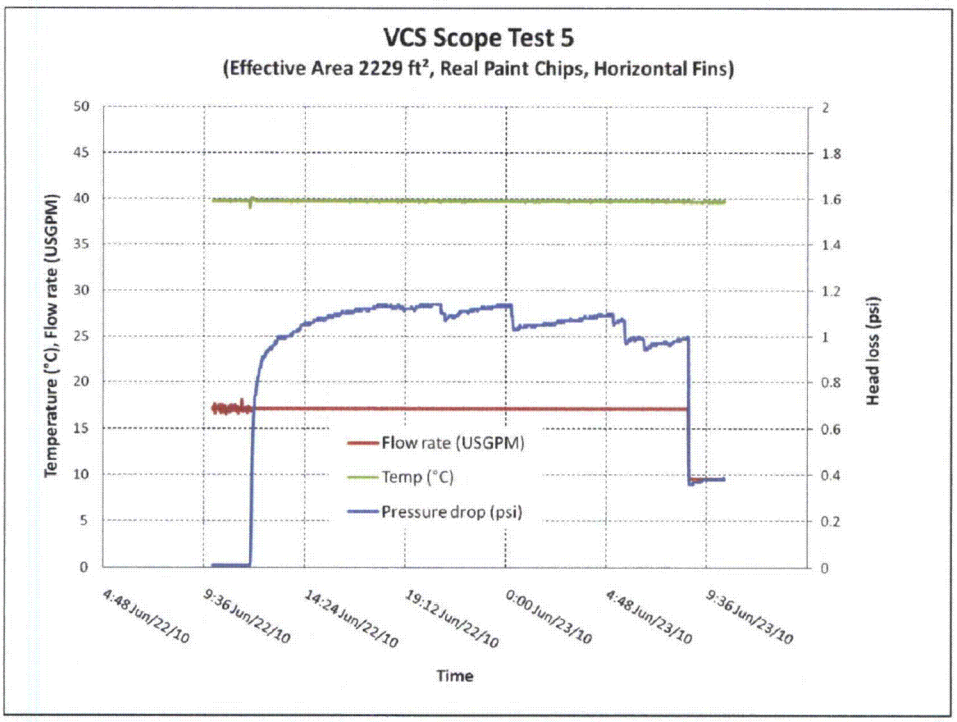


**Figure 8**
**Scope Test 5 Pressure Drop versus Time**

# Commitment #3

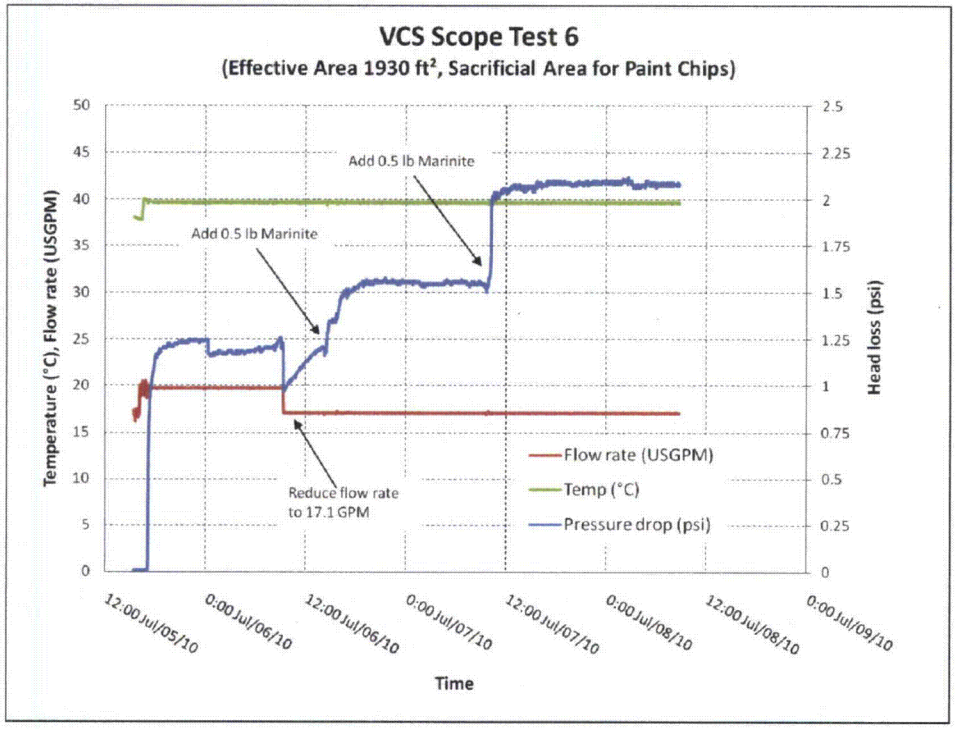


**Figure 9**
**Scope Test 6 Pressure Drop versus Time**

Based on the scoping tests, the following protocol was followed for the chemical effects test:

- The Marinite debris load case was the bounding case.
- Deduct paint chips allowance area from the effective strainer surface area for the chemical effects test instead of adding actual paint chips. By using this protocol, the head loss result was conservative as compared to the large-scale testing.
- Test module surface area 5.08 ft².
- Pressure-spray particulate debris mixture (Marinite dust, walnut shell flour and zinc powder) for three minutes using loop water. Add fibrous debris to the mixture and manually mix for 3 minutes.
- Add debris mixture to the test rig in one addition.
- Debris is maintained in suspension within the debris addition tank using a propeller-type stirrer.

The B train strainer is limiting with a surface area of 2379 ft$^2$. This surface area is reduced to account for both the sacrificial area and the paint chip loading prior to scaling the test debris load.

| | |
|---|---|
| Train B Strainer Surface Area | 2379 ft$^2$ |
| Sacrificial Area (75% of 200 ft$^2$) | -150 ft$^2$ |
| Paint Chips (75% of 398 ft$^2$) | -299 ft$^2$ |
| Total Available Surface Area | 1930 ft$^2$ |

## Commitment #3

The strainer test screen surface area is 5.08 $ft^2$. The scaling factor is therefore

Scaling Factor = 5.08 $ft^2$ / 1930 $ft^2$ = 0.002632

The debris loading scaled to the Rig 89 test is detailed on Table 5. The fiber, particulate and chemical debris additions for the chemical effects tests of the Rig 89 test loop are provided in Table 6. The chemical debris loading exceeds the design basis load to characterize the strainer performance. The design basis pressure drop with chemical debris loading is detailed with the discussion of the test results later in this letter.

**Table 5**
**Debris Load for Rig 89 Testing Based on 1930 $ft^2$ Effective Strainer Fin Area**

| Station Debris | | | | Test Debris | | | | |
|---|---|---|---|---|---|---|---|---|
| Type | | Quantity | As-fabricated Density | Scaling Factor | Scaled Volume | Type | As-fabricated Density | Test Debris Mass |
| Latent Fiber | | 16 lb | 2.4 $lb_m/ft^3$ | 5.08/1930 = 0.00263 | 30.2 $in^3$ (495.5 $cm^3$) | NuKon | 2.4 $lb_m/ft^3$ | 0.042 $lb_m$ (19.1 g) |
| Marinite Board Dust | | 8.58 $ft^3$ | 46 $lb_m/ft^3$ | | 39.1 $in^3$ (640.2 $cm^3$) | Marinite Sawdust | 46 $lb_m/ft^3$ | 1.04 $lb_m$ (471.7 g) |
| Epoxy Paint | Nu-Klad | 260 lb | 132 $lb_m/ft^3$ | | 16.2 $in^3$ (266 $cm^3$) | 325-Mesh Walnut Shell | 81 $lb_m/ft^3$ | 0.761 $lb_m$ ( 345.2 g) |
| | Amercoat 66 | 6 lb | 125 $lb_m/ft^3$ | | | | | |
| | Other | 146 lb | 94 $lb_m/ft^3$ | | | | | |
| Alkyd Paint | | 410 lb | 98 $lb_m/ft^3$ | | 19 $in^3$ (311.8 $cm^3$) | 325-Mesh Walnut Shell | 81 $lb_m/ft^3$ | 0.892 $lb_m$ (404.6 g) |
| Latent Particulate | | 89 $lb_m$ | 169 $lb_m/ft^3$ | | 2.4 $in^3$ (39.2 $cm^3$) | 325-Mesh Walnut Shell | 81 $lb_m/ft^3$ | 0.112 $lb_m$ (50.8 g) |
| Zinc Particulate | | 469.4 lb | 457 $lb/ft^3$ | | 4.7 $in^3$ (76.8 $cm^3$) | Zinc Powder | 457 $lb_m/ft^3$ | 1.24 $lb_m$ (562.5 g) |

