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Wolf Creek Large-Scale Fibrous Debris Penetration and Head Loss
Test Plan – Revision 00

1162WCGSI-300-00

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1.0 Objectives

This document defines the large-scale fibrous debris penetration and head loss test program for Wolf Creek Generation Station (WCGS). The test program is designed to satisfy requirements developed in the ENERCON test specifications for penetration [2] and head loss [3] testing. The large-scale fibrous debris penetration testing must experimentally quantify fibrous debris penetration of modified WCGS strainer stacks as well as provide data to analyze debris penetration of the strainer assemblies as a function of time [2]. The purpose of large-scale head loss testing is to determine the potential peak head loss that could occur during a postulated loss of coolant accident (LOCA) [3]. Furthermore, an assessment of the validity of head loss temperature scaling will be completed such that both peak sump temperature and long-term core cooling conditions can be evaluated. The results of testing will be used by ENERCON as part of the resolution to Generic Letter 2004-02 for WCGS [2] [3].

2.0 Approach & Basis

The objective of fiber penetration testing is to experimentally quantify fibrous debris penetrating the WCGS strainers for a variety of break sizes in the event of a LOCA. Furthermore, fibrous debris penetration testing must also provide data to show debris penetration as a function of time for the previously mentioned accident. Additionally, the data must be sufficient to allow extrapolation of the results to the 30 day post-LOCA point. Two tests may be conducted to achieve the penetration testing objectives. The parameters of the first test will be selected to be representative of the most conservative conditions. The test parameters will be selected based on the inputs provided in the penetration test specification [2]. If executed, the second test will be informed by the results of the first and will either be conducted as a confirmatory test or to examine the effect of a particular parameter on penetration quantity. The approach for fibrous debris penetration testing is further described throughout Section 3.1.2.

The objective of prototypical head loss testing is to determine the potential peak head loss that could occur during a postulated LOCA at WCGS. To evaluate the development of head loss across the WCGS strainer assemblies a “fully-loaded” debris bed test (Section 3.1.3.8.1 and a “thin bed” test (Section 3.1.3.8.2) will be performed. To meet the objective of head loss testing, debris loads that bound the postulated breaks will be evaluated.

Section 3.0 provides the requirements inherited from the Debris Penetration and Head Loss Test Specs ([2], [3]). A technical justification for the physical model of the WCGS sump strainers is defined in Section 4.0. Test conditions are described in Section 5.0. Instrumentation requirements are collected in Section 6.0. Testing Scope and Limitations are described in Section 7.0. The test procedures associated with each type of test are summarized in Section 8.0. Test acceptance and termination criteria are discussed in Section 9.0. Finally, safety precautions are discussed in Section 10.0.

3.0 Test Inputs

3.1 Design Inputs and Requirements

3.1.1 Prototypical Strainer Assembly Design

WCGS employs two strainer assemblies, both identical with respect to design, surface area, orientation, design flow, and configuration. Strainer assemblies are situated in separate but identical sumps and are comprised of eight “Type A” and eight “Type B” strainer stacks. A side view of a prototypical strainer assembly can be seen in Figure 3-1. Strainer stacks are subdivided into modules. The Type A stacks contain three strainer modules with 11 disks and one strainer module with 7 disks. The Type B stacks contain five modules with 11 disks.

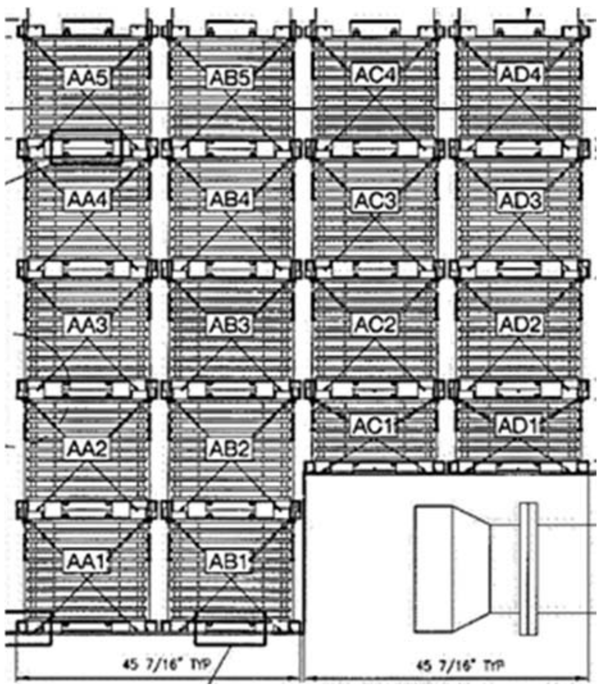


Figure 3-1: Side view of a prototypical strainer assembly [2]

Each strainer assembly sump pit at WCGS has one plenum that is common to all strainer stacks within the sump. The prototypical plenum has two sections, one for Type A and one for Type B strainer stacks, which have no divider between them. The plenum section for Type B strainer stacks has a clearance of 1’- 5/8” and the section for Type A strainer stacks has a clearance of 3’-2” [2].

All the strainer disks found at WCGS share identical geometries and base material characteristics such as thickness and perforation pattern. The top and bottom faces of strainer disks are constructed of stainless steel perforated plate. A wire grill is sandwiched between the faces of each strainer disk. The top and bottom disk faces are connected around the perimeter by a perforated rim of the same base material as the faces. Adjacent strainer disks are separated by a partially perforated gap disk located around the central core tube and four spacers located around the perimeter of the disks. All of the gap disks are geometrically consistent and are constructed of the same base material as the strainer disks.

A central core tube connects the strainer disks within each module. Core tubes of adjacent modules in a stack are separated by a gap. The gap is enclosed by a stainless steel sleeve with a large diameter to form an effectively continuous core tube for each strainer stack. All core tubes found at WCGS are of equal diameter. At the elevation of every disk is a row of four rectangular openings evenly spaced around the circumference of the core tube. The rectangular openings gradually increase in size from the bottom to the top of the core tube. The bottom core tube of each stack has a small gap between it and the plenum cover. This gap, similar to that between adjacent modules, is enclosed by a sleeve.

The WCGS strainer assemblies are surrounded by a 6 inch curb, which will not be represented in the tests [2][3].

Dimensions of strainer features described above are provided in Table 3-1.

Table 3-1: Prototypical strainer dimensions

Dimension/Feature and Reference	**Value/Description**
Disk width [2]	19” (square)
Disk thickness [2]	0.558”
Perforated plate [2]	22 ga. ASTM A240 type 304 stainless
Perforated hole diameter [2]	0.045”
Perforated hole pitch [2]	0.081” staggered, center-to-center
Wire grill [2]	7 ga. (0.180”) and 8 ga (0.165”)
Distance between adjacent module faces in stack [2]	3”
Gap between adjacent strainer disks [2]	1”
Gap disk outer diameter (OD) [2]	10.063”
Perforated height of gap disk [2]	0.675” out of 1” height
Core tube OD [2]	7.5”
Gap between adjacent core tubes [5]	0.5”
Gap, bottom core tube to plenum [5]	0.5”
Core tube sleeve height [5]	2.5” (between core tubes) 1.5” (bottom core tube to plenum)
Suction line diameters [5]	12” (nominal) 14” (nominal)

3.1.2 Inputs Specific to Debris Penetration Testing

All inputs specific to penetration testing are derived from Reference [2] unless otherwise noted.

3.1.2.1 Strainer Surface Area, Flow Rate, and Approach Velocity

The surface area of one plant-scale strainer assembly is 3,311.5 ft^2 [2]. The surface area of the strainers used for penetration testing can be derived using values from the PCI strainer surface area calculation [4]. This calculation determines the surface area of the 7-disk and 11-disk strainer modules. By subtracting out the surface area of each disk and gap ring removed (these surface areas can also be found in Reference [4]), the surface area of the strainer modules used for penetration testing can be found. The combined surface area of the two Type-A strainer stacks used for penetration testing is 188.56 ft^2.

The maximum flow rate for an individual strainer assembly is 8750 gpm, but 9100 gpm will be used to obtain the scaled test flow rate. This results in an approach velocity of 0.00612 ft/s [2].

For all test cases, the flow rate shall be consistently maintained at +5%/-0% of the prescribed test flow rate.

3.1.2.2 Debris Type and Quantity

Based on consideration of debris types generated by bounding breaks and similarities between characteristic sizes, only Nukon will be used in the penetration tests. Nukon has a macroscopic density of 2.4 lbm/ft^3.

Table 3-2 shows the maximum fibrous debris quantities transported to a single sump strainer with two trains active. Large-scale penetration tests will be performed with only fine debris.

Table 3-2: Bounding fibrous debris quantities at the strainer for Wolf Creek [2]

Weld Name (Break Location)	Compartment	Pipe ID (in.)	LDFG Fines (Includes Latent Fiber) (lbm)
BB-01-S101-07	SG 1&4	8.75	51.5
EJ-04-F025	SG 1&4	10.5	82.9
BB-01-F001	SG 1&4	11.188	71.7
BB-01-S402-03	SG 1&4	11.5	77.4
BB-01-F201	SG 2&3	27.5	325.6
BB-01-F204	SG 2&3	29	470.9
BB-01-F405	SG 1&4	31	485.6

Table 3-3 summarizes the batching requirements, in the penetration test specification for the bounding debris loads transported to the Sump B strainer, which must be met for each of the listed break sizes. Batches at intermediate debris loads must be added to the batching requirements in order to eliminate sudden, large fiber load increases. Batch sizes must increase gradually throughout the penetration testing.

The batch schedule that will be used for testing may be found in Section 5.1.3.1 and Table 5-3.

Table 3-3: Required plant-scale debris surrogate quantities for Wolf Creek [2]

Representative Break Size (in.)	Bounding Fibrous Debris Quantities at the Strainer (lbm)	10% Margin over Plant Debris Load (lbm)	Cumulative Total Plant Debris Load to be Tested (Including Margin) (lbm)
10.5/11.118/11.5	82.9	8.29	91.19
27.5	325.6	32.56	358.16
29	470.9	47.09	517.99
31	485.6	48.56	534.16

3.1.2.3 Test Water

Sodium hydroxide (NaOH) is used as the buffer to adjust the sump pool pH. The maximum long-term post-LOCA recirculation sump pool pH of 9.62 at 80°F results from a boron concentration of 2117 ppm and corresponding NaOH concentration of 4.5797 g/L.

The test solution shall be prepared with deionized (DI) water meeting the requirements in Section 3.2.2.

The test water temperature to be used during testing shall be fixed at 120°F ±5°F.

3.1.2.4 Fiber Concentration

Fiber concentration is defined as the mass of fibrous debris divided by water volume. The minimum fiber concentration was specified to be 0.00260 lbm/ft^3, and the maximum fiber concentration was specified to be 0.02748 lbm/ft^3. The intermediate fiber concentration is taken to be the average of the minimum and maximum values, 0.01504 lbm/ft^3. A target concentration between the intermediate and maximum prototypical values shall be used during testing.

3.1.2.5 Isokinetic Sampling System

Samples of the debris-laden water downstream of the test strainer shall be taken using an isokinetic sampling system. The sampling system should be installed downstream of the test strainer and upstream of the filter housing. For each test, sampling should be done eight different times, with two samples taken each time.

3.1.2.6 Filter Bag Treatment Prior to Test

Prior to testing, filter bags shall be uniquely labeled and verified to be free of damage. The bags shall be dried and weighed to obtain a steady state baseline weight. Care shall be taken to ensure that foreign debris shall not be introduced to the filter bags during this process.

3.1.2.7 Process of Filter Bags after Test

The filter bags with collected fibers shall first be rinsed with DI water to remove any residual chemicals. The bags shall then be dried and weighed with the weight gain of each bag taken to be the amount of debris collected.

3.1.2.8 Control Filter Bag

After preparation of the test loop has been completed, one filter bag, having met requirements in Section 3.1.2.6, shall be installed inside a filter housing as the test pump is run at test conditions for 10 pool turnovers (PTOs) without debris addition. Afterward, the bag shall be removed and processed according to Section 3.1.2.7 and marked CONTROL. This bag will serve as a reference for baseline weight gain.

3.1.2.9 Fiber Penetration Filtering System

Water and fiber that pass through the test strainer enter a filtering system to collect the fibers during debris penetration testing. The filtering system must meet the following requirements:

1. The filtering system must have at least two filter housings installed in parallel to facilitate filter bag changes during the test, one of which must be online at all times during a test and be rated to accommodate the total flow.
2. The filter bags shall have a retention rating of >97% for the smallest debris of interest to be captured (i.e. Nukon fines, per Section 3.1.2.2).

3.1.2.10 Debris Addition Interval Timing

Before introducing additional debris when multiple batches are required for a given break size, a minimum of 5 PTOs shall be run after the completion of bulk addition, and it shall be confirmed that little to no debris from the previous batch remains suspended in the test tank.

3.1.2.11 Filter Bag Change Schedule

The filter bag change schedule shall ensure that fiber penetration data obtained from the testing is adequate to evaluate both prompt penetration occurring as fiber arrives at the strainer as well as long-term penetration due to fiber erosion and shedding from the fiber bed formed on the strainer. Long-term fiber penetration shall be evaluated for the last batch of debris, as well as some intermediate batches. The long-term penetration data shall be adequate to accurately extrapolate the penetration results out to 30 days.

A minimum duration of 10 hours after final debris addition is required to gather adequate data to evaluate shedding penetration.

3.1.2.12 Test Cases

One test must be performed at the maximum approach velocity, with prototypical debris type and concentration. A second, optional test may be performed.

3.1.3 Inputs Specific to Head Loss Testing

3.1.3.1 Strainer Surface Area, Flow Rate, and Approach Velocity

The surface area of one strainer assembly is given as 3,311.5 ft^2; however, a sacrificial strainer surface area of 15 ft^2 will be used to account for miscellaneous debris and tags, resulting in an effective strainer surface area of 3,296.5 ft^2 [3].

For a total flow rate of 9,100 gpm and net strainer surface area of 3,296.5 ft^2, the approach velocity for the strainer assembly is determined to be 0.00615 ft/s [3].

The flow rate for testing during chemical precipitate addition shall be 5,150 gpm, resulting in an approach velocity of 0.00348 ft/s.

3.1.3.2 NPSH Margin and Strainer Structural Design Differential Pressure

The acceptable conventional debris head loss based on consideration of RHR and CS pump net positive suction head (NPSH) margin is 3.862 ft [3].

The structural differential design pressure of the WCGS strainer is 2.38 psi. An acceptable head loss for chemical debris introduction will be provided by WCGS prior to introducing chemical debris to the test tank. The acceptable head loss is not anticipated to be greater than 6 psid [3].

3.1.3.3 Debris Type and Quantity

3.1.3.3.1 Conventional Debris

The following fibrous debris sources are found at WCGS: Nukon, Antisweat blankets, Cerablanket, latent fiber, and Thermolag 330-1. The only fibrous debris to be used during head loss testing will be Nukon, which will be used as a surrogate for latent fiber, Cerablanket, and fiberglass from Thermolag 330-1.

WCGS contains the following particulate debris sources: FOAMGLAS, qualified coatings (inorganic zinc, or IOZ, and epoxy), unqualified and degraded coatings (IOZ, epoxy, alkyds), fire barrier material (Thermo-Lag 330-1) and latent particulate. The microscopic density and characteristic size of the particulate types are listed in Table 3-4. The following particulate debris sources will be modeled with the following surrogates:

- Unqualified coatings (IOZ, epoxy and alkyds), and degraded coatings will be modeled by pulverized acrylic or silica flour with a mean size distribution of 10 microns
- Thermolag 330-1 particulate will be modeled by pulverized acrylic or silica flour with a mean size distribution of 10 microns
- Latent particulate will be modeled with PCI Dirt/Dust mix
- FOAMGLAS will be modeled by pulverized acrylic or silica flour with a mean size distribution of 10 microns

Table 3-4: Material characteristics for particulate types

Debris Type	Microscopic Density (lbm/ft^3)	Characteristic Size (µm)
FOAMGLAS	156	10
IOZ	208 and 220	10
Epoxy	112, 115, and 171	10
Alkyds	98	10
Thermo-Lag 330-1	144.2	10
Latent Particulate	169	17.3

Conventional plant debris loads have been provided by Enercon from debris generation and transport analyses that were completed for a range of postulated pipe breaks. The resultant postulated debris loads exhibit variation in fiber and particulate quantities for a collection of pipe breaks. A plot showing particulate transported to the strainer as a function of the transported fibrous debris load is shown below in Figure 3-2. The fibrous and particulate debris quantities from Figure 3-2 have been broken up into their respective individual components and are shown in Table 3-5.