# Commitment #3

**Table 6**
**Chemical Effects Test Debris Additions**

| Addition Type/Event | Temperature | Description |
|---|---|---|
| Establish Chemical Environment | 60°C | 3.02 kg $H_3BO_3$<br>240 L deionised water<br>NaOH as needed for pH 7.5(approx. 31 g) |
| Particulate and Fibrous Debris Addition | 60°C | 471.7 g Marinite sawdust<br>801 g walnut shell<br>562.5 g zinc powder<br>19.1 g NuKon |
| Aluminum Addition #1 | 60°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 0.9 g/m$^2$ Al |
| Aluminum Addition #2 | 60°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 6.1 g/m$^2$ Al |
| Aluminum Addition #3 | 60°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 11.4 g/m$^2$ Al |
| Aluminum Addition #4 | 60°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 16.7 g/m$^2$ Al |
| Aluminum Addition #5 | 60°C | 1.8 g Al (~6.6 g $NaAlO_2$) Strainer Load: 20.4 g/m$^2$ Al |
| Aluminum Addition #6 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 29.8 g/m$^2$ Al |
| Aluminum Addition #7 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 35.1 g/m$^2$ Al |
| Aluminum Addition #8 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 40.4 g/m$^2$ Al |
| Aluminum Addition #9 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 45.7 g/m$^2$ Al |
| Aluminum Addition #10 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 51.0 g/m$^2$ Al |
| Aluminum Addition #11 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 56.3 g/m$^2$ Al |
| Aluminum Addition #12 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 61.6 g/m$^2$ Al |
| Aluminum Addition #13 | 40°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 66.9 g/m$^2$ Al |
| Aluminum Addition #14 | 40°C | 2.65 g Al (~9.7 g $NaAlO_2$) Strainer Load: 72.5 g/m$^2$ Al |
| Aluminum Addition #15 | 20°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 77.8 g/m$^2$ Al |
| Aluminum Addition #16 | 20°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 83.1 g/m$^2$ Al |
| Aluminum Addition #17 | 20°C | 2.5 g Al (~9.3 g $NaAlO_2$) Strainer Load: 88.4 g/m$^2$ Al |
| Aluminum Addition #18 | 20°C | 2.2 g Al (~8.1 g $NaAlO_2$) Strainer Load: 90.6 g/m$^2$ Al |

**Test Rig 89**

The Rig 89 test facility consists of multiple single test loops. Each single test loop, as shown in Figure 10, includes a strainer box and a cylindrical debris addition tank. Test modules are installed inside the strainer box. Each test loop has the same configuration except that the strainer box orientation and test module may differ; a horizontal strainer box was used for V.C. Summer chemical-effects testing (Figure 1).

The top side and bottom side of the strainer box have clear windows to observe the debris bed on strainer screens inside the box. Stainless steel tubes and Swagelok fittings connect the strainer box to other components of the loop. Each loop is capable of producing flow rates from 1 to 30 US gpm (1.9 L/s). Flow rates can be adjusted via a variable frequency drive. A magnetic flow meter is installed to provide feedback for constant flow-rate control.

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Each loop is equipped with a 6-kW in-line stainless-steel heater to provide heating to a maximum temperature of 140°F (60°C). Cooling is provided by an in-line stainless-steel cooler using service water and is dependent on seasonal variations in river water temperature. Two temperature reductions were performed during the V.C. Summer chemical-effects test; the first, on 2010 Aug 27 from 60°C to 40°C, did not require service water; the second, on 2010 Sep 13 from 40°C to 20°C, required service water and the 20°C set point was achieved.

Non-chemical debris including fiber and particulate were added through the debris-addition tank. The debris-addition tank is equipped with a paddle-type stirrer to keep the debris suspended, and mixed debris was slowly metered out through a manual valve on the pipe leading to the tank. The tank can also be bypassed during or after debris addition, though this was not necessary. Chemical solutions were added via the chemical injection point using a metering pump.

The loop is instrumented with a thermocouple (TE-1) to measure the water temperature and a flow meter (FT-1) to measure the flow rate through the test loop. The strainer box is instrumented with a differential pressure transmitter (PDT-1) for measuring the debris-bed pressure drop. The test facility instrumentation is listed in Table 7. The pump speed, heater and cooler were controlled by a Programmable Logic Controller (PLC) during the test. The water temperature and flow rate, and the debris-bed pressure drop were monitored and recorded by the PLC. Monitoring of pH was via grab samples.

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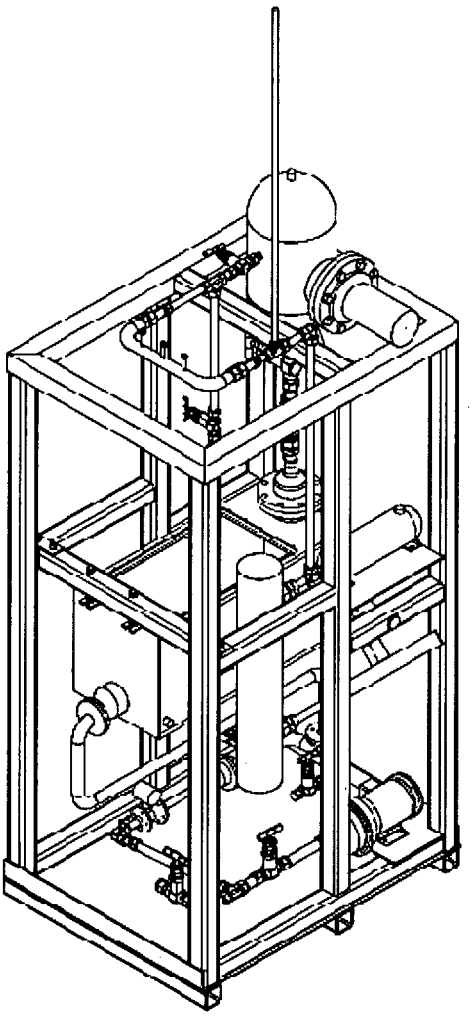

Figure 10
AECL Rig 89 Test Loop

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**Table 7**
**Test Facility Instrumentation**

| Equipment ID (Label) | Description | Model | Calibrated Range | Accuracy | Calibration Date | Calibration Due Date |
|---|---|---|---|---|---|---|
| 456-2619 (TE-1) | Thermocouple | T-Pak | 21 – 125°C | ±1.1°C or 0.4% | 2010 Mar | 2011 Mar |
| B14155 (FT-1) | Flow Meter | Yokogawa | 1 – 30 US gpm | ±3% of FS | 2009 Dec | 2011 Dec |
| B14163 (PDT-1) | Differential Pressure Transmitter | Yokogawa | 0 – 400 in. $H_2O$ | ±0.075% of FS | 2010 Mar | 2011 Mar |
| FS0993 | Balance | Ohaus | 0 – 60 lbm | ±0.01% of FS | 2010 Mar | 2011 Mar |
| 456-0575 | Balance | Mettler AE-200-S | 0 – 200 g | ±0.5 mg | 2010 Mar | 2011 Mar |

**Chemical Effects Test**

The chemical-effects test was conducted in Rig 89, a multi-loop test facility at AECL's Chalk River Laboratories designed specifically for chemical-effects testing. The test loop was fitted with a strainer test module with identical pitch, perforation and corrugation bend angle as the installed strainer. The test loop flow rate and strainer fin area were chosen to scale the installed strainer, as were test debris including precipitants. Once the debris bed was established, sodium aluminate (an aluminum precipitant) was added to the test rig in a series of 17 aluminum additions spanning three temperatures: 60°C (140°F), 40°C (104°F) and 20°C (68°F). While the assessed sump aluminum release was conservatively calculated, the amount of aluminum precipitant added exceeded the assessed quantity in order to gain a better understanding of the behavior of the system. The different test temperatures were used to obtain information regarding aluminum solution stability with respect to precipitation as well as the relationship between fluid viscosity and debris bed head loss. The temperature transitions mark the division of the test into three parts: Part A at 60°C (140°F), Part B at 40°C (104°F) and Part C at 20°C (68°F).

The fibrous and particulate debris were prepared and added to ~35 L of water (solution) removed from the debris addition tank. Fibrous debris was separated into single fine. Figure 11 presents photographs of the debris bed formed on the test module.

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**Figure 11**

**Photograph of debris bed formed on V.C. Summer Rig 89 strainer module. These photographs were taken 2010 September 3 around 08:00h.**

Table 8 describes the chemical environment chosen for the testing. A pH of 7.5 was chosen because it gives the minimum for aluminum hydroxide solubility over the expected pH range (7.5-8.5).

**Table 8**
**Chemical Environment for Rig 89 Chemical-Effects Testing**

| Species | Concentration[(a)] | Chemical | Quantity[(b)] |
|---|---|---|---|
| B | 2200 ppm | $H_3BO_3$ | 3.02 kg |
| pH | pH = 7.5 at 25°C | $HNO_3$ and/or NaOH | As needed |

Note: (a) Nominal boron concentration for chemical-effects test.
(b) The quantities of chemicals were based on a total test rig volume of 240 L, which includes 30 L in the head tank.