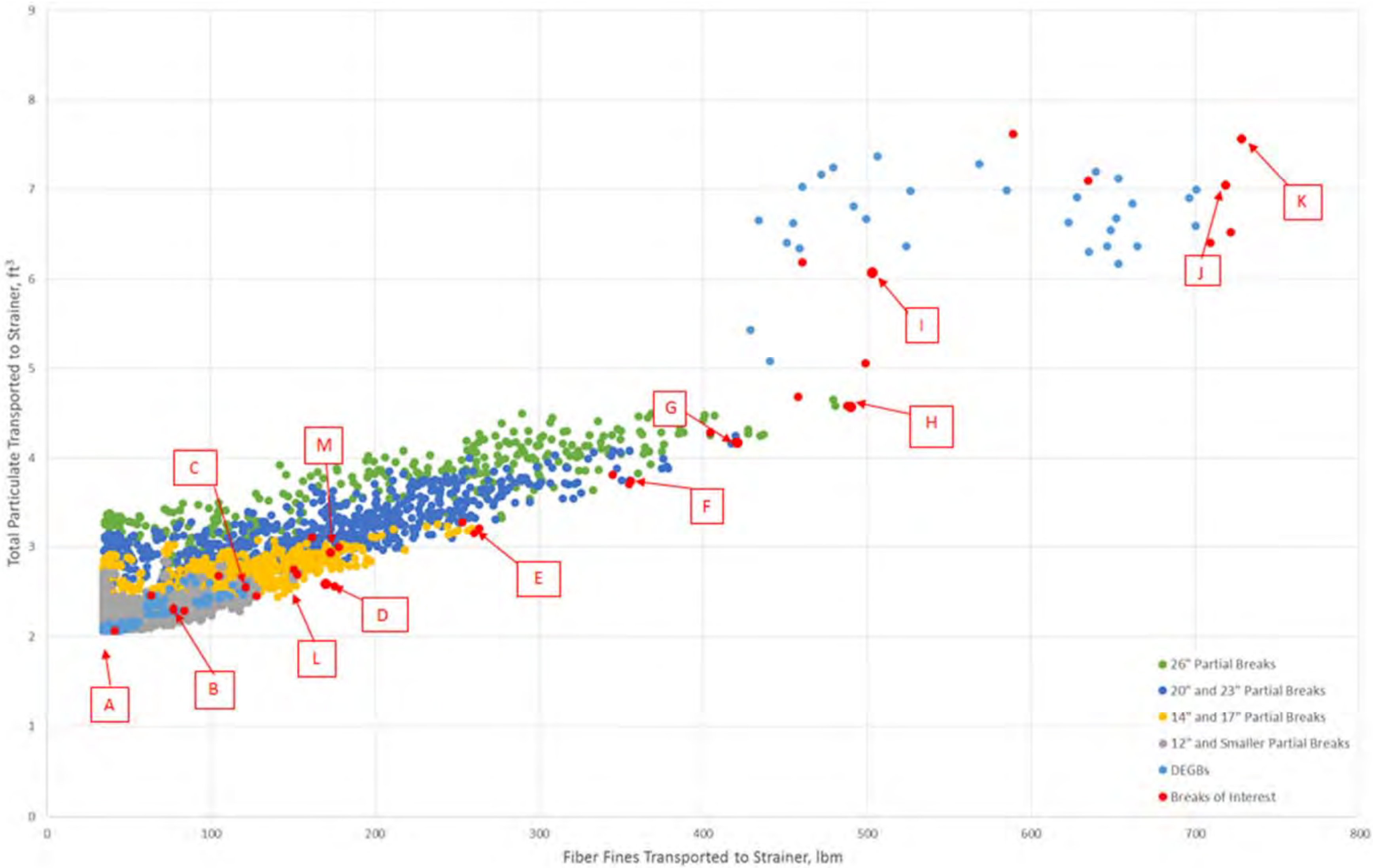


Figure 3-2: Total particulate load vs. fibrous debris transported to the strainer [3]

Table 3-5: WCGS debris loads transported to the strainer for various break sizes [3]

Weld Name (Break Location)	Point on Figure 9	Compartment	Pipe ID or Break Size	Thermolag 330-1		FOAMGLAS (ft^3)	Unqualified and Qualified Coatings (IOZ, Epoxy, Alkyds) (ft^3)	Latent Particulate (lbm)	LDFG (lbm)		Cerablanket (lbm)
				Fiber (lbm)	Particulate (ft^3)				Fines (Includes Latent Fiber)	Smalls	Fines
BB-01-S405-05	A	SG_1_4	2.626	8.92	0.50	0.00	1.24	54.47	16.56	13.63	0.00
EP-01-FW307	-	SG_1_4	8.75	8.92	0.50	0.00	1.63	54.47	38.83	53.17	0.00
BB-01-S101-07	-	SG_1_4	8.75	8.92	0.50	0.00	1.46	54.47	58.74	99.37	0.00
-	B	-	-	8.92	0.50	0.00	1.63	54.47	58.74	99.37	0.00
BB-01-S001-6	-	SG_1_4	11.188	8.92	0.50	0.00	1.86	54.47	79.83	127.61	0.00
EJ-04-F025	-	SG_1_4	10.5	8.92	0.50	0.00	1.62	54.47	103.21	202.36	0.00
-	C	-	-	8.92	0.50	0.00	1.86	54.47	103.21	202.36	0.00
BB-01-F204	-	SG_2_3	14	8.92	0.50	0.00	1.77	54.47	87.45	156.81	0.00
BB-01-F105	-	SG_1_4	14	8.92	0.50	0.00	1.74	54.47	150.4	296.4	0.00
-	D	-	-	8.92	0.50	0.00	1.77	54.47	150.4	296.4	0.00
BB-01-F304	-	SG_2_3	17	8.92	0.50	0.00	2.11	54.47	145.14	290.16	0.00
BB-01-S202-02	-	SG_2_3	17	8.92	0.50	0.00	2.09	54.47	169.25	321.33	0.00
-	E	-	-	8.92	0.50	0.00	2.11	54.47	169.25	321.33	0.00
BB-01-S302-02	-	SG_2_3	20	8.92	0.50	0.00	2.58	54.47	222.67	453.46	0.00
BB-01-S202-02	-	SG_2_3	20	8.92	0.50	0.00	2.5	54.47	231.75	469.02	0.00
-	F	-	-	8.92	0.50	0.00	2.58	54.47	231.75	469.02	0.00
BB-01-S302-02	-	SG_2_3	23	8.92	0.50	0.00	3.04	54.47	278.12	578.49	0.00
BB-01-S202-02	-	SG_2_3	23	8.92	0.50	0.00	2.93	54.47	293.77	594.87	0.00
-	G	-	-	8.92	0.50	0.00	3.04	54.47	293.77	594.87	0.00
BB-01-S302-02	-	SG_2_3	26	8.92	0.50	0.00	3.43	54.47	331.68	707.35	0.00
BB-01-S202-02	-	SG_2_3	26	8.92	0.50	0.00	3.34	54.47	361.65	747.24	0.00
-	H	-	-	8.92	0.50	0.00	3.43	54.47	361.65	747.24	0.00
BB-01-F401	-	SG_1_4	27.5	8.92	0.50	0.00	5.35	54.47	435.65	934.23	0.00
BB-01-F201	-	SG_2_3	27.5	8.92	0.50	0.00	3.89	54.47	390.83	808.41	0.00
-	I	-	-	8.92	0.50	0.00	5.35	54.47	390.83	808.41	0.00
BB-01-S402-02	-	SG_1_4	29	8.92	0.50	0.00	6.28	54.47	610.12	1311.42	0.00
BB-01-F204	-	SG_2_3	29	8.92	0.50	0.00	5.16	54.47	583.11	1258.5	0.00
-	J	-	-	8.92	0.50	0.00	6.28	54.47	583.11	1258.5	0.00
BB01-S404-03	-	SG_1_4	31	8.92	0.50	0.00	6.8	54.47	564.15	1213.86	0.00
BB-01-F205	-	SG_2_3	31	8.92	0.50	0.00	5.28	54.47	595.57	1300.68	0.00
-	K	-	-	8.92	0.50	0.00	6.8	54.47	595.57	1300.68	0.00
BB-01-S201-02	L	RX	12	8.92	0.50	0.26	1.6	54.47	12.09	2.92	80.16
BB-01-S201-02	-	RX	26	8.92	0.50	0.26	2.02	54.47	21.23	24.49	80.16
BB-01-F103	-	RX	26	8.92	0.50	0.26	1.91	54.47	37.48	55.99	80.16
-	M	-	-	8.92	0.50	0.26	2.02	54.47	37.48	55.99	80.16

3.1.3.3.2 Chemical Debris

The only chemical precipitate that will be considered for head loss testing is aluminum oxyhydroxide (AlOOH). The maximum amount of AlOOH formed in containment is 148 kg. It should be noted that the maximum temperature at which AlOOH is formed is 116.4°F.

3.1.3.4 Test Water

Sodium hydroxide (NaOH) is used as the buffer to adjust the sump pool pH. The minimum recirculation sump pool pH of 8.73 at 86°F results from the maximum boron concentration of 2,406 ppm and with a corresponding NaOH concentration of 2.7195 g/L.

The test solution shall be prepared to the standards described in Section 3.2.2.

The nominal operating water temperature will be 120°F and below 100°F for conventional and chemical debris additions respectively. The conventional debris addition water temperature must be maintained within 5°F of the target value.

3.1.3.5 Clean Strainer Head Loss

Prior to debris introduction for the first debris-laden head loss test, a clean strainer head loss measurement of the test system shall be recorded for a range bounding the flow rates that will be used during head loss testing.

3.1.3.6 Head Loss Measurement

At points during the test where a head loss measurement is required for a debris load, a period of time, not less than 5 PTOs and where the increase in strainer head loss is less than 1% in two consecutive 30 minute intervals, shall be observed before continuing or terminating the test.

After adding chemical debris to the test loop, adequate head loss data shall be collected to estimate the strainer head loss at 30 days.

3.1.3.7 Debris Bed Characterization

Following conventional debris addition and at the end of chemical debris addition, the debris bed on the strainer will be characterized to document the flow characteristics through the debris bed and the debris bed compressibility. A discussion of how the data resulting from debris bed characterizations will be used can be found in Section 5.2.5. An in-depth discussion of the procedural steps relating to the debris bed characterization is presented in Section 8.8.1.3.

3.1.3.8 Test Cases

Two head loss tests shall be performed: one Full Debris Load (FDL) test and one Thin Bed (TB) test. An optional contingency test may be performed depending on the results of the FDL and TB tests. If the contingency test is to be performed, the test parameters shall be agreed upon by Wolf Creek and ENERCON prior to implementation by Alden.

A certain amount of debris margin is to be added to each test. Table 3-6 shows the margin that will be added to each of the two full debris load head loss tests, while Table 3-7 shows the margin that is to be added to the thin bed test.

Table 3-6: Full debris load head loss testing margin

Debris Type	Margin Quantity
Latent Fiber	15.9 lbm
Latent Particulate	90.27 lbm
Unqualified Coatings (IOZ, Epoxy, Alkyds, OEM Coatings)	0.625 ft^3
Degraded Coatings	0.435 ft^3
Nukon Fines	15 lbm

Table 3-7: Thin bed head loss testing margin

Debris Type	Margin Quantity
Latent Particulate	90.27 lbm
Unqualified Coatings (IOZ, Epoxy, Alkyds, OEM Coatings	0.625 ft^3
Degraded Coatings	0.435 ft^3
FOAMGLAS	0.026 ft^3

3.1.3.8.1 Full Debris Load Test (FDL)

The full debris load (FDL) head loss test will evaluate the development of head loss across the WCGS strainer for debris loading that results from postulated breaks outside the reactor cavity, and bound breaks inside the reactor cavity.

The trajectory of incremental debris batches will be such that the ratios of fibrous debris to particulate reach specific quantities represented by points in Figure 3-2 and listed in Table 3-5. Point B is the first target point, followed by Point C. At this time, if the measured head loss exceeds 80% of the acceptable head loss provided in Section 3.1.3.2, additional batches may only be added with client approval. The margin debris load batch from Table 3-6 shall be added after Point C. If the measured head loss is determined to be acceptable, debris batches to test Points D, E, F, G, H, I, J, and K shall be incrementally added. After all of the conventional debris has been added, or if 80% of the pre-determined maximum allowable head loss, described in Section 3.1.3.2, is exceeded, chemical precipitates will be added as described in Section 3.1.3.8.3.

Fines should be substituted for smalls except for the last debris load point tested. Smalls should only be added to the test after all of the fiber fines have been added to the test loop. Once all of the fines have been added for a target break point, smalls may be added for that break point. The particulate debris should be split between the batches proportional to the weight of fibrous debris in each batch. The implemented approach for the FDL test discussed in Section 5.2.6.4.1 incorporates the following critical aspects of the specified approach: all fiber fines are added before fiber smalls, fines added to the test could be used to displace smalls. See Section 5.2.6.4.1 for additional details on the batching approach for the FDL test.

For all debris batches fibrous and particulate debris components of each batch will be individually prepared. Prior to the conventional debris batch addition, individual components of the batch to be introduced will be combined into a homogenous mixture.

Additionally, for the FDL test the test strainer submergence will be lowered to 0.5' when the total debris quantity added to the test tank reaches or exceeds Point A from Table 3-5. If vortexing is observed, the tank water level and flow rate shall be recorded in the test log. Water level shall then be increased until vortexing is no longer observed, and this water level shall also be recorded in the test log. Afterwards, the water level will be maintained at the requirements defined in Section 3.1.4.6.

3.1.3.8.2 Thin Bed (TB) Test

The second test will be the Thin Bed test. The purpose of the TB test is to form a particulate-filtering debris bed with minimal fiber. The particulate debris load will be informed by the results of the FDL test and consider the additional margin selected by ENERCON and shown in Table 3-7. Fibrous debris for the TB test will be Nukon. All of the particulate debris will be added to the test tank before any fibrous debris is added. Fibrous debris will be added to the loop in batches equal to the amount required to form a 1/16" theoretical debris bed on the test strainer. Fibrous debris batches shall continue to be added to the test until the tank has cleared, complete strainer coverage is observed, or when the most recent fibrous debris addition produced a much lower rise in head loss compared to previous additions.

3.1.3.8.3 Contingency Test

An optional contingency test may be performed based on the results of the first two tests.

3.1.3.8.4 Chemical Debris

Chemical debris additions have the same requirement for each test. All chemical debris additions will be done after the conventional debris additions have been completed. Chemical debris additions will be done in a small, slow incremental manner to avoid rapid increases in head loss. Chemical additions will continue until there is no increase in strainer head loss or the amount of chemical introduced when scaled is equivalent to the total plant debris load.

3.1.4 Common Inputs to Debris Penetration and Head Loss Testing

3.1.4.1 Debris Introduction System

The introduction of fibrous debris will be done away from the test strainer and in a manner that avoids effects on the total system flow rate and minimizes splashing. Debris introductions will encourage dispersion of the fines within the test tank, which will prevent agglomeration and encourage transport to the strainer.

3.1.4.2 Strainer Suction Piping

The piping connecting the test strainer to the filter housing shall be designed to avoid the settling of fibrous debris. Flow velocity greater than 1 ft/s shall be maintained to ensure complete fiber transport. There shall be no sudden and significant flow area expansions or contractions on horizontal pipes along the flow path as these may facilitate fiber settling and accumulation in front of the area of change.