Solutions of sodium aluminate at concentrations of less than 200 mg/L Al were added to the test rig via the chemical injection point in multiple additions to obtain a profile of pressure drop with respect to aluminum precipitated. The test was divided into three parts: Part A was conducted at 60°C, Part B at 40°C and Part C at 20°C. The additions where made consistent with the test protocol as detailed on Table 6. Part C of the test was stopped prior to the last addition, however the total strainer aluminum load exceed the design basis load.

Each injection of sodium aluminate involved the removal of several liters of loop water (which were discarded). The sodium aluminate solutions were prepared by dissolving sodium aluminate in distilled water at concentrations less than 200 mg/L Al. Once dissolved, sodium aluminate hydrolyzes to form many species of aluminum: $Al(OH)_4^-$ (aq), $Al(OH)_3$ (aq), $Al(OH)^{2+}$, $Al(OH)^{2+}$ and $Al^{3+}$. The near-neutral pH of the boric acid-buffered loop water makes it unsuitable for dissolving sodium aluminate, as the solubility of aluminum hydroxide ions is low under those chemistry conditions. The result of using distilled water and discarding loop water is two-fold: the injected solution has a high pH (around pH 11) and the boric acid concentration in the loop

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is reduced. Therefore, following each injection, the boric acid concentration was increased by adding boric acid to small volumes of loop water and injecting the concentrated solution. The combination of high-pH sodium aluminate injections and low-pH boric acid injections had a levelling effect on the pH such that pH adjustments were not necessary during the testing once pH 7.5 had been established. The quantity of aluminum removed with discarded water was accounted for in the final debris load calculations.

V.C. Summer chemical-effects testing commenced on August 19, 2010. The test rig was cleaned with hypochlorite (bleach) solution and rinsed with distilled water. Following this, the test loop was filled with a solution containing 3.02 kg boric acid ($B(OH)_3$) and 31 g NaOH. The pH of this solution was 6.43. The pump was then started and the flow rate set to 19.74 USGPM. The heater was turned on and set to 60°C (140°F).

The fiber and particulate debris was added to the debris addition tank. The clean strainer head loss was 0.01 psi. Debris addition commenced at 1554. After debris addition, the head loss peaked at 1.23 psi at 0821 on 2010 August 20. The pressure drop versus time up to the first chemical addition is shown in Figure 12. The addition of debris increased the pH to 6.81. An addition of 0.38 g NaOH was made prior to the first sodium aluminate injection, which increased the pH to 6.83.

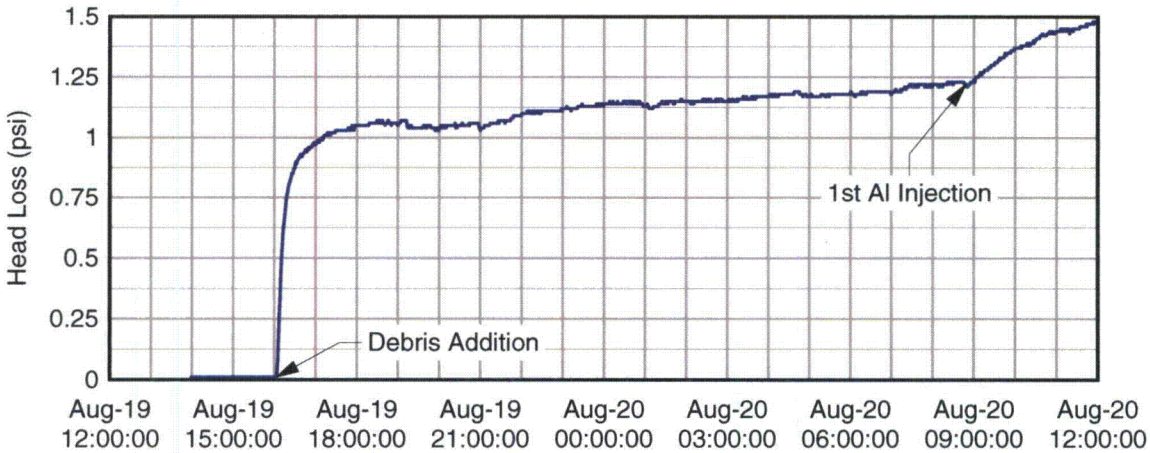


**Figure 12**
**Non-Chemical Debris Pressure Drop versus Time**

The first sodium aluminate injection commenced at 0846 on August 20, 2010 with the injection of 8.8 g $NaAlO_2$ in 13 L of distilled water. A loop water sample was also taken at that time; the measured aluminum concentration prior to the first addition was less than 0.4 mg/L Al, the method detection limit for ICP-AES at 10x dilution. The head loss of the strainer for the day of the first aluminum addition and the remainder of the weekend is shown in Figure 13. To compensate for the increase in loop volume, 13 L of loop solution was removed at 1247. A compensatory boric acid addition of 164 g $B(OH)_3$ was made commencing at 1316. The pH of the loop solution following injection at 1415 was pH 6.81 which was below the test protocol range. Subsequently, 300 g of NaOH were added commencing at 1430 to bring the pH to within

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specification. At 1518, the pH was within specification at pH 7.61. The pH remained within specification the remainder of the test.

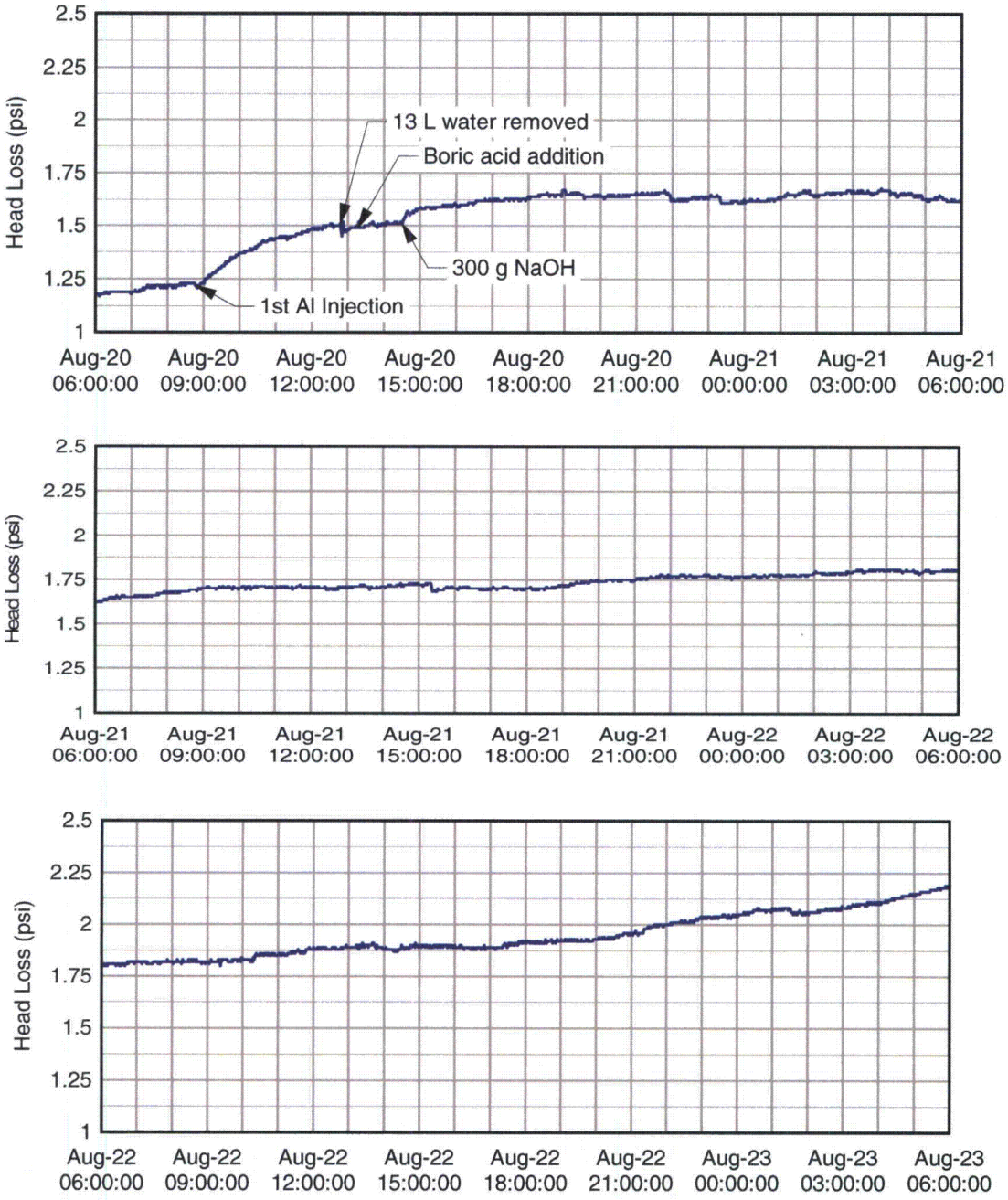


**Figure 13**

**Strainer head loss resulting from the 1st aluminum addition.**

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Prior to each injection, the last ½ hour of pressure drop data recorded by the PLC was analysed for stability. Additions were made once it had been verified that the pressure drop had changed by less than 5% or 0.01 psi (0.07 kPa), whichever was greater, and exhibited no general steadily increasing trend in pressure within that ½ hour. Prior to injections, samples of the loop water were taken for chemical analysis by ICP-AES.

The chemical additions continued over the next few weeks using the addition schedule provided on Table 6. After the first five additions, the temperature was lowered from 60°C to 40°C. After 9 more additions (14 total), a flow sweep was completed. Flow was decreased in 2 gpm increments down to 5.7 gpm and then back up in 2 gpm increments to 19.74 gpm. The temperature was then lowered to 20°C and a second flow sweep was completed. Three more chemical additions were made for a total of 17 chemical additions. This exceeded the design basis chemical effects debris load. While the test remained running additional aluminum loading data was collected in order to further characterize the debris bed response.

Test events and important test data are summarized in Table 9. Figure 14 shows the strainer head loss for the full duration of the test, and aluminum additions are indicated on the graph. Figure 15 through 18 are photographs of the strainer fins after the chemical additions. It is clear that the first 2 aluminum additions had the most dramatic impact on the strainer head loss, although the remaining 15 aluminum additions had a significant cumulative effect.

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## Table 9
## Test Summary Table: Aluminum Additions, Aluminum Concentrations, Strainer Head Losses and Temperatures

| Event | Date | $NaAlO_2$ Added (g) | Al Added (g)[a] | [Al] Added (mg/L)[b] | [Al] Prior (mg/L) | [Al] After (mg/L)[c] | Max Head Loss (psi) | Temperature (°C) | Volume Change (L) |
|---|---|---|---|---|---|---|---|---|---|
| Added debris | Aug 19 | | | | | | | | |
| 1st Al injection | Aug 20 | 8.8 | 2.5 | 10.4 | <0.4 | <0.4 (3 d) | 2.25 | 60 | +13/-13 |
| 2nd Al injection | Aug 23 | 8.8 | 2.5 | 10.4 | <0.4 | <0.4 (1 d) | 2.61 | 60 | +13/-8.5 |
| 3rd Al injection | Aug 24 | 8.8 | 2.5 | 10.4 | <0.4 | 2.1 (1 d) | 2.79 | 60 | -10/+17 |
| 4th Al injection | Aug 25 | 8.8 | 2.5 | 10.4 | 2.1 | 4.0 (1 d) | 2.87 | 60 | -17/+17 |
| 5th Al injection | Aug 26 | 6.4 | 1.8 | 7.5 | 4.0 | 5.1 (1 d) | 3.06 | 60 | -17/+17 |
| Temperature Reduction | Aug 27 | | | | 5.1 | 1.1 (3 d) | | 40 | |
| 6th Al injection | Aug 30 | 8.8 | 2.5 | 10.4 | 1.1 | 3.8 (1 d) | 3.21 | 40 | -12/+17 |
| 7th Al injection | Aug 31 | 8.8 | 2.5 | 10.4 | 3.8 | 4.5 (1 d) | 3.30 | 40 | -15/+17 |
| 8th Al injection | Sep 1 | 8.8 | 2.5 | 10.4 | 4.5 | 4.6 (1 d) | 3.37 | 40 | -12.5/+17 |
| 9th Al injection | Sep 2 | 8.8 | 2.5 | 10.4 | 4.6 | 4.7 (1 d) | 3.45 | 40 | -19/+17 |
| 10th Al injection | Sep 3 | 8.8 | 2.5 | 10.4 | 4.7 | 2.7 (4 d) | 3.52 | 40 | -18/+17 |
| 11th Al injection | Sep 7 | 8.8 | 2.5 | 10.4 | 2.7 | 4.6 (1 d) | 3.57 | 40 | -14/+17 |
| 12th Al injection | Sep 8 | 8.8 | 2.5 | 10.4 | 4.6 | 5.0 (1 d) | 3.64 | 40 | -17/+17 |
| 13th Al injection | Sep 9 | 8.8 | 2.5 | 10.4 | 5.0 | 4.9 (1 d) | 3.76 | 40 | -13/+17 |
| 14th Al injection | Sep 10 | 9.3 | 2.6 | 11.0 | 4.9 | 3.4 (3 d) | 3.85 | 40 | +17 |
| Flow Sweep #1 | Sep 13 | | | | 3.4 | 3.5 (5 h) | | 40 | -17 |
| Temperature Reduction | Sep 14 | | | | 3.5 | 1.5 (1 d) | | 20 | |
| Flow Sweep #2 | Sep 14 | | | | 1.5 | 0.9 (1 d) | | 20 | |
| 15th Al injection | Sep 15 | 8.8 | 2.5 | 10.4 | 0.9 | 2.3 (1 d) | 4.09 | 20 | +17 |
| 16th Al injection | Sep 16 | 8.8 | 2.5 | 10.4 | 2.3 | 3.4 (1 d) | 4.27 | 20 | -12/+17 |
| 17th Al injection | Sep 17 | 8.8 | 2.5 | 10.4 | 3.4 | 1.5 (1 d) | 4.40 | 20 | -17/+17 |

Notes:
(a) Calculated using the wt% of Al in $NaAlO_2$ (28.4 wt% Al).
(b) Calculated using a total loop volume of 240 L (this is a conservative estimate).
(c) This is the concentration of aluminum in the loop water measured after the event, with the length of time between the event and time the sample was taken for analysis indicated by the parenthesis.

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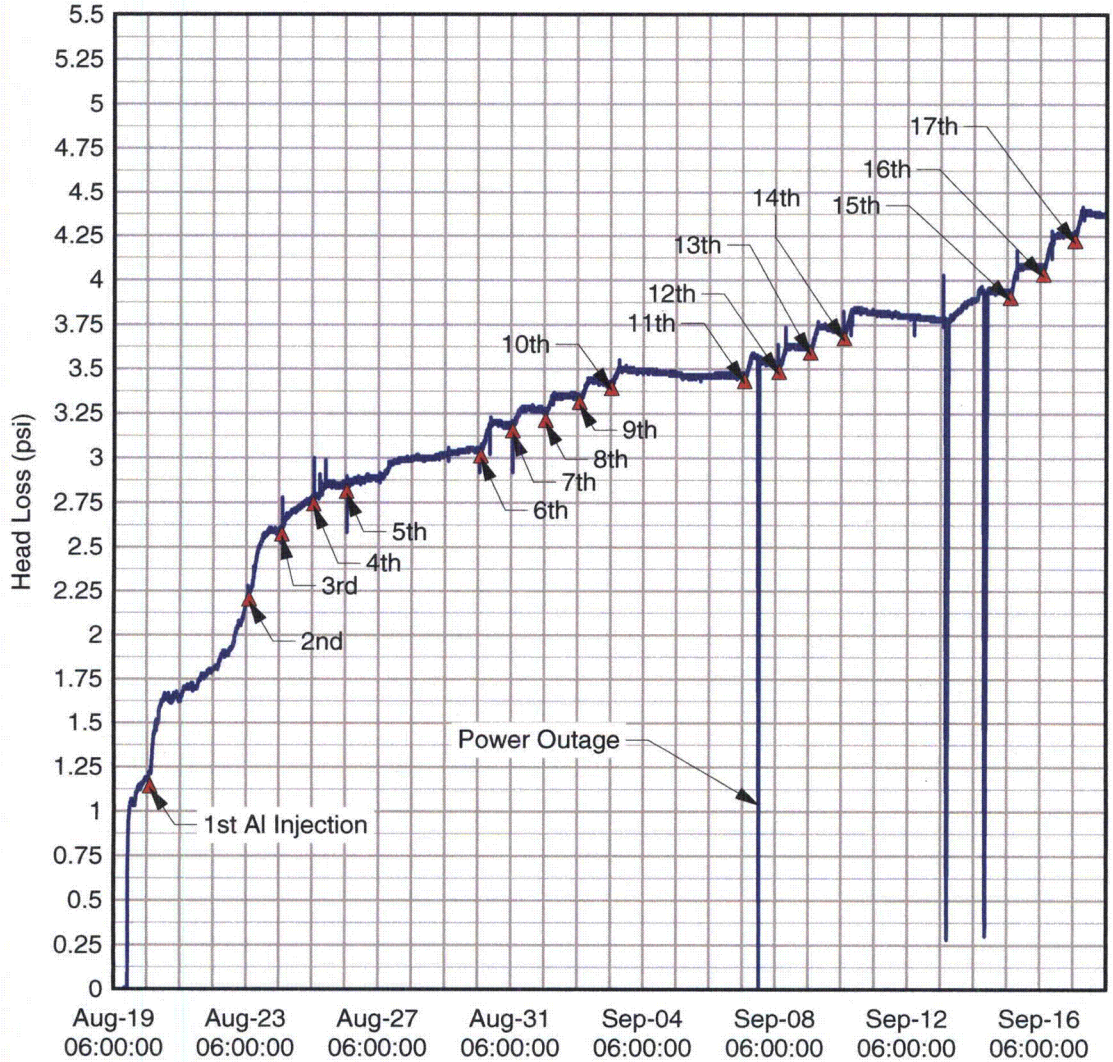