3.1.4.3 Test Loop Pump

The pump shall be sized to provide sufficient head to circulate water through the test loop while maintaining the flow rates specified in Sections 3.1.2.1 and 3.1.3.1. The pump shall be placed upstream of the debris introduction system and downstream of the filter bags.

3.1.4.4 Test Loop Air Entrainment

Prior to starting large-scale testing, the test loop shall be water solid with minimal amount of air entrainment. Bubble formation shall be minimized and have little to no effect on fiber debris surrogate transport and settling.

3.1.4.5 Debris Preparation

It must be confirmed that debris materials have been heat treated according to Section 3.2.1 and fiber fines prepared according to Section 3.2.1. When separating fiber from the bulk material, care shall be taken to prevent creation of shards.

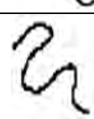
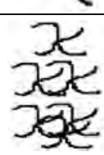
Fines preparation for Nukon begins by cutting the raw material into pieces approximately 2" x 2". A consistent process must be used for each test. For Nukon, the tough outer layer in the un-burnt portion of the Nukon blanket is removed and torn into smaller pieces with one side of the torn piece remaining 2" long. Tearing helps ensure that this tough layer is broken up.

Fiber smalls are prepared to contain fibers ranging from Class 3 up to pieces as large as the starting material (up to 6" long for Nukon).

Debris will be pressure washed using the appropriate test water. Acceptable debris characteristics will be documented via light table picture for each debris batch prepared. Fines batches will be acceptable once their composition is predominantly Class 2 (see Table 3-8), consisting mainly of individual fibers with lesser quantities of fiber shards and small entanglements.

Light table photographs will continue to be taken for each batch prepared to document that the chosen preparation duration was sufficient for all batches.

Table 3-8: NUREG/CR-6224 description of processed fiber classes [20]

Class No.	Description	
1		Very small pieces of fiberglass material, "microscopic" fines which appear to be cylinders of varying L/D.
2		A single flexible strand of fiberglass, essentially acts as a suspended strand.
3		Multiple attached or interwoven strands that exhibit considerable flexibility and which due to random orientations induced by turbulence drag could result in low fall velocities.

3.1.4.6 Test Strainer Submergence

The submergence of the test strainer will be maintained as close to that of the actual strainer as possible (i.e., from 1.17' to 1.51'). Submergence shall be adequate to prevent vortexing, fully submerge the debris bed, and reduce impact to debris transport to the strainer. If vortexing is observed, the test tank water level and flow rate shall be recorded in the test log.

The only exception to the strainer submergence requirement is the low water level condition for the FDL test. See section 3.1.3.8.1 for further details.

3.1.4.7 Tank Turbulence Level

The turbulence level inside the testing tank shall be maintained high enough to maximize transport of fiber fines to the test strainer and prevent non-representative settling of small fiber pieces. The turbulence level close to the test strainer shall be carefully controlled to avoid disturbances to the debris bed formed on the strainer. This level of turbulence shall be maintained throughout each test.

3.1.4.8 Fiber Transport

The design and implementation of the test conditions will maximize the transport of fiber fines to the strainer and prevent non-representative settling of fiber. If non-representative settling is observed, additional agitation or collection followed by reintroduction will be implemented whenever possible without disturbing the debris bed. Remaining quantities of settled fiber after agitation or reintroduction will be photographed, noted in the test log book, and collected for post-test drying and weight measurement.

Floating fiber (>~1g) will be collected and reintroduced to the test tank. At least 5 PTOs shall be run after the re-introduction. All fiber reintroductions must be tracked in the data acquisition and the test log book.

3.2 Accepted Standards and Practices

3.2.1 Processed Fiber

Fiber fines will be prepared in a manner consistent with the NEI debris preparation protocol [7]. Generation of fines under this protocol occurs through the application of high pressure spray to bulk fibrous material. The protocol also requires that the bulk material be heat treated such that the binder burnout extends approximately halfway through the sheet.

3.2.2 Test Water

Test water generation is controlled under the Alden QAP, QP-3220 [14]. The test water will be prepared with deionized water consistent with "Type IV" laboratory reagent water per ASTM Standard D1193 – the water should have a conductivity less than 5 μS/cm at 25°C [18].

3.2.3 Chemical Precipitate Generation

The AlOOH (aluminum oxyhydroxide) precipitate will be generated according to instructions provided in WCAP-16530-NP [19]. AlOOH is generated by first dissolving aluminum nitrate into tap water and then adding sodium hydroxide. The resulting precipitates must pass the acceptance tests provided below in the last paragraph of this section. Table 3-9 provides the constituent chemicals and the required quantities as given in the original recipes [19].

Table 3-9: AlOOH recipe

Aluminum Oxy Hydroxide (AlOOH)		Aluminum Nitrate Nonahydrate		Sodium Hydroxide	
100	g	625	g	200	g

The generated precipitates can have a wide range of acceptable concentrations, 2.1 to 11 g/L. However, all precipitates must be checked for acceptable settling behavior at a 2.1 to 2.3 g/L concentration and acceptable pH. The pH at the conclusion of the 1 hour mixing period is to be higher than 6.5 and the maximum clear volume at the top of a 10mL sample after one hour is 4mL. Once a successful settling test has been completed, the precipitates remain acceptable for use for 24 hours if the suspension is continuously mixed. The precipitate use period can be extended by completing additional settling tests; the clear volume at the top of the 10 mL sample must be within 1.5 mL of the freshly prepared precipitate clear volume in addition to having a maximum of 4 mL.

4.0 Model Definition

4.1 Large Scale Test Strainer Design

4.1.1 Debris Penetration Test Strainer

For large scale testing, two Type-A strainer stacks will be deployed. The prototypical mounting hardware and support frame will be installed for testing. The prototypical spacing between disks, 1" (Table 3-1), could lead to bridging under fiber-only test conditions. Bridging is the buildup of a fibrous debris bed at the inlet to the test strainer without first filling all of the interstitial volume. Since bridging effectively represents a drastic reduction in the active strainer area, debris penetration is substantially reduced and therefore potentially non-conservative relative to prototypical conditions. For debris penetration testing, bridging will be avoided by removing every other disk in order to increase disk spacing, in accordance with the recommendation in Section 6.1.1 of Reference [2]. This will result in 22 disks per stack, for a total of 44 disks used during debris penetration testing. With the individual disk surface area determined in Section 3.1.2.1, the total surface area of the debris penetration strainer assembly is found to be 188.56 ft^2.

To ensure that the flow control is properly maintained with disk removal, custom spacers and gap disks assemblies will be installed in place of the strainer disk. The custom gap disks will be comprised of one prototypical gap disk that will interlock with one non-perforated stainless steel gap disk. The non-perforated stainless steel gap disk will be 1.558 inches tall which accounts for the height of the removed strainer disk and half the height of each gap disk that would be adjacent to the removed disk. This maintains the correct perforated area for the gap disks. The overall gap disk height will be 2.558 inches.

Four seismic cables cross around the exterior faces of each strainer module, seen below in Figure 4-1 [2]. The seismic cables provide a surface for fibrous debris to adhere to prior to entering the strainer configuration. The debris that is caught on the cables provides an opportunity for the formation of a debris bridge around the outside of each strainer module, thus reducing the quantity of debris that can pass to the surface of the strainer disks. Therefore, the seismic cable will not be installed for penetration testing.

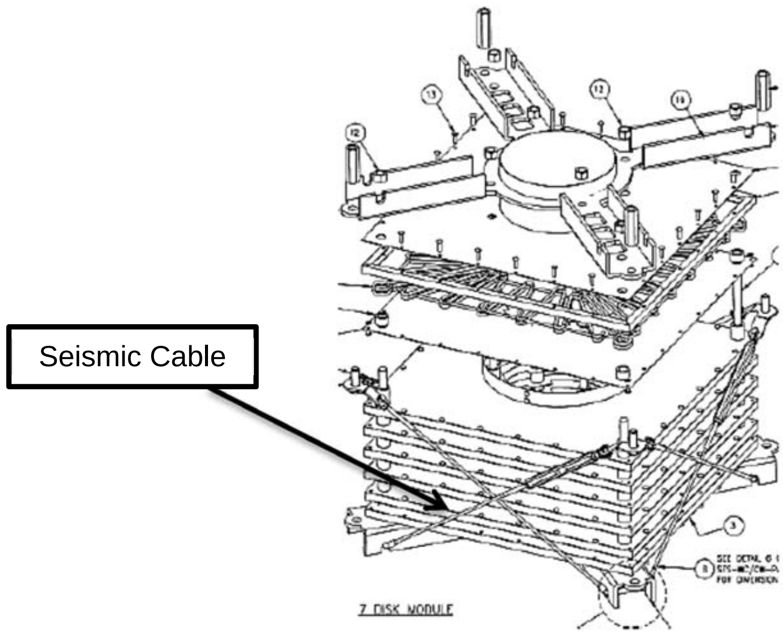


Figure 4-1: Location of seismic cables

The ratio between test strainer surface area and prototypical plant strainer assembly surface area is used to scale plant debris loads to the test strainer surface area. This ratio for debris penetration testing is 0.05695.

4.1.2 Head Loss Test Strainer

For large-scale head loss testing, the disk gap will remain prototypical in order to simulate as closely as possible the plant conditions. The prototypical type-A strainer stacks have 40 disks, for a total of 80 disks used during head loss testing. The surface area of the head loss test strainer, 348.2 ft^2, is based on the surface area of the individual strainer disk provided in 3.1.2.1.

The ratio between test strainer surface area and effective prototypical plant strainer assembly surface area is used to scale plant debris loads to the strainer surface area. This ratio for head loss testing is 0.1056.

4.2 Test Loop Layout

An overview of the experimental setup for large-scale testing is provided in Figure 4-2.

The differential pressure (DP) across the strainer is measured by DP1. Water flows through the strainer, past the isokinetic sampler (installed only for debris penetration testing, and with a location meeting the requirements in Section 3.1.2.5), and through one of two parallel filter housings, or the bypass pipe, each of which is fitted with isolation valve(s) to support both debris penetration and head loss testing. DP2 measures the pressure difference across the filter housings. The pump providing the test strainer suction flow is located downstream of the filter housings (Section 3.1.4.3). A flow meter (FM1/DP3) measures the total flow through the test loop. A temperature probe (T1) is installed in the flow loop to measure the temperature of the test solution. Flow is then split with a relatively small portion directed towards the debris introduction hopper and the transition tank system. The small portion of flow is then directed through one of two flow meters, (FM2/DP4) or (FM3/DP5), which measure the hopper flow and transition tank flow respectively.

The debris introduction flow passes through the hopper and then exits via gravity and travels into the mixing region of the tank. The transition tank operation is described below in Section 4.11. The remaining larger portion of flow which was not directed to the introduction hopper can be partially diverted to pass through a heat exchanger, allowing temperature to be controlled to meet requirements in Sections 3.1.2.3 and 3.1.3.4). Downstream of the heat exchanger flow is combined and enters directly into the test tank through an assortment of mixing nozzles. The loop contains three drains. The first, a large-diameter drain, is located downstream of the flow split for the hopper in the debris mixing piping; this drain is used to drain the loop at the completion of testing. The second, a small-diameter drain, is located upstream of FM2 in the debris introduction flow piping; this drain will be utilized for in-test draining activities. A third drain allows for the transition tank to be drained.

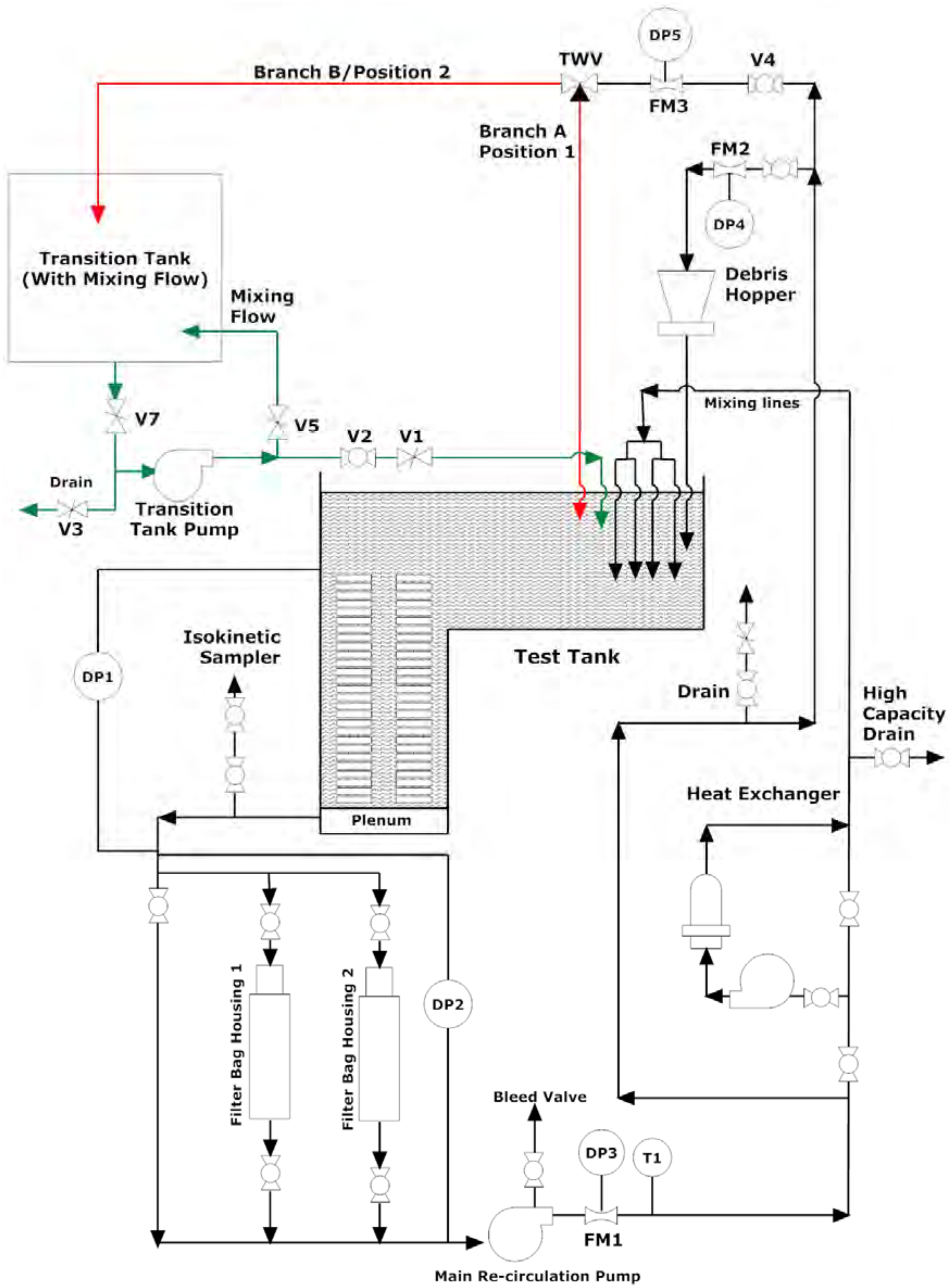


Figure 4-2: Piping and instrumentation diagram (P&ID)

Note: Only the valves for the transition tank set up are labeled with a valve number

4.3 Test Tank Design

This section discusses the test tank that will be employed for both penetration and head loss testing. The test tank will be similar between test types with geometric changes made to the pit for penetration testing. It should be noted that all tank dimensions provided in this section, unless otherwise specified, will be verified to within 1/8" during the facility inspection. If any dimensions are not within a half inch of the specified value the tank volume and the associated debris transport times provided in Section 5.1.3.3 must be recalculated.