**Figure 14**
**Pressure Drop versus Time for the entire Chemical Effects Test**

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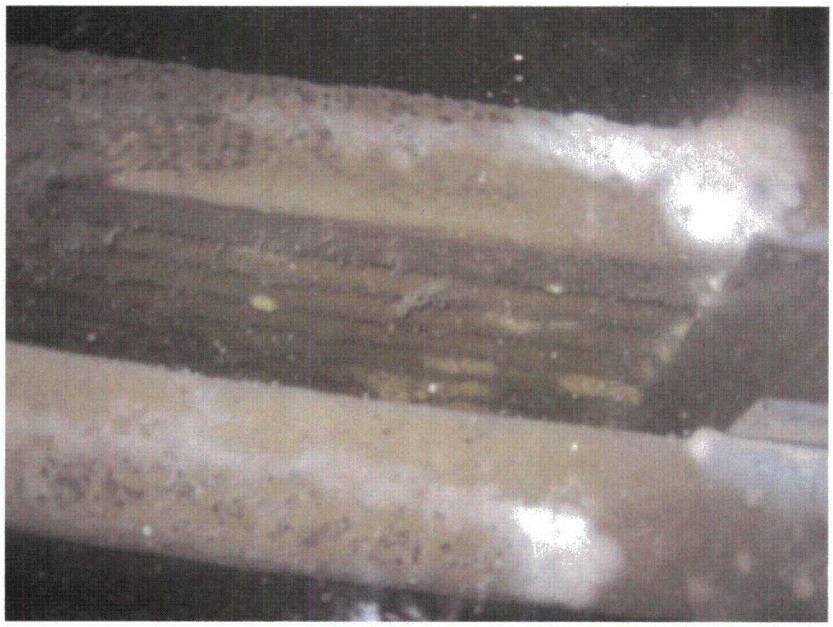

**Figure 15**
**Top view photograph of strainer debris bed taken 2010 September 7 after power outage.**

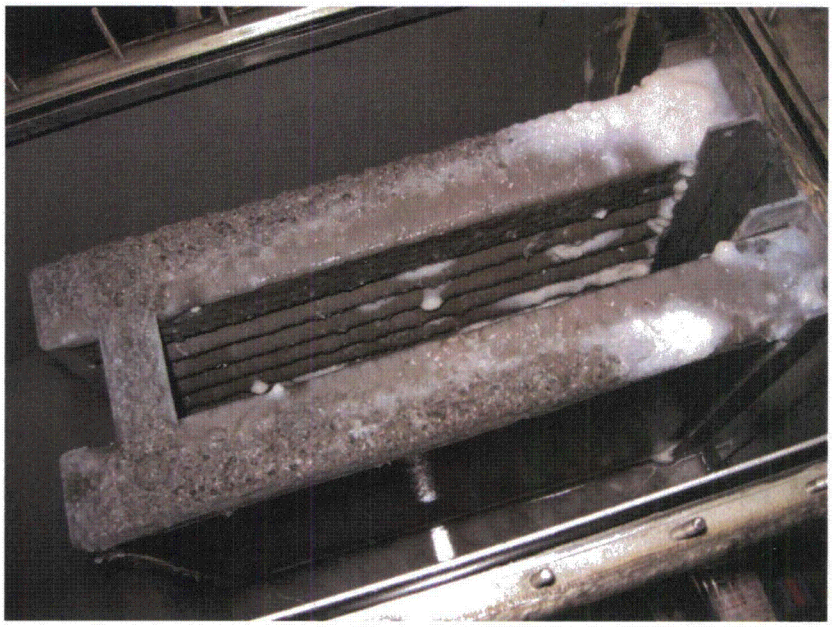

**Figure 16**
**Top view photograph after draining test loop on September 20, 2010.**

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**Figure 17**
**Side view of Fin 1 after draining the test loop.**
**Photograph taken 2010 September 20.**

**Figure 18**
**Side view of Fin 2 after draining the test loop.**
**Photograph taken 2010 September 20**

# Commitment #3

## Chemical Effect Test Results

Aluminum Concentration

The behavior of dissolved and suspended aluminum throughout the test was complex due to the addition of sodium aluminate and the precipitation of aluminum hydroxide. While each addition of sodium aluminate solution should have raised the concentration of aluminum in the test loop by about 10 mg/L Al, the highest concentration observed during the course of the testing was only 4.8 mg/L Al (Figure 19). As might be expected, the aluminum concentration was observed to decrease when the temperature was reduced. However, the aluminum concentration was also observed to decrease when additions ceased for a period of time (for example, over the weekends). In general, the aluminum concentration seldom exceeded 4.5 mg/L Al and seldom dropped below 1.0 mg/L Al.

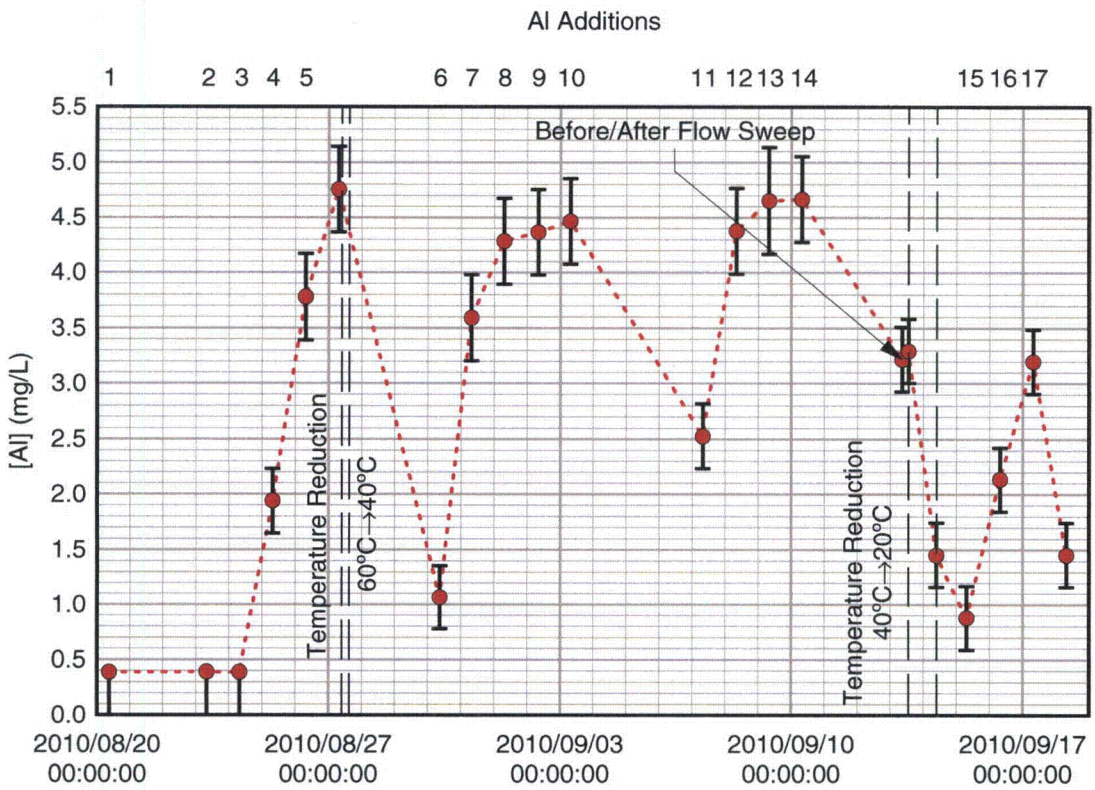


**Figure 19**
**Aluminum concentrations for the duration of the test. Symbols indicate the aluminum concentration. Error bars indicate twice the standard error in the value.**

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Assessment of Aluminum Load

*Strainer aluminum load* may be defined as the mass of aluminum precipitated per unit area of test strainer. To calculate the mass of aluminum precipitated, the mass of aluminum added is tallied, the mass of aluminum discarded by volume replacement is tallied, and the mass of aluminum suspended or dissolved in solution is accounted for. The equations used to calculate strainer aluminum load and mass of aluminum precipitated are as follows:

$$\text{Strainer Aluminum Load (g/m}^2) = \frac{\text{Mass of Aluminum Precipitated (g)}}{\text{Area of Test Strainer (m}^2)}$$

$$\text{Mass of Aluminum Precipitated (g)} = \sum \frac{\text{NaAlO}_2\text{ Added (g)}}{3.52\text{ g NaAlO}_2\text{ / g Al}} - \sum\left(\frac{V_{Discarded}\text{(L)}\times[\text{Al}]\text{ (mg/L)}}{V_{Rig\,89}\times 1000\text{ mg/g}}\right) - \frac{V_{Rig\,89}\times[\text{Al}]\text{ (mg/L)}}{1000\text{ mg/g}}$$

$V_{Discarded}$ is the volume of loop water discarded before an addition and $V_{Rig\,89}$ is the volume of water in the Rig 89 test loop, including head tank, and is assumed to be 240 L.