The test tank was designed to maintain high enough turbulence to maximize transport of fiber fines to the test strainer and to prevent non-representative settling of small fiber pieces. For the purpose of discussion, the test tank can be conceptually divided into three unique regions. A mixing region will be implemented for debris introduction and dispersion. This region contains mixing nozzles, described in detail in Section 4.7, that provide sufficient turbulence to promote uniform dispersion of debris throughout the water column. A transport region will prevent the turbulence of the upstream mixing region from disturbing debris bed formation. This region will be designed to encourage complete transport to the strainer. A deep pit region, located at the end of the transport region, will house the two test strainer stacks and the components associated with it. The test tank geometry can be seen below in Figure 4-3.

The tank walls of the mixing region and the transport region will be 36 inches tall, measured from the tank floor to the top of the tank side wall. A height of 36 inches is sufficient to accommodate the maximum strainer submergence of 1.51 feet (Section 3.1.4.6) while also providing ample freeboard to safeguard against any unanticipated splashing or tank overflow. These regions will be 27 inches wide to match the width of the downstream pit that will be deployed during penetration testing. The transition between the transport and mixing regions of the test tank is not specifically defined by a geometric change. The individual lengths of these regions will not need to be verified. However, the overall length of the mixing and transport regions, measured from the most upstream wall of the mixing region to the edge of the pit, will be verified to be eight feet during the facility inspection. The upstream dimensions of the test tank will be verified to a half inch during the facility inspection.

The final region of the test tank, the pit, houses the two strainer stacks. The depth of the pit, measured from the floor of the upstream transport region to the top of the strainer base plate, will be the same for both penetration and head loss testing. This depth will be 58 inches [5]. The width and the length of the pit are dictated by the orientation of the two strainer stack and will vary between penetration and head loss testing as described below.

There are two different orientations in which two strainer stacks can be arranged with respect to the approach flow: side by side or one behind the other. By situating the strainer disks one behind the other, the test strainer will model both the internal strainer stack (strainer stacks not located on the perimeter of a 16-stack assembly) and external strainer stacks (strainer stacks located on the perimeter of the 16-stack assemblies). This orientation is more representative of the entire configuration and therefore will be the orientation used during testing.

In order to prevent bridging during penetration testing, and thus increase conservatism, the gap between the edge of strainer modules and the walls of the test tank will be maintained at four inches. The width and length of the test tank will be 27 and 50 inches, respectively. For head loss testing where prototypical bridging results in a more conservative test, all the gaps between strainer modules and tank wall (with the exception of the most upstream gap) will be reduced to 2.5 inches. A 2.5 inch gap allows for the full representation of the two inch symmetry boundary between adjacent modules. The additional half inch accounts for boundary layer effects at the test tank walls which could influence the debris bed development. Therefore, during head loss testing the width and length of the pit will be 24 and 48.5 inches, respectively.

The strainer submergence level bounds, 1.17 feet and 1.51 feet measured from the top of the uppermost strainer disk face to the water surface (Section 3.1.4.6), correspond to the minimum and maximum upstream tank volume of 310 and 360 gallons respectively [6]. The upstream tank volumes considered the entire volume of the test tank upstream of sump edge. The upstream tank volumes will be verified during the facility inspection and used to determine the debris transport time to the strainer in Section 5.1.3.3.

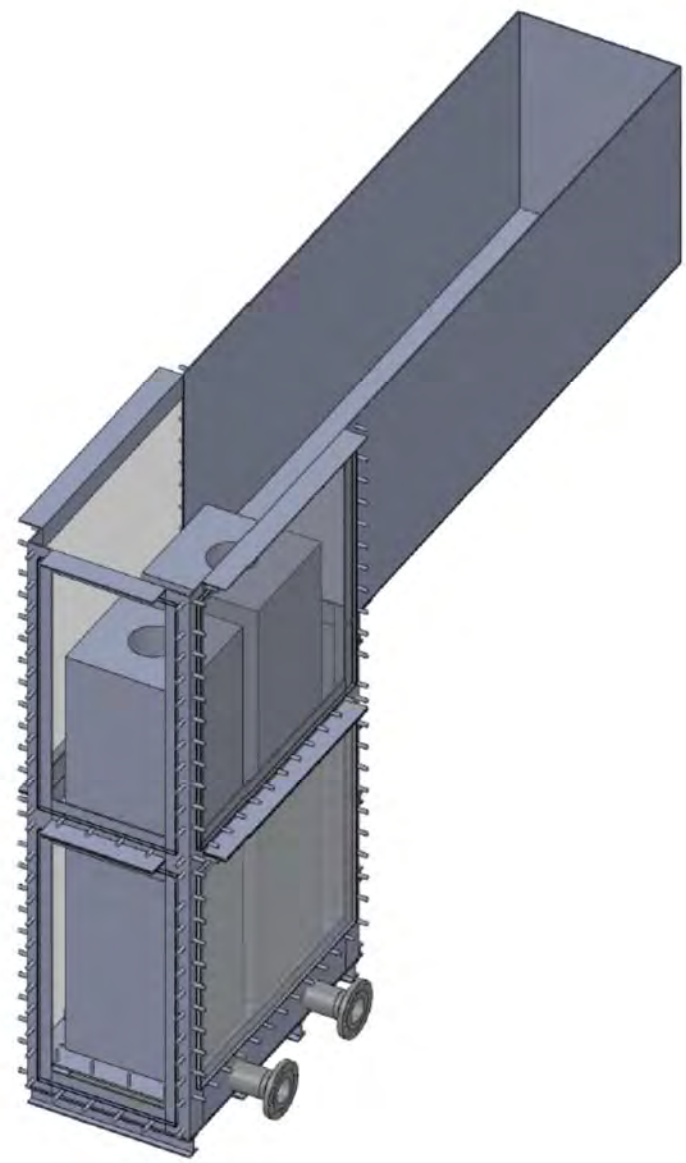


Figure 4-3: Test tank geometry

4.4 Plenum Design

The strainer configuration at WCGS is designed to be flow controlled. The plenum must therefore be designed to draw equal flow from each strainer stack. To achieve equal flow, both strainer stacks will share a common plenum that is segregated into sections with flow channels of similar dimensions. The flow channels will then direct flow to the plenum takeoff piping. The piping will be sized such that the velocity immediately inside the piping is similar to those found at WCGS. There will be two four-inch diameter piping takeoffs, one for each vertical stack. Both discharge piping branches will have identical pipe lengths and fittings until the flow from each branch is recombined by a piping manifold. This ensures that the ensuing losses are the same for each branch. Additionally, caution will be taken to ensure that no debris settles or is caught inside the plenum.

4.5 Fines Introduction System

A debris hopper will be used to introduce the fine debris slurry or particulate slurry (for a head loss thin bed test) into the test tank. The introduction system is designed to fulfil the requirements of Section 3.1.4.1. The introduction system essentially remains online for the entire test in debris penetration and throughout conventional debris addition for head loss testing. The system consists of a debris introduction hopper that releases debris into the mixing region of the test tank in a controlled manner. Figure 4-4 shows a sketch of the debris hopper used for testing. Water flows in through the bottom inlet and out through the side, where gravity feeds the debris slurry from the hopper into the test tank. Flow for the hopper is measured by a flow meter and an associated DP cell. The hopper includes a flow control valve at the inlet. It should be noted that prior to the start of every debris addition the hopper will be inspected to ensure that no residual debris is present.

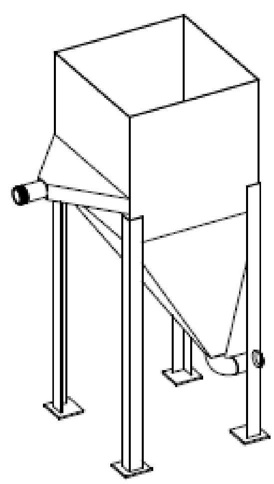


Figure 4-4: Debris hopper sketch

4.6 Fiber Smalls Introduction

For head loss testing fiber smalls will be introduced into the mixing region of the test tank directly. Slowly pouring the debris slurry directly into the mixing region is an acceptable method for introduction. This method will be designed to fulfil the requirements of Section 3.1.4.1.

4.7 Mixing inlet design

The mixing lines will be designed such that sufficient turbulence is provided to fulfil the requirements of Section 3.1.4.7. To achieve this, the piping that provides the mixing flow will be sized such that the velocity of the incoming flow is between 1 ft/sec (to promote transport) and 2 ft/sec (to avoid disturbances to the strainer debris bed). These velocities can be approximated by dividing the total mixing flow proportionally (based on nozzle size) to each mixing nozzle and then dividing the individual flow of a mixing nozzle by the cross-sectional area of that particular mixing nozzle. For head loss testing implementing four mixing lines, each eight inches in diameter will achieve the prescribed velocities. For debris penetration testing the mixing nozzles can be reduced to six inches in diameter to maintain the required velocity range. The exact location of the mixing nozzles will be determined during shakedown test. The final nozzle location will promote complete mixing and transport. The mixing nozzle design will be documented at the start of each test as well as during the facility inspection.

4.8 Piping design

To maintain the pipe velocity requirements from Section 3.1.4.2 at the minimum acceptable flow rate derived in Section 5.1.2, the piping diameter must be smaller than 14.6 inches. For debris penetration testing these requirements must be met by the piping connecting the plenum discharge to the filter housings. For head loss testing the flow velocity requirement must be met by the entire main pipe loop. Take-offs for hopper flow and heat exchangers do not need to meet the requirement as these flows are small relative to the overall recirculation flow.

4.9 Isokinetic Sampling

For debris penetration testing, an isokinetic sampling section must be installed downstream of the strainer in a section of pipe with at least five diameters of straight piping upstream of the sampling section. The sampling section layout will resemble Figure 4-5.

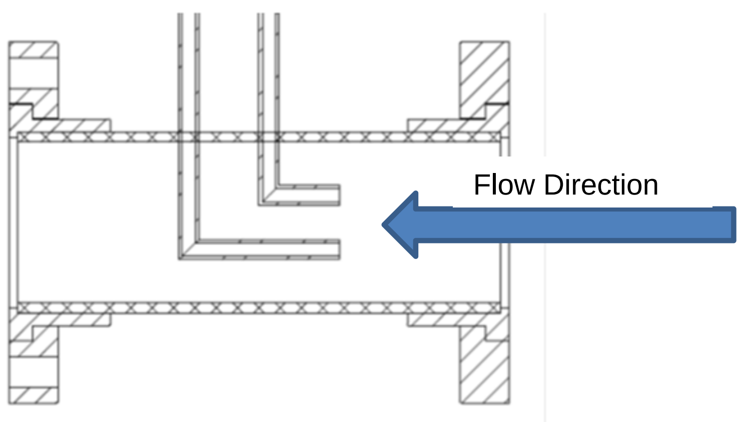


Figure 4-5: Isokinetic sampler

Key requirements for the sampler are as follows:

1) Sample nozzle(s) inner diameter > 0.2" (larger than longest expected debris penetration fiber)
2) Sample nozzle(s) extends more than 3 inner nozzle diameters upstream from vertical penetration.
3) Sample nozzle(s) is (are) visually parallel to the pipe it is installed in.

4) System must contain a minimum of two valves, one to throttle the flow and one to function as a shut-off
5) The sample nozzle should not remove more than 10% of the flow in the pipe

Each nozzle in the isokinetic sampling manifold must be able to be controlled to the correct suction velocity if the manifold is setup for independent nozzle suction. The correct suction velocity is the velocity of the bulk flow at the cross-section in the piping immediately upstream of the isokinetic sampler, at the operating flow rate of the test. In order to avoid the use of a pump, the isokinetic sampling section must be installed below sufficient static water head to require the control valve to be throttled when the shut-off valve is open. The valve position is adjusted by allowing a sample container of known volume to fill in the correct amount of time, as given in Equation (4-1). When a test sample is being taken all nozzles should flow at the same time, substantially reducing the fill time during testing.

$$t_{fill} = \frac{Vol_{sample} \cdot A_{pipe}}{Q \cdot A_{nozzle}} = \frac{Vol_{sample}}{A_{nozzle} \cdot V_{nozzle}} \qquad \textbf{(4-1)}$$

Where:

t_{fill} = Sample fill time (sec)

Vol_{sample} = Sample volume (ft^3)

A_{pipe} = Internal pipe cross-sectional area (ft^2)

Q = Strainer flow rate (ft^3/sec)

A_{nozzle} = Internal nozzle cross-sectional area (ft^3)

V_{nozzle} = Internal nozzle velocity, matches the pipe velocity at the isokinetic sampling location (ft/s)

Fill times should be monitored as testing progresses. Valve adjustments should be made to account for any head loss that develops at the strainer. Before a sample bottle is filled, the water currently in the lines must be purged. The purge time required depends on the sample nozzle length and the operating pipe velocity, as given in Equation (4-2):

$$t_{purge} = \frac{L_{sample} \cdot A_{pipe}}{Q} \qquad \textbf{(4-2)}$$

Where:

t_{purge} = purge time (sec)
L_{sample} = length of the longest sample nozzle (ft)

The number of isokinetic samples to be taken will be as specified in Section 3.1.2.5.

4.10 Fiber Penetration Filtering System

Water and fiber that pass through the test strainer enter a filtering system to collect the fibers during debris penetration testing. The filtering system must meet the requirements described in Section 3.1.2.9. The capture efficiency of the filter bags will be documented during filter qualification [13]. The bag verification procedure also checks the variability in bag capture efficiency by evaluating the capture efficiency of several bags.

4.11 Transition Tank Setup

A transition tank will be used during head loss testing, for both conventional debris additions and chemical debris additions. The schematic is shown in Figure 4-2, with lines associated with the transition tank drawn in red and green, and associated valves labeled V1 through V7, which will be used in describing the transition tank operation. The transition tank allows for an effectively larger test water volume while maintaining strainer submergence within prototypical levels. The contents of the transition tank can be recirculated through the primary test tank or isolated from the flow, with the changeover between the two able to be executed with no change in strainer flow. The transition tank can also be isolated again from all flow and then drained through a filter bag to document the debris contained in the transition tank at the time of draining.

The transition tank is connected to the branch flow via a three way valve (TWV). This valve can either divert flow to the main test tank or the transition tank. Valve (V4) throttles the flow diverted to the three way valve. Branch A from the TWV returns flow to the main test tank. Branch B from the TWV diverts flow to the transition tank. These two branches will have similar piping length and fitting characteristics to provide equal loss. In addition, Branch B will discharge at an elevation that is between the minimum and maximum water levels of the test tank.

A pump below the transition tank will take suction from the bottom of the transition tank and discharge flow back to the transition tank to provide mixing and agitation for its contents. When isolation valve V1 is open, the pump will also be able to move the contents of the transition tank to the main test tank. V2 is used to throttle the flow from the transition tank in order to maintain a flow balance between the flow discharging through Branch B and being withdrawn by the pump. Valve V3 is used to drain the transition tank and must be connected to a filter bag assembly that allows any debris in this fluid to be measured.

4.11.1 Conventional Debris Addition

During conventional debris addition, water level will be maintained within the acceptable limits by diverting flow from Branch A to Branch B as needed, instead of draining water from the system. Drain operations will continue without recirculation from the transition tank until head loss needs to be stabilized. Before the transition tank is put online, adequate mixing of any debris in the transition tank will be visually verified. During stabilization the contents of the transition tank will be recirculated back to the main test tank until a stable head loss has been established.

The hopper will remain on-line during operation of the transition tank.

The operation of the transition tank is discussed in Section 8.8.1.3 for use during conventional debris additions.

4.11.2 Chemical Debris Addition System

During chemical debris additions the transition tank setup allows larger-volume chemical debris additions, while maintaining the required strainer submergence, by initially draining flow from the suction of the strainer to the transition tank. Once chemical debris introduction has concluded the contents of the transition tank can be recirculated back to the main test tank until a stable head loss has been established.

During chemical debris addition, the debris introduction hopper will be taken off-line and isolated from flow. The flow to the mixing lines located in the turbulent mixing region of the test tank will be uninterrupted. The transition tank supply flow will be connected through a branch flow that can also be measured by the transition tank flow meter.

The operation of the transition tank is discussed in Section 8.8.1.3 for use during chemical debris additions.