The strainer aluminum load is calculated in Table 10 for each addition. The aluminum concentration used for the discarded solutions depended upon when the solution was discarded: before or after an addition. The concentration of the loop water was measured before additions; the concentration of the loop water after an addition was not known, but for calculation purposes was assumed to be the expected concentration had none of the sodium aluminate precipitated. The aluminum concentration used to calculate the mass of aluminum suspended or dissolved was taken to be the concentration measured after each addition but before the next event (another addition, flow sweep, or test termination).

The strainer aluminum load is paired with the maximum head loss reached after each addition in Table 11. The viscosity-adjusted head loss is also given for each of the three test temperatures (60, 40 and 20°C) using: (this relationship is developed in a subsequent section of this letter).

$$\Delta p \propto \mu^{0.1}$$

As shown in Figure 20, a nearly linear relationship is formed between head loss and aluminum load.

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## Table 10
## Calculation of Strainer Aluminum Load after Each Addition

| Event | Al Added (g) | Accumulated Al Added (g) | Volume Discarded (L) | [Al] in Discarded Solution (mg/L)[a] | Al Discarded (g) | Accumulated Al Discarded (g) | [Al] After Addition (mg/L) | Al in Solution (g) | Al Precipitated (g) | Strainer Aluminum Load ($g/m^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1st Al injection | 2.50 | 2.50 | 13 | 10.4 | 0.14 | 0.14 | <0.4 (3 d) | 0.10 | 2.27 | 4.8 |
| 2nd Al injection | 2.50 | 5.00 | 8.5 | 10.4 | 0.09 | 0.22 | <0.4 (1 d) | 0.10 | 4.68 | 9.9 |
| 3rd Al injection | 2.50 | 7.50 | 10 | 0.4 | 0.01 | 0.23 | 2.1 (1 d) | 0.50 | 6.78 | 14.4 |
| 4th Al injection | 2.50 | 10.00 | 17 | 2.1 | 0.04 | 0.26 | 4.0 (1 d) | 0.97 | 8.77 | 18.6 |
| 5th Al injection | 1.82 | 11.82 | 17 | 4.0 | 0.07 | 0.33 | 5.1 (1 d) | 1.21 | 10.27 | 21.8 |
| 6th Al injection | 2.50 | 14.32 | 12 | 1.1 | 0.01 | 0.35 | 3.8 (1 d) | 0.92 | 13.06 | 27.7 |
| 7th Al injection | 2.50 | 16.82 | 15 | 3.8 | 0.06 | 0.40 | 4.5 (1 d) | 1.08 | 15.33 | 32.5 |
| 8th Al injection | 2.50 | 19.32 | 12.5 | 4.5 | 0.06 | 0.46 | 4.6 (1 d) | 1.11 | 17.75 | 37.6 |
| 9th Al injection | 2.50 | 21.82 | 19 | 4.6 | 0.09 | 0.55 | 4.7 (1 d) | 1.14 | 20.13 | 42.7 |
| 10th Al injection | 2.50 | 24.32 | 18 | 4.7 | 0.09 | 0.63 | 2.7 (4 d) | 0.64 | 23.04 | 48.8 |
| 11th Al injection | 2.50 | 26.82 | 14 | 2.7 | 0.04 | 0.67 | 4.6 (1 d) | 1.11 | 25.04 | 53.0 |
| 12th Al injection | 2.50 | 29.32 | 17 | 4.6 | 0.08 | 0.75 | 5.0 (1 d) | 1.19 | 27.4 | 58.0 |
| 13th Al injection | 2.50 | 31.82 | 13 | 5.0 | 0.06 | 0.81 | 4.9 (1 d) | 1.19 | 29.82 | 63.2 |
| 14th Al injection | 2.64 | 34.46 | 0 | | | 0.81 | 3.4 (3 d) | 0.81 | 32.83 | 69.6 |
| 15th Al injection | 2.5 | 36.96 | 17 | 3.4 | 0.06 | 0.87 | 2.3 (1 d) | 0.54 | 35.55 | 75.3 |
| 16th Al injection | 2.5 | 39.46 | 12 | 2.3 | 0.03 | 0.90 | 3.4 (1 d) | 0.82 | 37.74 | 80.0 |
| 17th Al injection | 2.5 | 41.96 | 17 | 3.4 | 0.06 | 0.96 | 1.5 (1 d) | 0.37 | 40.63 | 86.1 |

Notes: [a] The first two discarded solutions were removed after an addition instead of before. Loop water samples are taken before, not after additions. Therefore, the concentrations of these discarded solutions are not known. It is conservative to assume a concentration equal to the expected concentration after an addition, assuming complete solubility.

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## Table 11
## Relationship Between Strainer Aluminum Load and Maximum Head Loss Viscosity-Adjusted to 60, 40 and 20°C

| Event | Strainer Aluminum Load ($g/m^2$) | Max Measured Head Loss at Temperature (psi) | Max Head Loss at 60°C (psi) | Max Head Loss at 40°C (psi) | Max Head Loss at 20°C (psi) |
|---|---|---|---|---|---|
| 1st Al injection | 4.8 | 2.25 | 2.25 | 2.33 | 2.43 |
| 2nd Al injection | 9.9 | 2.61 | 2.61 | 2.70 | 2.82 |
| 3rd Al injection | 14.4 | 2.79 | 2.79 | 2.89 | 3.01 |
| 4th Al injection | 18.6 | 2.87 | 2.87 | 2.97 | 3.10 |
| 5th Al injection | 21.8 | 3.06 | 3.06 | 3.16 | 3.30 |
| 6th Al injection | 27.7 | 3.21 | 3.10 | 3.21 | 3.35 |
| 7th Al injection | 32.5 | 3.30 | 3.19 | 3.30 | 3.44 |
| 8th Al injection | 37.6 | 3.37 | 3.26 | 3.37 | 3.52 |
| 9th Al injection | 42.7 | 3.45 | 3.34 | 3.45 | 3.60 |
| 10th Al injection | 48.8 | 3.52 | 3.40 | 3.52 | 3.67 |
| 11th Al injection | 53.0 | 3.57 | 3.45 | 3.57 | 3.73 |
| 12th Al injection | 58.0 | 3.64 | 3.52 | 3.64 | 3.80 |
| 13th Al injection | 63.2 | 3.76 | 3.64 | 3.76 | 3.92 |
| 14th Al injection | 69.6 | 3.85 | 3.72 | 3.85 | 4.02 |
| 15th Al injection | 75.3 | 4.09 | 3.79 | 3.92 | 4.09 |
| 16th Al injection | 80.0 | 4.27 | 3.96 | 4.09 | 4.27 |
| 17th Al injection | 86.1 | 4.40 | 4.08 | 4.22 | 4.40 |

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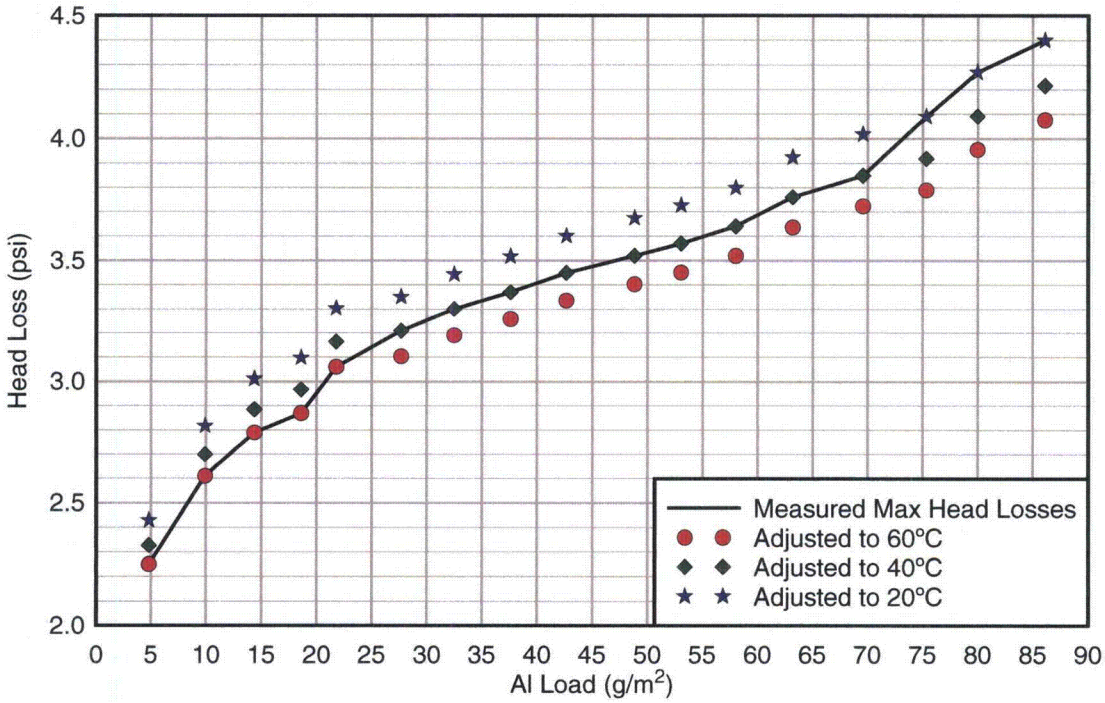


**Figure 20**
**Strainer head loss as a function of aluminum load. Head losses have been viscosity-adjusted to each of the test temperatures. The solid line joins the head loss values as measured (these have not been viscosity-adjusted).**

# Commitment #3

Flow Sweeps

Two flow sweep evaluations were completed during the chemical effects tests. The first flow sweep was completed at a temperature of 40°C (~104°F) at 14 chemical additions. The flow rate set point was reduced from the test flow rate of 19.74 gpm to 5.74 gpm in 2 gpm decrements and then to 5.0 gpm. The flow rate set point was then increased in reverse order. The flow rates and resulting head losses are shown in Figure 21. The logarithm of the strainer head loss ($\Delta p$) can be plotted against the logarithm of flow rate to determine the velocity exponent ($n$) in the relation:

$$\Delta p \propto Q^n$$

Linear regression of the data indicates the following relationship with $R^2 = 0.9999$:

$$\Delta p \propto Q^{1.886}$$

The second flow sweep was completed at a temperature of 20° (~70°F). The flow rate set point was reduced from the test flow rate of 19.74 gpm to 5.74 gpm in 2 gpm decrements and then to 5.0 gpm. The flow rate set point was then increased in reverse order. The flow rates and resulting head losses are shown in Figure 22. Linear regression of the data indicates the following relationship with $R^2 = 0.9999$:

$$\Delta p \propto Q^{1.873}$$

Two observations can be made from the flow sweep. First, there was no hysteresis. The pressure drop changes on the way down were the same as those on the way back up. The debris bed was stable. The second was that the pressure drop varied roughly with the square of the flow. The flow through the bed is turbulent.

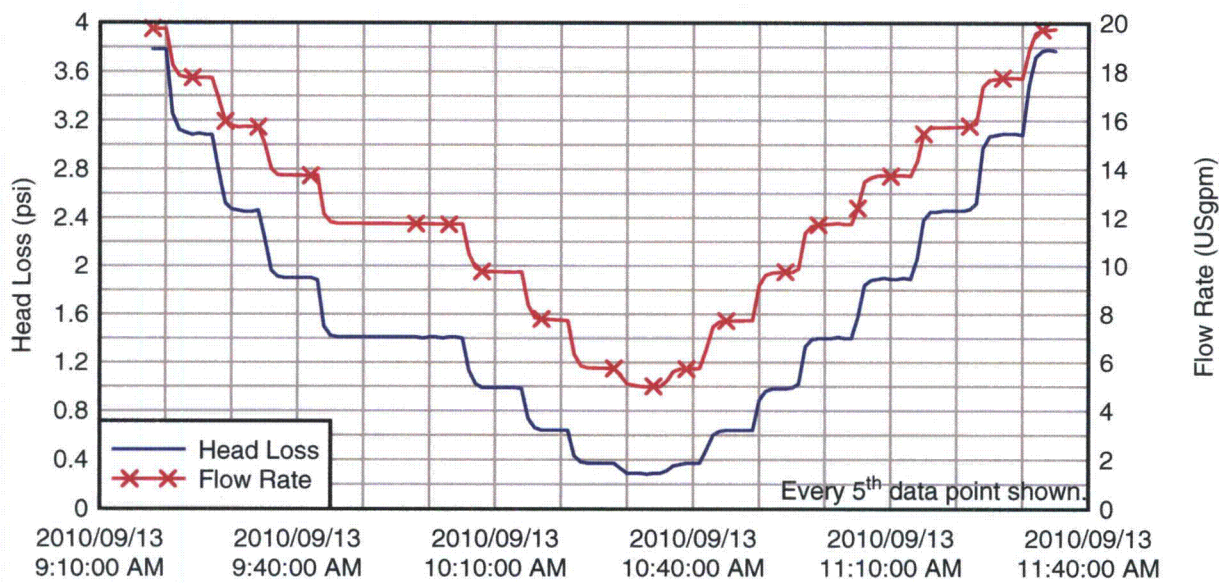


Figure 21
Flow Sweep data at 40°C

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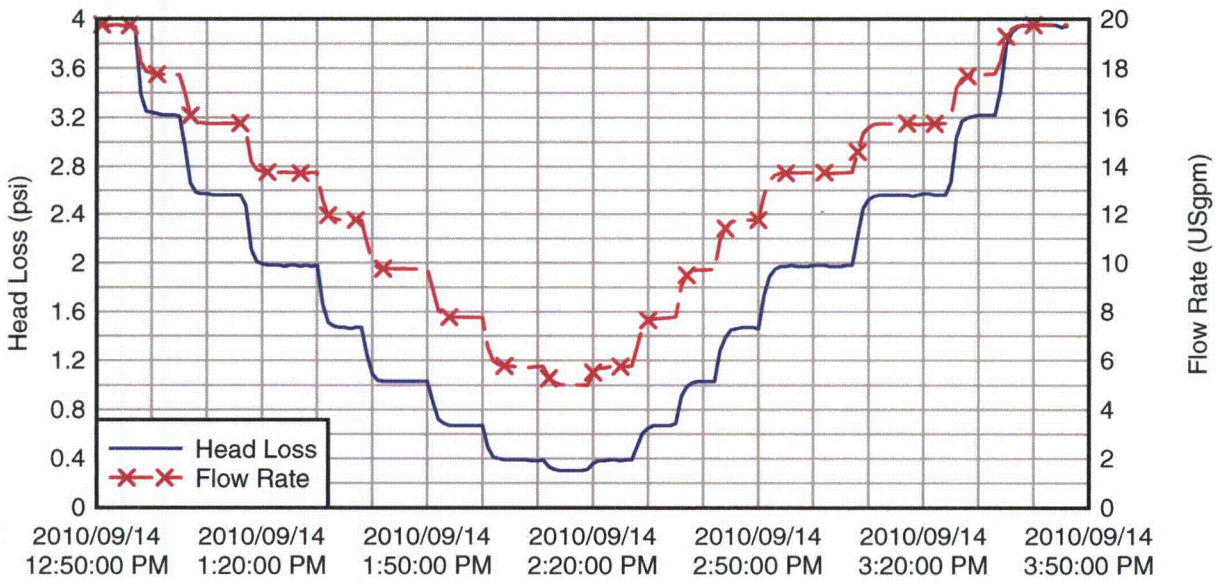


Figure 22
Flow Sweep data at 20°C

Temperature Variation

The pressure drop was also evaluated as how it varies with temperature. The initial test temperature was 60°C (~140°F). After the 5th chemical injection, the temperature was reduced to 40°C (~104°F). This pressure drop increased from 2.90 psi to 3.00 psi as shown on Figure 23. The data suggests that at this point in the testing, the pressure drop ($\Delta p$) was proportional to the viscosity ($\mu$) to the power of 0.1:

$$\Delta p \propto \mu^{0.1}$$

The second temperature drop was from 40°C (~104°F) to 20°C (~70°F). This was run after the 14th chemical addition. This pressure drop increased from 3.79 psi to 3.95 psi as shown on Figure 24. The data suggests that at this point in the testing, the pressure drop ($\Delta p$) was proportional to the viscosity ($\mu$) to the power of 0.1:

$$\Delta p \propto \mu^{0.1}$$

This testing demonstrates a very weak relationship with viscosity, again indicating the bed is in the turbulent flow regime.