5.0 Experimental Conditions

5.1 Fiber Penetration Experimental Conditions

5.1.1 Summary of Conditions for Fiber Penetration Testing

All parameters are selected conservatively based on the inputs of the test specification and results of previously executed small-scale test programs. Table 5-1 outlines the parameter values for the first large-scale fiber penetration tests.

Table 5-1: Fiber penetration test parameters

Parameter	Value	Source
Approach Velocity (Section 3.1.2)	0.00612 ft/s	Reference [2], Table 3
Fiber Type (Section 3.1.2.2)	Nukon only	Reference [2] Table 3
Temperature (Section 3.1.2.3)	120 °F	Reference [2] Table 3
Water Chemistry (Section 3.1.2.3)	Boron: 0.1958 mol/L NaOH: 0.1145 mol/L pH: 9.62 @ 80 °F	Reference [2], Section 2.3
Fiber Concentration (Section 3.1.2.4)	0.01504 lbm/ft^3 – 0.02748 lbm/ft^3	Reference [2], Table 3
Strainer submergence (Section 3.1.4.6)	14.0” – 18.1” (from top face of top disk)	Reference [2], Section 2.2

5.1.2 Test Flow Rates

The target flow rate is 518.2 gpm, based on the strainer surface area presented in Section 4.1.1 and the plant-prototypical approach velocity from Section 3.1.2.1. Flow rates will be maintained within a range of +5%/-0% for the fiber penetration tests. Therefore the maximum flow rate will be 551.1 gpm. A flow meter uncertainty of ±2% is sufficient to control the flow rates within these limits.

Table 5-2: Penetration flow rates

Flow Parameter	Value
Total Flow Rate	518.2 gpm
Total Flow Rate +5%	544.1 gpm
Pool Turnover Time	41 Seconds

5.1.3 Fiber

5.1.3.1 Fiber Batching

The plant fibrous debris loads per strainer assembly were given in Table 3-3. The prescribed batch sizes shown in Table 5-3 target the various break sizes. Test debris quantities were determined by scaling the total plant debris loads by the scaling factor from Section 4.1.1. The cumulative bed depth shown below is a hypothetical measurement that was estimated based on the macroscopic density of Nukon (see Section 3.1.2.2).

Batch 1 and Batch 2, when scaled, cumulatively bound the quantity of fiber fines that would be expected for a postulated 10.5”/11.118”/11.5” break, with no margin included. Batches 3 through 8 will be of equal size. The cumulative quantity of the first eight fines batches targets the largest expected break of 31”. No specific intermediate breaks will be targeted. Batch 9 will consist of a 10% margin of the cumulative debris plant debris load. This is reasonable because the model that will be developed as a result of the debris penetration testing will be valid for any given debris load [1].

Table 5-3: Fibrous fines debris batching

Batch #	Batch Size [g]	Cumulative Hypothetical Bed Depth [in]	Incremental Bed Depth Gain [g]
1	1070.66	0.0626	0.0626
2	1070.66	0.1252	0.0626
3	2600.45	0.2772	0.1520
4	2600.45	0.4292	0.1520
5	2600.45	0.5812	0.1520
6	2600.45	0.7333	0.1520
7	1254.31	0.8066	0.0733

5.1.3.2 Fiber Introductions and Concentrations

The fiber concentration within the test tank, defined as the mass of fibrous debris divided by the water volume in the tank, will be targeted within the maximum and intermediate debris concentrations presented in Section 3.1.2.4. Equation (5-1) estimates the peak debris introduction concentration based on the test characteristics. It neglects the fact that the test tank is essentially free of debris at the start of debris introduction. In reality the tank debris concentration slowly rises during the introduction period and typically remains below the target concentration during the entire introduction period. The actual test tank concentration resulting from a debris introduction time calculated from Equation (5-1) is therefore lower, resulting in less potential for agglomeration and is therefore acceptable.

$$time = \frac{w}{Q * C} \quad \textbf{(5-1)}$$

Where:

$time$ = the introduction time (seconds)
w= the weight of the debris batch (lbm)
Q = the flow rate by which the batch will be diluted (ft^3/s)
C = the target debris concentration in the test tank (lbm/ft^3)

The upper and lower time range limits for debris introduction shown in Table 5-4 were calculated using the intermediate and maximum debris concentrations respectively. The introduction time range is provided as a tool to help ensure consistency among debris introduction rather than as an acceptance criterion which must be met. The hopper flow rate does not play a primary role in determining the target debris introduction time. The primary role of the hopper is to provide an opportunity for fiber agglomerations to be broken up prior to reaching the test tank. The hopper flow rate therefore must be sufficient to accomplish this goal and its performance will be verified prior to testing.

Table 5-4: Fibrous debris introduction times for penetration testing

Batch #	Minimum Target Introduction Time [Min:Sec]	Maximum Target Introduction Time [Min:Sec]
1	01:14	02:16
2	01:14	02:16
3	03:01	05:30
4	03:01	05:30
5	03:01	05:30
6	03:01	05:30
7	01:27	02:39

5.1.3.3 Batch and Filter Change Schedule

Fiber additions will occur according to the schedule in Table 5-5. This schedule satisfies the requirements presented in Sections 3.1.2.8 and 3.1.2.11. The first set of reference filter bags will be control filters that document the cleanliness of the test loop prior to debris additions. For each batch the first set of reference filters collect fiber that promptly penetrates the strainer. The prompt penetration filters will remain online until 3 PTOs of the test tank have elapsed following the completion of the bulk fiber addition. This is sufficient as 3 PTOs allows 95% of the fiber remaining in the tank at the end of the debris introduction to transport to the strainer. Following each debris batch introduction, at least one additional set of filter bags will be used to measure the residual shedding of fibers from the bed after the test tank has essentially cleared of fiber. The shedding filter will ensure that the 5 PTO requirement from Section 3.1.2.10 is met. At the end of the test, one set of filter bags is left online for an extended period to collect long term shedding fiber. In each case the time period for shedding fiber collection is marked as a minimum. Debris preparation activities may require longer wait periods. Longer wait periods between batches are acceptable provided all bag filter changes are recorded both in the electronic data acquisition record as well as the manual test log.

It is essential not to allow excessive time to elapse after the completion of the initial debris transport period as doing so could hinder the ability to accurately quantify debris shedding from the strainer. Therefore, if any debris must be reintroduced, testing activities shall continue, i.e. switch to a shedding filter bag, once the bulk of the reintroduced debris has transported to the strainer.

Table 5-5: Bag change intervals

Batch	Contents	Change interval
N/A	Control	10 PTOs
1	Prompt penetration	3 PTOs*
	Shedding fiber	min. 30 minutes
2	Prompt penetration	3 PTOs*
	Shedding fiber	min. 30 minutes
	Shedding fiber	min. 30 minutes
3	Prompt penetration	3 PTOs*
	Shedding fiber	min. 30 minutes
4	Prompt penetration	3 PTOs*
	Shedding fiber	min. 30 minutes
5	Prompt penetration	3 PTOs*
	Shedding fiber	min. 30 minutes
6	Prompt penetration	3 PTOs*
	Shedding fiber	min. 30 minutes
7	Prompt penetration	3 PTOs*
	Shedding fiber	min. 30 minutes
	Shedding fiber	min. 10 hours
* 3PTOs measured from end of introduction		

The transport time implemented after the end of debris introduction is set at 3 PTOs which was calculated to be 2 minutes and 3 seconds based on expected tank dimensions. With the expected tank geometry, the transport time is driven by the turn-over time of the entire region of the tank upstream of the strainer sump. This volume is calculated to be 360 gallons which corresponds with the maximum water level which occurs at maximum strainer submergence. The minimum test flow rate (see Section 5.1.2 will be used to calculate the transport time as this will provide the largest time interval of 3 PTOs. The tank volume used is based on the dimensions in Section 4.3 and will be verified during the facility inspection.

5.2 Head Loss Testing Experimental Conditions

All parameters are selected conservatively based on the inputs of the test specification and results of previously executed small-scale test programs. Table 5-6 outlines the parameter values for the large-scale head loss tests.

Table 5-6: Head loss test parameters

Parameter	Value	Source
Fiber Type (Section 3.1.3.3.1)	Nukon	Reference [3], Section 5.1
Particulate Type (Section 3.1.3.3.1)	Pulverized acrylic, silica flour, PCI Dirt/Dust mix	Reference [3], Section 5.2
Chemical Precipitate Type (Section 3.1.3.3.2)	Aluminum oxyhydroxide	Reference [3], Section 2.6.2
Water Chemistry (Section 3.1.3.4)	Boron: 2406 ppm NaOH: 2.7195 g/L pH: 8.73	Reference [3], Section 5.5
Water Temperature (Section 3.1.3.4)	Conventional debris: 120°F Chemical debris: <100°F	Reference [3], Section 5.6
Approach Velocity (Section 3.1.3.1)	0.00615/0.00348 ft/s	Reference [3], Section 5.7
Strainer Submergence (Section 3.1.4.6)	14.0” – 18.1” (from top face of top disk)	Reference [3], Section 2.3

5.2.1 Flow Rates

The target testing flow is based on the ratio between the plant-prototypical strainer surface area and the surface area of the strainer used in testing (presented in Section 4.1.2), and the plant-prototypical flow rates from Section 3.1.3.1. Flow rates will be maintained within a range of +5%/-0% for the head loss tests. The target flow rates for head loss testing are provided in Table 5-7 below. A flow meter uncertainty of ±2% is sufficient to control the flow rates within these limits.

Table 5-7: Head loss flow rates

Flow Parameter	Value for Conventional Debris Additions	Value for Chemical Debris Additions
Nominal flow rate (gpm)	961.2	544.0
Flow rate +5% margin (gpm)	1009.3	571.2
Pool turnover time (sec)	21	38

5.2.2 Water Chemistry

Prototypical water will be used for the initial tank fill (and flush) as well as debris preparation activities for conventional debris, following the requirements from Section 3.1.3.4. During the facility inspection a small volume of test water will be prepared to establish the target pH for the water at room temperature. Some variation of pH with temperature is expected but the pH of the test water will be checked prior to test start to be within 0.2 of the target pH measured during the facility inspection.

5.2.3 Temperature

The general operating temperature ranges for head loss testing are summarized in Table 5-6. At the completion of conventional and chemical debris additions the debris bed will be characterized as described in Sections 5.2.5 and 8.8.1.4.

5.2.4 Water Level

The water level minimum and maximum will fulfil the requirements described in Section 3.1.4.6. Regular checks of the water level inside the debris tank are essential since debris introduction will result in a rising water level.

As described in Section 3.1.3.8.1, the submergence of the test strainer shall be decreased to 0.5' once the total debris quantity added to the tank reaches or exceeds Point A from Table 3-5. Point B bounds Point A, and will be used as the vortex test during the FDL test.

To maintain an acceptable water level, water must be removed from the test loop after debris additions. It is important to track the potential debris loss that occurs through water level management. Water must therefore be drained downstream of the strainer during conventional debris introduction so that debris has had the opportunity to be filtered by the strainer debris bed. After the chemical debris introduction additions have been completed, it is acceptable to maintain the test tank water level with a sump pump. Furthermore, drain operations must be limited to times where head loss is relatively flat, increasing by no more than 1% per 30 minutes and preferably decreasing. Water must also be drained downstream of the main recirculation flow meter to ensure the drain operation maintains an acceptable strainer flow rate, unless draining is performed via sump pump directly from the tank.

Water that is drained from the test loop is drained through 5 micron filter bags that have been pre-weighed so that the total amount of debris captured by drain operations can be tracked and demonstrated to be negligible relative to the overall debris quantity. For all tests the drain filter bags must be changed at the end of conventional debris introductions, at the least. The filter bag identification and changes must be logged in the log book and the electronic data record.

5.2.5 Debris Bed Characterization

At specified points during the test, the response of the debris bed to different test conditions will be documented in order to establish the flow regime within the debris bed, and the associated actions are called "debris bed characterization" throughout the present document. The temperature will be increased and then returned to nominal, and then the flow rate will be incrementally lowered and then returned to nominal, all following detailed procedural steps outlined in Section 8.8.1.4. The results of the debris bed characterization will be used to justify the extrapolation method for the test results to plant conditions that see lower flow rates or higher temperatures than tested. The combination of temperature and flow sweeps will clarify to what extent the flow field within the debris bed is laminar.

5.2.6 Debris

5.2.6.1 Conventional Debris Concentration

Debris concentration is defined as the mass of debris divided by water volume. The debris concentration within the test tank is managed by controlling the debris introduction time. The relationship between debris concentration and introduction time was provided in Equation (5-1).

Using the relationships set forth above, a target introduction time will be established for each batch containing fibrous debris. The primary purpose of the target introduction time is to provide a parameter to maintain consistency between introductions of similar debris quantities. The actual debris concentration with the test tank is not necessarily meaningful with respect to consistency. Particularly prior to the development of a fiber bed, debris recirculates through the test loop resulting in climbing debris concentrations in the test tank. Additionally, the actual debris introduction time may be limited by the flow rate limitations of the hopper utilized during testing. Once a debris batch of a particular size has been introduced all proceeding batches of similar sizes should target the actual introduction time of the first batch of that particular size.

The initial target introduction time will be based on an average of the maximum and minimum expected debris concentration at WCGS calculated from the minimum and maximum sump pool volumes discussed in Section 5.3 of the debris penetration test spec [2], and the fibrous debris loads associated with Point B and Point K from Table 3-5. This results in minimum and maximum fibrous debris concentrations of 0.00473 lbm/ft^3 and 0.05064 lbm/ft^3, respectively; the average of these two values, 0.0277 lbm/ft^3 [6], will be targeted for head loss testing. Introduction times will be calculated using Equation (5-1).

The introduction of particulate (except dirt and dust) for thin bed testing is not controlled with respect to rate, since all of the introduced debris will continue to circulate until fiber is added later.

Dirt and dust should be added to the tank with a maximum concentration of 0.05 lbm/ft^3. This will ensure that this relatively heavy material is well dispersed in the test fluid. To achieve this concentration, dirt and dust is added over at least 2:35 minutes directly to the test tank during thin bed testing. For the thin bed testing one addition of 17.12 lbm will be completed.

5.2.6.2 Fiber

All fibrous debris for WCGS head loss testing will be modeled using Nukon. Fibrous debris types will simulate prototypical plant heat exposure as described in Section 3.2.1. The characteristics of fibrous fine debris used in head loss testing will be as described in Section 3.2.1. Fiber smalls will be prepared using blankets cut into 2”x2”, 2”x4”, 1”x4” and 1”x6” strips and processed following the methods in Section 3.1.4.5 in order to achieve the range of sizes prescribed in Section 3.1.4.5. The procedure associated with fiber processing is described in Section 8.3.

This debris class will have a greater tendency to settle. Fiber settling shall be addressed per the methods described in Section 3.1.4.8.

5.2.6.3 Chemical Debris

The AlOOH (aluminum oxyhydroxide) precipitate will be generated according to instructions provided in WCAP-16530-NP [19] and described in Section 3.2.3.

Table 5-8 specifies the target preparation concentration in g/L. The provided concentrations are such that samples from the prepared solution do not need to be diluted to be evaluated according to the acceptance criteria discussed below in the last paragraph of this section. The raw debris quantities required do not necessarily fit into the available water tanks. Furthermore, chemical debris will be added in various increments, depending on the evolution of head loss (see below). The first row of Table 5-8 quantifies the total weights of the components to satisfy the recipe given in Table 3-9 and the prototypical amount of AlOOH precipitate (see Section 3.1.3.3.2) scaled to the strainer surface area. The second row of Table 5-8 takes facility limitations into account, where AlOOH precipitate will be prepared in 500 gallon tanks.

The concentrations used in Table 5-8 are selected within the acceptable range to put the calculated volume at a practical volume increment and allow the prepared precipitate to be checked for settling without further dilution.

The verified tanks may not be verified to the exact volume required in Table 5-8. If the verified volume for the total tank is close to the corresponding manufacturer's graduation mark (within ½") then the remaining graduation marks on the tank can also be considered valid for the purposes of providing the starting water volume. This is acceptable since the allowable prepared debris concentration is much higher than the concentrations specified here and small variations in prepared concentration around the volumes prescribed will not affect the quality of chemical precipitates produced.

The flow rate of chemicals will be verified by displacement measurement (time to fill a known volume) at the start and end of each chemical debris introduction. The storage tank levels for the precipitate will also be documented at the start and end of each introduction to confirm the amount of precipitate introduced for each increment. The increments of introduction will be based on the head loss response of the debris bed and the concentration of chemical debris within the test tank. The initial increment for debris addition will be 200 gallons of prepared AlOOH suspension. Subsequent increments will be scaled based on the response of this initial increment. The increments can be increased or decreased depending on the head loss response.

Table 5-8: AlOOH chemical precipitate recipe summary

Aluminum Oxy Hydroxide (AlOOH)		Aluminum Nitrate Nonahydrate		Sodium Hydroxide		Concentration (g/L)	Volume	
15.63	kg	97.71	kg	31.27	kg	2.294	1800	gal
4.342	kg	27.14	kg	8.684	kg	2.294	500	gal

5.2.6.4 Conventional Debris Batching

5.2.6.4.1 Full Debris Load Head Loss Test (FDL)

To achieve a trajectory that bounds the points of interest in Section 3.1.3.8.1, the debris batching schedule shown in Table 5-9, and further broken down in

Table 5-10 and Table 5-11, has been designed using the methodology outlined below.

The scale factor developed in Section 4.1.2 was applied to the provided plant loads to determine the appropriate debris loads for the break points of interest. The amount of debris added to reach each break point will then be divided into manageable batches.

The FDL target points proposed by ENERCON and introduced in Section 3.1.3.8.1, recommend targeting Point B, then Point C, then adding the FDL debris margin, and finally adding to debris Points D, E, F, G, H, J, and K.

Sudden increases in the ratio of particulate to fiber will be avoided. If multiple proposed target points fall very close to a single line, the batching trajectory will follow the particulate to fiber slope defined by that line instead of explicitly reaching each target point. This allows for fewer individual debris batch sizes compared to having a different debris batch size associated with each target point. This allows for increased efficiency in debris weighing, verification, preparation, and introduction, and also reduces the possibility of error.

To maintain more consistent debris additions, the required margin quantities of fiber and particulate will be added in the batching after Point A, resulting in a modified target point C that contains the particulate and fiber margin, C’. In the following text, target points that are primed (e.g. C’, D’, etc.) incorporate the designated debris margin in fiber and particulate. Note that batching from point A to point C’ will nearly pass through point B, adding a slight excess of particulate relative to the ideal quantity. This will be described further in this section below.

The incremental debris quantities between target points will be subdivided to consist of manageable debris batches. The number of batches for each fibrous debris form is constant. For example, if two batches of fine fiber are used to move from one target point to the next then two batches of smalls fiber are also used. The particulate debris will be mixed with the fibrous debris and divided among the fines and smalls based on maintaining a consistent particulate to fiber ratio on a mass basis. No smalls will be added until all additions of fines have been completed for the entire test. Therefore, the smalls quantities for intermediate target points and their corresponding particulate quantity will be reserved. When a designated threshold of head-loss during the addition of fines (with particulate) has been exceeded, all fibrous fines additions will cease and all of the reserved batches of smalls will begin to be added, mixed with the correct amount of particulate, starting with the earliest reserved batches first.

In order to ensure that these reserved smalls quantities do not contain very large amounts of particulate, the smalls debris quantity for point A will be converted to fines (1.44 lbm at test scale).

Figure 5-1 is a plot of fiber versus particulate on a test scale basis. The plot shows the fibrous fines quantities plotted against the associated particulate quantities for points of interest as well as the total fiber quantity and particulate quantity for points of interest. The difference between these two curves represents the smalls quantity and associated particulate. Also shown on the plot is an ideal test result where all conventional debris is added. The test debris curve initially follows the fines points for all points of interest and then begins bridging the gap to the total fiber quantity points through smalls additions and their associated particulate content. Although debris is added in discrete increments, the increments are sufficiently small to require representation as a curve in Figure 5-1.

It should be noted that points A, B, and C represent debris loads without margin, and points C’, D’, E’, F’, G’, H’, J’, and K’ represent points with the desired debris margin accounted for.

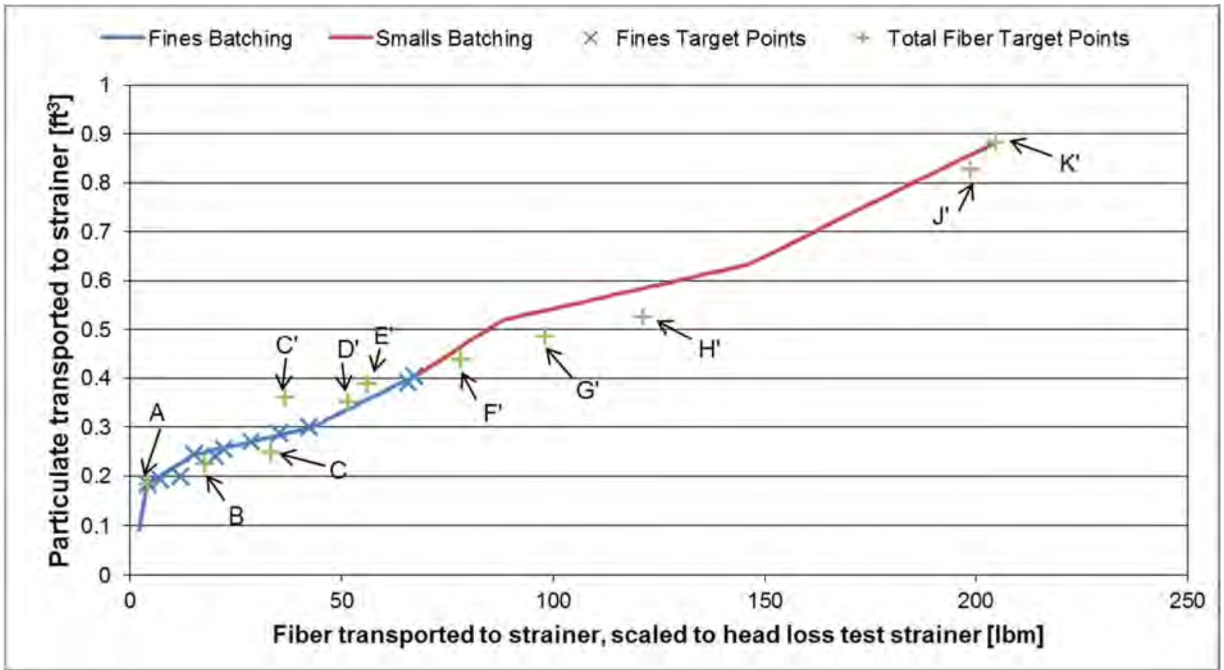


Figure 5-1: FDL batching strategy – all debris added to test tank

Table 5-9 contains the fibrous fines batching schedule for the FDL test. Table 5-10 is the matching table for fibrous smalls. Note that the batching targets the following points explicitly: A, C', H' and K'. Other points of interest (B, D', E', F', G', I', J') are closely approached as debris is added to the tank according to the batching schedule. Table 5-11 shows the batch ID's when these remaining points of interest are most closely approached but bounded and the difference between the target point and the total debris added to the test at that time.

Table 5-9: Debris batching schedule for fibrous fines

Target Point	Batches / Intervals	Fines (lbm)	Coatings Particulate surrogate (ft³)	Thermolag / Foamglas surrogate (ft³)	Dirt & Dust (lbm)
A	2	2.07	0.06549	0.02641	2.877
C'	9	1.22	0.00669	0	0.359
H'	22	1.24	0.00243	0	0
K'	23	1.07	0.00460	0	0

Table 5-10: FDL fibrous smalls

Target Point	Batches / Intervals	Smalls (lbm)	Coatings Particulate surrogate (ft³)	Thermolag / Foamglas surrogate (ft³)	Dirt & Dust (lbm)
A	2	0	0	0	0
C'	9	2.37	0.01303	0	0.70

Target Point	Batches / Intervals	Smalls (lbm)	Coatings Particulate surrogate (ft^3)	Thermolag / Foamglas surrogate (ft^3)	Dirt & Dust (lbm)
H'	22	2.62	0.00511	0	0
K'	23	2.54	0.01088	0	0

Table 5-11: Closest bounding batches to points of interest

Target Point	Closest Bounding Batch	Excess Fiber (lbm)	Excess Particulate (ft^3)
B	A + 4	0.87	0.0377
D'	C' + 4	0.51	0.0397
E'	C' + 6	3.60	0.0188
F'	C' + 11	0.68	0.0069
G'	C' + 17	3.98	0.0035
J'	H' + 22	2.16	0.0394

Figure 5-2 shows a second example of batch additions that could be encountered in testing. For this example, the threshold for finishing fines addition is exceeded after the fifth batch beyond point C’. At that point, the reserved smalls batches are added to the test tank. In this example, the maximum allowable conventional debris bed head-loss is closely approached two batches before the reserved smalls batches have been used up and conventional debris bed addition is therefore stopped. The plot clearly shows the terminal point for conventional debris addition and the points of interest bounded by it. In this case, for example, Point D’ is nearly bounded by the end point.

The final debris batch schedule for the full load debris test may be altered from that presented but Alden personnel as well as Enercon and utility representatives have to approve the final debris load schedule before the first debris addition to the tank. The threshold for termination of fines addition will be determined at the start of the test but will likely lie between 50% and 75% of the allowable head-loss provided in the test specification.

The specific gravity (or density) will be used to convert the provided coatings debris volumes to weights that are able to be measured out for testing. Each batch of particulate surrogate could have slightly varying densities and the conversion is therefore reserved for time of debris preparation.

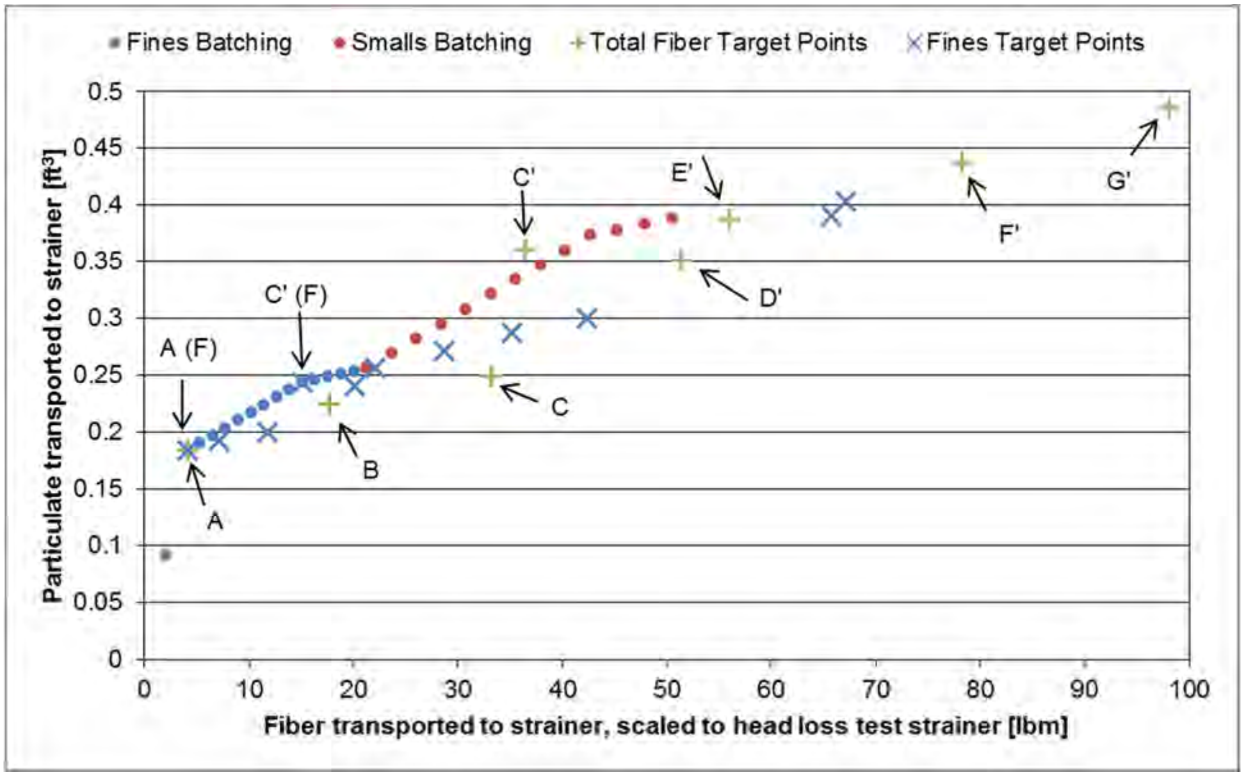


Figure 5-2: FDL batching strategy – partial fines addition with partial smalls addition

5.2.6.4.2 Thin Bed Head Loss Test

The debris batching for the Thin Bed test will follow the requirements described in Section 3.1.3.8.2. All designated particulates will be added to the test first and kept in circulation. Small increments of NUKON fine fiber are then added until head-loss increases from the most recent addition have decreased significantly from the previous additions or the test tank is visually clear with the dominant portion of the particulates having been filtered out by the debris bed on the strainer. The fibrous debris increment used in thin bed testing will be 1800 g, produced in two preparations with 900 g each. A hypothetical 1/16" debris bed thickness using a debris bed density of 2.4 lbm/ft^3 (manufactured density of NUKON) will weigh just above 1950 g.

5.2.6.4.3 Contingency Test

An optional contingency test may be performed based on the results of the first two tests.

6.0 Instrumentation

6.1 Summary

Required instrumentation uncertainties are summarized in Table 6-1.

Table 6-1: Instrumentation summary

Measurement	Minimum range	Maximum uncertainty
Hopper flow rate	20-30 gpm	5% of reading
Total flow rate	300-1050 gpm	2% of reading
Strainer differential pressure	250 inH_2O(Re68°F)	0.5 inH_2O(Re68°F)
Bag filter head loss	150 inH_2O(Re68°F)	5 inH_2O(Re68°F)
Test water temperature	70°F -135°F	±2°F (±1°F for head loss)
Filter bag weights	1500 g	±0.02g
Debris / chemical weight	5000* g	0.05g or 0.5%, whichever is greater
pH meter	7-10pH	±0.2pH
Conductivity meter	5 µS/cm	Allow verification < 5 µS/cm
DAQ board	1-10V	0.2% or demonstrate overall measurement train uncertainty acceptable
Resistance	450-550 Ω anticipated	0.1% or demonstrate overall measurement train uncertainty acceptable
*Smaller scale capacities can be used as long as the aggregate uncertainty of combined measurements is acceptable.		

6.2 Uncertainty Derivations

All uncertainties in the following sections are derived by propagating the uncertainties of each component with the general approach discussed in Reference [9] which uses Equation (6-1).

$$\frac{\delta y}{y} = \sqrt{\sum_i \left(\frac{\partial y}{\partial x_i}\right)^2 \left(\frac{\delta x_i}{y}\right)^2} \tag{6-1}$$

Where:

δy = uncertainty of the measurement in question
y = measurement under consideration
x_i = measured variables that comprise *y*

Equation (6-1) assumes measurement uncertainties are independent (i.e. not due to bias errors). Treatment of bias errors will be discussed in specific cases where appropriate.

6.3 Flow Measurement

Flow rates will be measured using calibrated flow meters installed at various locations within the test loop. The flow-induced deflection across the meter will be monitored with a differential pressure transducer (DP cell) where the measured deflection will be correlated to a flow rate based on Equation (6-2) [8]:

$$Q = C_d A_t \sqrt{\frac{2\Delta p}{\rho(1-\beta^4)}} \quad \textbf{(6-2)}$$

Where:

- Q = flow rate
- Δp = deflection
- C_d = discharge coefficient
- A_t = area of the throat / orifice
- ρ = density of the fluid
- β = beta ratio of the meter (ratio of throat/orifice diameter to pipe diameter)

The discharge coefficient for a given test will be derived by Reynolds number matching, and the discharge coefficient is to be calculated either from a discharge coefficient curve-fit or linear interpolation between the two closest Reynolds number calibration points.