## Commitment #3

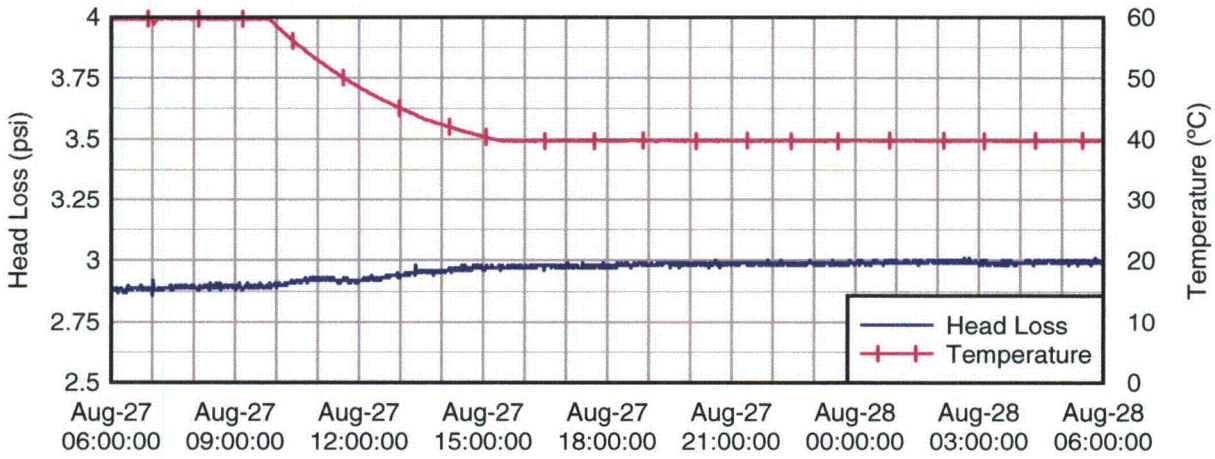


Figure 23
Pressure Drop Change from 60°C to 40°C

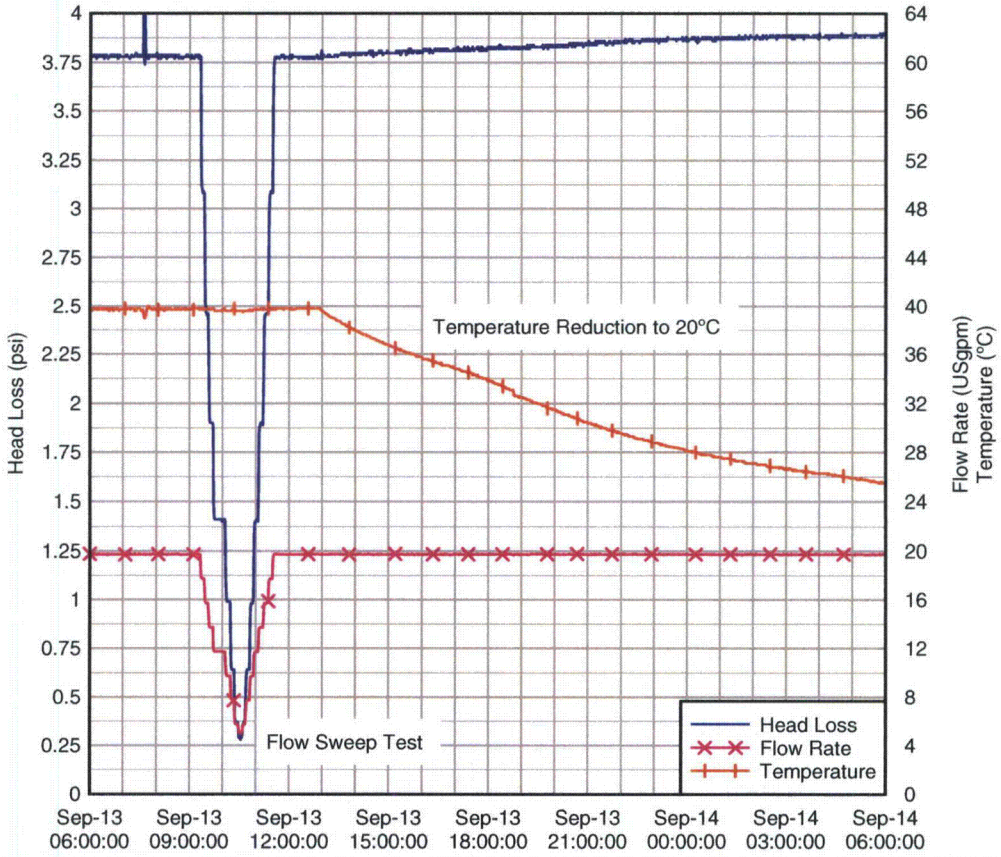


Figure 24
Pressure Drop Change from 40°C to 20°C

# Commitment #3

Design Strainer Head Loss

As described early, the design basis strainer aluminum loading is 73.5 g / $m^2$. Comparison with the data provided on Table 11, this loading was met by the 15th chemical addition (75.3 g/$m^2$ aluminum loading). The maximum strainer pressure drop used is therefore 4.09 psi at 20°C. This is a reduction in the strainer pressure drop used in supplemental GL 2004-02 response (RC-09-0134) provided in November 2009. Completion of the chemical effects test has increased margin for the V.C. Summer design.

**Impact on Analysis**

The pressure drop measured across the strainer during the chemical effects test is lower than was previously utilized in for both the pump NPSH and the strainer flashing. The calculations have been updated to reflect the design basis pressure drop measured in the chemical effects test to determine the increased margins.

The RHR pump and Reactor Building Spray pump NPSH are calculated at 70°F consistent with the original design basis. No credit is taken for subcooling consistent with the original calculations to satisfy commitments for Regulatory Guide 1.1, Revision 0. The measured strainer pressure drop at 70°F, with the design basis chemical effects debris, is 4.09 psi. This compares favorably with the 4.72 psi pressure drop applied in the supplemental response letter RC-09-0134. The updated RHR and RB Spray pump NPSH margins are as follows:

| NPSH Margin – No credit for subcooling of the sump water - 70°F sump water | | | | |
|---|---|---|---|---|
| Pump | Flow Rate | NPSH Required | NPSH Available | NPSH Margin |
| RHR Pump A | 4300 gpm | 17 ft | 20.2 ft | 3.2 ft |
| RHR Pump B | 4200 gpm | 16 ft | 20.8 ft | 4.8 ft |
| RB Spray Pump A | 3300 gpm | 17 ft | 22.1 ft | 5.1 ft |
| RB Spray Pump B | 3300 gpm | 17 ft | 21.9 ft | 4.9 ft |

Note that the pressure drop from the A train strainer is conservatively taken as the same as limiting B train strainer. With the A train greater surface area, it has a lower velocity and lower debris loading per unit surface area.

The flashing calculation was similarly updated to apply the pressure drops from the design basis chemical effects test. The methodology is the same as presented in the RAI response letter RC-09-0134 (Attachment I, page 46 of 121). It is repeated here for clarity. The strainer pressure drop from the test is used directly in the test without temperature corrections.

# Commitment #3

The evaluation of flashing is based on the submergence of the strainer fin, pressure inside the reactor building, vapor pressure of the sump water and the pressure drop across the sump strainer. The vapor pressure and pressure drop are both temperature dependent. If the pressure inside the strainer falls below the vapor pressure, then flashing would occur.

$P_S = P_{RB} - \Delta P_T + Z \times (\rho_T / 144\ in^2/ft^2)$
Where
$P_S$ is the pressure inside the strainer (psia)
$P_{RB}$ is the reactor building pressure (psia)
$\Delta P_T$ is the pressure drop at Temperature (T) of interest (psi)
Z is the submergence (ft)
$\rho_T$ is the water density at Temperature (T) of interest ($lb/ft^3$)

If the water vapor pressure equals the reactor building pressure, this reduces to a comparison between submergence and pressure drop.

The Reactor Building saturation temperature is based on initial Reactor Building conditions established by Technical Specification 3.6.1.4 which limits pressure to -0.1 and +1.5 psig. Therefore, a saturation temperature of 212°F was evaluated for flashing. No credit is taken for subcooling at or above this temperature. Subcooling is credited for lower temperatures. Several sump temperatures were evaluated to confirm the limiting temperature was selected.

| Temperature | Strainer Pressure Drop | Level Margin |
|---|---|---|
| 70 °F | 4.09 psi | 26.9 ft |
| 140 °F | 3.79 psi | 22.3 ft |
| 212 °F | 1.23 psi | 0.6 ft |

As was the case with the pump NPSH calculation, margin to flashing has increased based on the chemical effects test result.