The facility inspection will calculate flow uncertainties and verify that the flow meters installed in the test meet the requirements in Table 6-1 based on these developments. The facility inspection will also develop the meter coefficients that will be required for all planned testing conditions (see Section 7.1). The facility inspect will also include a step to verify that a tag has been affix to all flow meters that could be dismantled stating “Calibrated meter section, do not disassemble”.

6.3.1 Strainer Flow Rate

The total flow rate will be measured using a calibrated flow meter. A maximum uncertainty of 2% will be required, which is adequate to provide a good data resolution for the target flow rates.

6.3.2 Hopper Flow Rate

The hopper flow rate will be measured using a calibrated flow meter. A maximum uncertainty of 5% will be required. The range of flow rates provided for the hopper and corresponding uncertainty has been shown to be adequate in previous similar tests.

6.4 Differential Pressure Measurement

6.4.1 Flow Meter Differential Pressure

The DP cell range for the flow meters can be determined from Equation (6-3).

$$\Delta P_{range} = \left(\frac{Q}{C_d A_t}\right)^2 \cdot \frac{\rho(1-\beta^4)}{2} \cdot \left(\frac{2.307 \cdot 12 \cdot 144}{(60 \cdot 7.4805)^2}\right) \qquad \textbf{(6-3)}$$

Where:

Q = Flow in gpm
C_d = Meter calibration coefficient (from calibration data)
A_t = Area of the throat in in^2
ρ = Density of water in $slug/ft^3$
β = Ratio of throat diameter to pipe diameter
ΔP_{range} = Differential pressure range in inH2O (at 68°F)

As discussed above in Section 6.1, the facility inspection will ensure the chosen measurement equipment is adequate to provide the required uncertainty performance for flow measurement.

6.4.2 Strainer Differential Pressure

The upstream differential pressure tap for the measurement is installed in the tank in a relatively quiescent region of the tank near the strainer disks. The downstream differential pressure tap for the measurement must be installed downstream of the strainer in a length of straight pipe with at least five diameters of straight pipe upstream of the tap location. The tap location must be oriented in such a way that it is unlikely to trap air or be subject to debris clogging. Mounting pressure taps on the top and bottom of piping will be avoided.

Both upstream and downstream strainer differential pressure tap locations must be documented in the facility inspection. It is also necessary to document the piping characteristics between the test strainer and the downstream differential pressure tap during the facility inspection.

Strainer differential pressure will be measured for both penetration and head loss testing. This measurement is not required for penetration testing, but it serves as a good indicator of debris bed conditions, and is useful for observational purposes.

6.4.3 Filter Bag Housing Differential Pressure

Filter bag housing differential pressure will not be measured during head loss testing, because the housings are only online during the cleanliness check at the beginning of the test.

Filter bag housing differential pressure is not a primary output of the test sequence during penetration testing, but it will be measured because it may be used to determine potential problems with the test. For example, excessive head loss across either the filter bags or strainer is not expected for a fiber-only test and could indicate potential contamination of the test loop. These measurements are also useful markers of certain test activities. For example, a filter bag swap will show up in the bag filter DPs as the head loss through each configuration differs slightly. The integrity of the debris bed can be assessed qualitatively through the strainer DP measurement. These objectives can be accomplished even if the uncertainty in the housing DP measurement is relatively high.

6.5 Temperature Measurement

Temperatures will be measured throughout testing. For debris penetration testing, temperatures must be maintained within ±5°F (Section 3.1.2.3); therefore, an uncertainty of the temperature measurement of ±2°F would be sufficient. For head loss testing, the debris bed characterization (Section 8.8.1.3) involves maintaining a narrower temperature range and requires an uncertainty no greater than ±1°F. Temperature measurement below 70°F (below the chemical debris addition temperature limit) and above 130°F (the bed characterization upper limit) will not be required.

6.6 Filter Bag Weight Gain Measurement

6.6.1 Penetration Testing

The amount of debris that passes through the strainer is measured by determining the weight gain in the filter bag between its clean state and its debris-laden state, as prescribed in Sections 3.1.2.6 and 3.1.2.7. A filter bag rating of 5 microns is expected to be sufficient to achieve this goal since Nukon fibers have a nominal fiber diameter of 7 microns [7].

6.6.2 Head loss Testing

Filter bags will also be employed in head loss testing. The filter bag requirements for head loss testing will be identical to those described in Sections 3.1.2.6 and 3.1.2.7 for debris penetration testing. In head loss testing the filter bags are used to document that any debris which may be discarded in test tank drain operations represents a negligible fraction of the overall debris introduced. Pre- and post-processing of these filter bags will be identical to that for debris penetration testing.

6.7 Isokinetic Sampling

During penetration testing, isokinetic samples will be taken 2 PTOs after the start of fiber introductions and 1 PTO after the completion of each debris addition. After testing, select water samples will be processed in accordance with QP-3227 [17]. This procedure, described in Section 8.7.1, prescribes the use of two scales in order to determine the fibrous debris concentration within each sample and to establish a coarse particle size distribution of the fibrous debris in those samples.

The percent uncertainty for each isokinetic sample concentration will be calculated using Equation (6-4) and then multiplied by the respective concentration to determine each uncertainty. This uncertainty calculation accounts for the uncertainty in the following measurements: the mass of the debris retained on the filter discs, the mass of the water in each sample, and the uncertainty in the density of the water. The uncertainty of the isokinetic sample results is dominated by the uncertainty of the scale used to weigh the filter discs. For this reason it is important to select a scale with a low uncertainty to drive down the uncertainty in the concentration measurement.

$$\frac{\delta C}{C} = \sqrt{\left(\frac{\delta \rho}{\rho}\right)^2 + \left(\frac{\delta M_d}{M_d}\right)^2 + \left(\frac{\sqrt{\delta M_{bf}{}^2 + \delta M_{be}{}^2 + \delta M_d{}^2}}{M_w}\right)^2} \qquad \textbf{(6-4)}$$

where,

ρ = Density of water at the temperature of the sample (standard temperature of 20°C)
M_d = Mass of the debris collected by the filter disc

M_{bf} = Mass of the sample bottle filled with the isokinetic sample
M_{be} = Mass of the empty bottle
M_w = Mass of water in sample

6.8 pH Measurement

The pH measurements conducted for these tests are predominately for confirmatory purposes since the concentrations of all test water components are specified directly. A sample of test water shall be prepared during facility inspection; the pH of the test water shall be compared to the water prepared during facility inspection. The uncertainty requirements provided in Table 6-1 will allow the final test water characteristics to be documented and monitored with sufficient accuracy. The range requirement covers the expected pH range provided in the test specification [2] [3] (see Sections 3.1.2.3 and 3.1.3.4).

6.9 Data Acquisition System

A data acquisition is required to monitor electronic sensors used in the test. To accommodate the stated test requirements, the data acquisition system must be able to accommodate five differential pressure measurements and a temperature measurement. In order for the data acquisition to have negligible impact on the overall measurement train uncertainty, an uncertainty of less than 0.2% for voltage measurement of between 1 and 10 V is necessary. Alternatively, satisfactory performance for the overall measurement train can also be demonstrated during the facility inspection using a properly executed propagation of error calculation.

6.10 Ohmmeter

An ohmmeter is required to measure the resistance that converts the output signal of some differential pressure transducers from current to voltage. The accuracy of this resistance measurement affects the accuracy of the measurement train. By ensuring the uncertainty of the resistance measurement is lower than 0.1% the influence of this measurement can be neglected in the overall measurement train for the tests considered here. Alternatively, the entire measurement train may be analyzed to demonstrate satisfactory measurement train performance using calculations during the facility inspection.

6.11 Conductivity meter

A conductivity meter will be used to verify adequate deionized water characteristics in the production of prototypical water. The conductivity meter must be able to verify that the water produced has a conductivity below 5 μS/cm. Greater uncertainties in the meter will require a lower reading in order to ensure the true conductivity is below the limit.

6.12 Scales

Table 6-1 details several purposes and scale ranges required. For filter bag measurements, up to 6 filter bags will be measured together. This requires a relatively high initial range for the filter bag weight measurement while maintaining an uncertainty of 0.03 g in order to be compatible with the weight convergence criterion of 0.05 g. For debris quantity measurements, requiring an accuracy of 0.5% of measurement ensures that uncertainties in the debris addition weights have a negligible effect on overall test response. Specifying a lower limit for this uncertainty of 0.05 g is appropriate since the total debris additions in these tests will be much greater and any debris that is measured with an accuracy of 0.05 g will be adequately characterized relative to its weight. A relatively large range on debris weights is required since the quantities that will be measured are large (see Sections 5.1.3.1 and 5.2.6.4, for example).

7.0 Testing Scope & Limitations

7.1 Test Scope

7.1.1 Fibrous Debris Penetration Tests

One penetration test will be performed, in accordance with Section 3.1.2.12. The parameter values have been outlined in Table 5-1.

7.1.2 Head loss Tests

The two head loss tests described in Section 3.1.2.10 will be performed. Parameters for these tests are outlined in Table 5-6.

7.2 Limitations

Test limitations of the test setup and processes described in the present test plan include:

- The strainer operating head loss will be limited to around 20 ft to stay in a measureable range. Larger head loss could result in the loss of NPSH to the test pump.
- The materials selected will allow for operation up to 130±1^{o}F and do not have a higher limit (facility uses PVC piping).
- The maximum strainer submergence guaranteed to be possible using the current test facility is approximately 22 inches which is greater than the maximum required strainer submergence of 18.1 inches.
- Operation of the facility will be limited by the range of the flow instrumentation installed, the capacity of the pump (approximately 1000 gpm), and the head loss across the strainer (20 ft). The low flow rate accuracy limit for the flow instrumentation and the high flow rate limit for the installed flow instrumentation will be determined in the facility inspection.
- The largest continuous chemical debris addition is 500 gallons limited by the volume of the transition tank.

8.0 Test Processes

8.1 Filter Bag Weighing

Filter bag weight determination is controlled under the Alden QAP, QP-3203 [10]. This procedure meets the requirements described in Sections 3.1.2.6 and 3.1.2.7.

All fabric filter bags within the necessary capture rating are made from synthetic fibers that are to some extent hygroscopic. It is therefore important to measure both the clean and debris-laden weights in an environmentally controlled chamber at the same relative humidity before and after the test. In both the clean and debris-laden states, the filter bags will be inserted into an oven for more than an hour before being cooled and then placed in the environmental chamber. The oven temperature will be selected to remain below the rated operating temperature of the filter bags. In order for a converged weight to be obtained, consecutive weight measurements must be within 0.05 g of each other. Note that debris-laden filters are rinsed with deionized water prior to drying in order to remove any residual chemicals from the filters.

8.2 Water Generation

Test water generation is controlled under the Alden QAP, QP-3220 [14]. The test water will be prepared per the requirements described in Section 3.2.2. The conductivity meter will have sufficiently good uncertainty to confirm the conductivity of the water meets this criterion.

The chemicals used to produce the water must have a purity of greater than 97%. The purity of the chemicals may be taken into account when producing the water to provide a concentration that meets the target requirements, if the purity is below 97%. Chemicals with purity below 95% must not be used since a greater amount of unknown impurities are introduced into the test tank when the chemical purity is below 95%.

The test solution is made as follows. DI water is poured into a clean mixing tank, up to a verified graduation marking. Boric acid and NaOH are weighed out to provide the proper concentrations at the specified water volume. The water is continuously mixed while the boric acid is slowly poured into the tank. After mixing for ten minutes or until all of the boric acid has dissolved, the NaOH is slowly poured into the tank.

8.3 Fibrous Debris Preparation

For all fibrous debris preparation, Alden will confirm that debris materials have been properly heat-treated. Nukon blankets are treated so that approximately 50% of the Nukon blanket has visible binder burnout. Fibrous fines will be prepared using QP-3221 [15], which meets the standards discussed in Section 3.2.1.

8.3.1 Fiber Smalls Preparation

Fiber smalls preparation will be controlled by the same procedure as fines production (QP-3221 [15]), however the prepared debris must have a wider range of class sizes (see Section 3.1.4.5). Nukon blankets for smalls preparation are to be cut into 2”x2”, 2”x4”, 1”x4” and 1”x6” strips in order to meet the requirements of Section 3.1.4.5. Equal proportions of each of these sizes by mass are pressure washed separately until the desired distribution is obtained. The acceptance criteria defined here will be noted in the executed QP-3221 procedure. Once the fiber smalls requirement is met by all parts of the batch, the different sized components of the batch are combined. Light table photographs will be used to document that the chosen preparation duration was sufficient for each component of the fiber smalls batch.

8.4 Particulate Debris Preparation

Particulate debris must be prepared as a wet slurry. In preparing the slurry it is important to use the appropriate test water (see Section 5.2.2) and ensure that no foam is generated during the wetting process. Particulate debris may be prepared in advance of testing to ensure no floating particulate debris remains when the debris introduction is begun. The debris slurry must be sufficiently dilute to allow a determination to be made relative to the amount of remaining floating debris. A layer of clear water should develop after a successful wetting process, indicating that no debris remains floating.

When adding particulate during thin bed testing, the debris introduction concentration does not need to be controlled. During both the full debris load test, the particulate will be mixed with fiber prior to introduction and the introduction rate will be based on fibrous debris concentration requirements. For thin-bed testing, the particulate types must remain separate.

PCI PWR Dirt and Dust Mix is added to the test in a dry form. The dirt and dust will be sprinkled directly into the test tank for the thin bed test and added to the fibrous debris slurry for both the full debris load tests. The dry addition method for the thin bed test prevents clumping. The material in the dirt and dust mix is resistant to foaming and will not float.

8.5 Chemical Debris Preparation

Chemical debris preparation will occur according to QP-3222 [16], which follows the precipitate generation methodology in WCAP-16530 [19].

No time requirement is given in WCAP-16530 for ensuring dissolution of the aluminum nitrate and no specific debris addition rate limits are provided. The ingredients are to be added slowly. However, once the chemicals have been mixed, mixing is to continue until the pH is stable within 0.1 over 15 minutes, an indication that the chemical reaction has come to completion.

The purity of the base chemicals is not prescribed in WCAP-16530. A purity of 98% or greater will be required for solid ingredients to ensure high quality precipitates are generated.

The precipitates are generated at concentrations that allow the settling tests to be run directly from the debris suspension produced, as outlined in Section 5.2.6.3. All of the chemical precipitates produced have to pass the acceptance criteria provided in Section 5.2.6.3 prior to introduction to the test loop.

8.6 Facility Preparation

A typical test will include facility and strainer cleaning, strainer installation, test setup, test execution, and drain down.

Facility cleaning will require the strainer to be removed from the test loop. The tank will be visually examined to verify all debris has been cleared from the tank. The strainer assembly is visually inspected for cleanliness and then installed in the facility. The facility will then be filled with test water. The facility must be flushed and drained using new water before filling it for the test. Once the facility is filled with the appropriate water for the test, the data acquisition setup is checked to ensure all instrumentation is working and instrumentation alignments are correct. Then a set of clean, 1-micron, non-reference filters are put online for 10 PTOs of the total test tank and are checked for visible residue. Once one set of these pre-cleaning bags is acceptable, the test may proceed. For a debris penetration test, a reference filter bag set will be put online for 10 PTOs of the total test tank volume without debris addition to document that the facility is clean at the start of the test.

For all tests, the test tank water temperature is brought to 120°F±5°F during facility preparation activities. For head loss tests, the test tank level must be adjusted to the minimum tank level prior to starting debris addition in order to delay draining as long as possible.

Finally, the facility preparation portion of test procedures must assess the behavior of the strainer losses measured under clean conditions between the upstream and downstream pressure taps. These measurements allow the head loss that is due to debris accumulation to be determined with accuracy. The head loss measurement includes the losses through the clean strainer disks, flow through the suction takeoff and attached piping to the location of the downstream pressure tap.

8.7 Debris Penetration Test Procedure

The first set of 5-micron reference filter bags verifies that the test loop is free and clear of debris. The second set of 5-micron reference filter bags is installed in the offline housing and is put online when the first set of bags are taken offline. The second set of filter bags is for Batch 1 to collect promptly penetrating fiber. A third set of filter bags is loaded into the offline filter housing to collect the shedding debris from Batch 1. The pH and temperature of the test fluid are verified. The flow rates through various portions of the test loop are set and checked.

Fibrous debris is then carefully added to the introduction hopper, and the test tank water level is maintained via the drain located downstream of the filter housings. The fibrous debris introduction is photographed. At two PTOs after the start of the batch addition and again one PTO after the completion of the batch addition, two isokinetic test water samples are collected downstream of the strainer and upstream of the filters. Three PTOs following the conclusion of the bulk fiber introduction via the hopper, the filter bag assemblies may be swapped, so long as a large fraction of the fiber has transported to the strainer. If any debris that has been observed to be floating or settled is re-entrained or reintroduced, additional time should be allowed for the bulk of the re-introduced debris to transport to the strainer. The disturbance of any settled fiber after debris introduction will only be performed once per introduction prior to the end of the 3 PTO wait period at the end of fiber introduction. Any debris that has resettled will be collected and stored for post processing. The fiber bed is photographed at the end of each batch. This process is repeated according to the schedule in Table 5-5, which includes several sets of filter bags designated to collect shedding fiber. The last shedding filter bag set is left online for at least ten hours, possibly overnight. After the test is drained down, any non-transported fiber fines that settled outside of the immediate strainer vicinity will be collected for measurement.

8.7.1 Isokinetic Sample Processing

For the penetration testing, two sets of two isokinetic samples will be collected. The first set will be collected 2 PTOs after the start of each debris addition. The second set will be collected 1 PTO after the completion of each bulk debris addition. The isokinetic samples will be processed under QP-3227 [17]. This procedure establishes the concentration of fibrous debris in the test water downstream of the debris bed along with a coarse size distribution of the debris within each sample. Each sample is filtered through three filter discs of decreasing nominal pore size diameter: 20, 5 and 0.1 micron. Prior to sample processing, filter discs will be rinsed with DI water, dried in the oven, and then pre-weighed. After samples have been filtered through a filter of each nominal pore size the filter discs are again dried in the oven and weighed. The weight gain for each disc is then determined. The full and empty weights of the sample bottles are also measured to determine the volume of each sample on a gravimetric basis.

The ultimate goal of sample processing is to provide data for validation of the penetration model that is being developed based on collected filter bag weight gains. The penetration concentration with respect to time is an output of the penetration model. Depending on the results, a subset of the collected samples may be sufficient to obtain the desired validation of the model. Therefore, all samples will not necessarily be processed.

8.8 Head Loss Test Procedure

The head loss test procedure varies slightly between types of test being performed. Both of the full debris load tests are described first in Section 8.8.1.1 followed by the thin bed test in Section 8.8.1.2. The procedures for the transition tank, debris bed characterization, and chemical debris addition are discussed at the end in Sections 8.8.1.3, 8.8.1.4, and 8.8.1.5, respectively, since these activities apply to all three head loss tests with no change.

8.8.1.1 Full Debris Load (FDL) Test

The objective of the FDL test is to measure the head loss that occurs for debris quantities that are representative in debris quantities and composition to those that may occur in the plant without exceeding the pre-determined plant NPSH margin at peak sump pool temperatures. The debris quantities and composition were discussed in Section 5.2.6.4.1; the allowable NPSH margin, which defines the acceptable conventional debris head loss margin, was discussed in Section 3.1.3.2. If at any point during the test should 80% of the allowable head loss margin be exceeded (NPSH margin for conventional debris additions, strainer structural design pressure for chemical debris additions), debris addition will cease in order to establish a firm head loss plateau prior to continuing debris additions. A firm head loss plateau is described in Section 3.1.3.6. This definition of establishing a firm head loss plateau will apply throughout head loss testing.

The FDL test will batch in mixtures of fibrous, particulate, and dirt and dust debris until certain hold points have been reached. The batching schedule was previously detailed in Section 5.2.6.4.1. The test will proceed in the manner outlined in Section 3.1.3.8.1.

During debris introductions the test loop temperature must be monitored carefully since the introduced debris will be at a temperature lower than the test loop.

As the head loss approaches the full conventional head loss margin and a firm head loss plateau has been established, an optional debris bed characterization may also be performed to ensure that a characterization with remaining head loss margin exists, should the next debris addition result in unacceptable head loss (see Sections 5.2.5 and 8.8.1.3).

As debris additions continue, water level must be maintained. The water level will be controlled by periodically diverting flow to the transition tank by changing the alignment of the TWV as described in Section 4.11.1. The hopper will remain on-line during transition tank operation. More procedural details pertaining to the transition tank are given in Section 8.8.1.3. At the end of conventional debris addition, the debris bed will be characterized using both a temperature and flow sweep (see Section 8.8.1.4).

8.8.1.2 Thin Bed (TB) Test

The thin bed test introduces particulate and particulate-like debris first followed by incremental introductions of fibrous debris. The target conventional debris for the TB test is described in Section 5.2.6.4.2 and in Table 5-10. The total quantity of particulates to be used in the test is wetted as described in Section 8.4 and introduced into the test tank followed by the total plant debris quantity of dirt and dust, which will be introduced dry, directly into the test tank.

These debris additions are then followed by successive additions of fibrous debris quantities described in Section 5.2.6.4.2, and following the requirements of Section 3.1.3.8.1.

The transition tank will be utilized in order to limit draining of the test tank to the greatest extent possible. The water level will be controlled by periodically diverting flow to the transition tank by changing the alignment of the TWV as described in Section 4.11.1. The hopper will remain on-line during transition tank operation during conventional debris additions. More procedural details pertaining to the transition tank are given in Section 8.8.1.3.

After each introduction, the test tank is examined to determine whether the existing debris bed has filtered most of the small particles originally in circulation. To make a determination as to the head loss increase after each addition, the specifications from Section 3.1.3.6 should be followed. If any of the stopping criteria from Section 3.1.3.8.1 have been met, fibrous debris additions will end and the developed debris bed will be characterized.

8.8.1.3 Transition Tank

The transition tank setup was previously described in Section 4.11, with a piping schematic given in Figure 4-2, with details specific to conventional debris addition described in Section 4.11.1, and details specific to chemical debris addition described in Section 4.11.2.

For both conventional and chemical debris additions, test water will be diverted into the transition tank in order to maintain an acceptable water level within the test tank without draining debris from the test. When the water level in the transition tank allows for the mixing flow return of the transition tank pump to be submerged, the transition tank pump is turned on to recirculate the water in the transition tank and keep any associated debris from settling or agglomerating.

When the procedure calls for head loss stabilization, the contents of the transition tank will be circulated through the test tank. The transition tank recirculation isolation valve (V1) is opened. V2 is adjusted to maintain a constant level within the transition tank (which will also maintain a constant water level in the test tank). At least 1 PTO for the transition tank volume must be waited to determine if the water contained in the transition tank is able to contribute to head loss. If 200 gallons are in the transition tank and the flow rate into the transition tank is 10 gpm, a minimum of 20 minutes must elapse without significant head loss change in order to confidently declare that any debris contained in the transition tank will not affect head loss. Once a stable head loss has been achieved with the transition tank online (at least 1 transition tank PTO after the end of debris introduction), the TWV is switched to the main test tank and transition tank recirculation isolation valve (V1) is closed. The transition tank is now isolated from the main test tank. The transition tank pump is then secured and the water in the transition tank is drained through a filter bag to document the absence of significant debris in the water being drained. This process is repeated for all conventional and chemical debris additions.

8.8.1.4 Debris Bed Characterization

Debris bed characterization is important to establish the flow regime within the debris bed. To provide the most stable test tank conditions, the test tank must not be drained during debris bed characterization activities. Refer to Section 5.2.5 for discussion on how the data obtained from the debris bed characterization will be used.

Following and potentially during conventional debris addition, the debris bed can be characterized by using both a temperature and a flow sweep. The head loss is first stabilized to the point that head loss is changing by less than 1% per hour, maintaining flow to within -0%/+2% and temperature within one degree of 120°F. Using this criterion will allow any observed changes in head loss to be attributed to changes in test water temperature or flow rate rather than permanent changes in the debris bed characteristics. The conventional debris bed is first characterized by a temperature sweep. The temperature sweep is executed by raising the temperature of the test loop to 130°F±1°F and again maintaining the flow rate to within -0%/+2%. These conditions are maintained until the head loss steady state is achieved with a change of less than 1% per hour. If conventional debris addition is to continue, debris addition may resume before the temperature returns to 120°F. If conventional debris additions have concluded, the temperature of the test loop is reduced back to 120°F±1°F, once again achieving a steady state head loss condition (less than 1% change per hour). Once steady state has been documented again, a flow sweep will be performed by decreasing the test flow rate in approximately 10% increments down to 60% of the nominal flow and then slowly increasing the flow rate back to the nominal flow rate. At each flow rate, a short wait period will be implemented to allow the head loss reading to stabilize. It is expected that this occurs fairly quickly, within 5 minutes at each point. Completion of these steps marks the full characterization of the debris bed, after which chemical debris additions can commence.

After chemical debris addition, the debris bed can no longer be characterized using temperature sweeps since the resulting debris bed response is obscured by the sensitivity of chemical debris solubility to temperature. The debris bed is characterized using a decreasing velocity sweep down to 60% of the post chemical debris addition flow rate, similar to that conducted during conventional debris bed characterization. Once the flow rate has been returned back to the full test flow rate and steady state conditions have been reestablished, the test temperature is gradually allowed to drift downward to document how the debris bed responds to lower temperatures and higher viscosities. The final steady state temperature must be lower than 85°F but above 70°F. Once the temperature has been stabilized to within one degree and the head loss has reached a steady state (less than 1% change per hour), a final flow sweep is conducted, again down to 60% of the target test flow rate in at least 4 steps. The flow rate is then slowly returned to the target flow rate. Finally the flow rate is raised to the original conventional debris addition flow rate. Steady state conditions are reestablished before the test is allowed to be terminated.

8.8.1.5 Chemical Debris Addition

Regardless of the type of head loss test, the procedure for chemical precipitate debris addition will not change.

The specified chemical precipitate loading consists solely of Aluminum Oxy Hydroxide (AlOOH). Chemical debris introductions will occur at the target chemical debris introduction temperature specified in Section 3.1.3.3.2.

Chemical precipitate debris addition increments are dependent on the debris bed response. When the debris bed is sensitive to debris addition, the incremental additions will be relatively small. When the debris bed becomes less sensitive to chemical precipitate addition then the debris increments will increase. The precipitates will be pumped into the test tank. A volumetric flow rate measurement will be made by measuring the time to fill a container to a known volume immediately prior to an incremental volume addition and immediately after termination of an incremental volume addition. The debris addition increment calculated from the flow rate measurements and the duration of introduction is verified by documenting the level drop in the source tank of the chemical precipitate. AIOOH additions will continue until the plant design quantities have been reached, the addition of precipitate does not produce a new head loss peak, or the head loss has exceeded the acceptable limit defined in Section 3.1.3.2..

The transition tank setup was previously described in Section 4.11, with details specific to chemical debris addition described in Section 4.11.2. After the end of the conventional debris bed flow sweep, with the hopper flow secured and the TWV aligned back to the test tank, V4 is throttled to the total chemical debris introduction flow rate, as measured by the hopper flow meter. The transition tank is verified to be clean and empty, with the drain valve closed. When chemical debris introduction starts, the TWV is switched and aligned to discharge into the transition tank. The procedure regarding the transition tank is then followed as described in Section 8.8.1.3.

Chemical debris addition for a given batch may be terminated for four reasons:

1. a rapid change in head loss, given by a combined increase of more than 0.5 psid and 20% from the start of the introduction for the current batch

2. the head loss has reached 80% of the acceptable limit to be provided by WCGS
3. capacity in the transition tank has been exceeded, or because
4. a chemical debris supply tank switch must occur.

If chemical debris introduction must be terminated before the completion of a batch, then the procedure regarding the transition tank as described in Section 8.8.1.3 is also followed.

9.0 Test Acceptance and Termination Criteria

9.1 Debris Penetration Testing

The acceptance of the data for the debris penetration test depends on the following criteria:

- The total flow rate (flow through the strainer) was maintained within the range of 0 to +5% of the target for a minimum of 98% of the test duration. This considers the short term changes (<5 seconds) in flow that are associated with swapping filter housings or putting the debris hopper online or offline. Maintaining the flow in the required range for 98% of the test period promotes more repeatable test results.
- The test temperature must be maintained within 5°F of the target for a minimum of 98% of the test duration. This should allow for minor variations that may occur while adjusting the heat exchanger, but will maintain the proper test temperature during debris batch introductions and therefore will prevent significant deaeration and related debris bed effects.
- The control bag from the facility cleaning has a post-test weight within 5 g of its clean weight.
- Bag filter weights must be converged to within 0.05 g of successive readings in similar relative humidity environments.

Test termination can occur once the last reference filter bag was online for the required amount of time. Test engineer judgment will determine if any event may require premature termination. These types of events could include vortexing, facility failure, power loss, or safety risk to test personnel and test witnesses.

9.2 Head loss Testing

For head loss testing the following acceptance criteria apply:

- During conventional debris additions the flow rate is maintained between 0% and +5% of the target flow rate and the temperature remains within 5°F of 120°F.
- During chemical debris additions the flow rate is maintained between 0% and +5% of the target flow rate and the temperature remains within 5°F of 95°F.

The head loss test will be terminated once the total chemical precipitate quantity has been added, the facility limit in head loss has been reached or the last chemical debris addition did not produce a new head loss peak. The debris bed in this state must be characterized according to Section 8.8.1.3 prior to termination including achieving a final temperature below 85°F.

9.3 General Acceptance / Termination Criteria and Documentation Requirements

The following are general acceptance criteria applying to all tests:

- The instrumentation employed must meet the uncertainty requirements in Table 6-1.
- Purity of chemicals to produce chemical precipitates must exceed 98% and to produce test water must exceed 97%.
- Filter bags for penetration testing must have a minimum retention rating of 97%.

The test may be terminated at any time for safety reasons.

If at any point during testing the differential pressure across the strainer exceeds the design limits the flow rate must be reduced or the test terminated [3].

Both manual and electronic records will be maintained to document the testing, pertinent data, and test activities. The records will reflect all test observations made by the test personnel and witnesses, as appropriate. Photographs will be utilized to document various test activities.

Any deviations to the stated test acceptance and termination criteria must be addressed in the test report but may not invalidate the test, depending on the deviation. All deviations from the test procedure must be handled in accordance with the Alden QAP. In addition, explicit written approval must be obtained from ENERCON and/or the utility representative witnessing the testing.

10.0 Safety

The testing controlled by this test plan will involve several potentially hazardous activities. The items below address project-specific hazards and are not intended to represent a complete list. All safety hazards should be discussed in the safety brief conducted at the start of each test day. To ensure a safe work environment, the following will be adhered to:

- The material handling and preparation procedures for insulation materials have been implemented to ensure proper precautions are taken by personnel preparing debris (QP-3205 [11]). Personal Protective Equipment (PPE) is supplied by Alden, including safety glasses, various types of gloves, face masks, and full body suits (e.g., Tyvek).
- Chemical handling procedures have been implemented to ensure safe handling, storage, and disposal of the chemicals to be used under this Test Plan (QP-3206 [12]). Proper PPE should be employed.
- Hot water will be used during test execution. All personnel in the vicinity of the test setup should be made aware of the test temperature.
- Slipping and tripping hazards may be present near the test setup. Numerous overhead hazards also exist above and below the testing deck. Test personnel should be made aware of hazards and should take steps to eliminate potential hazards wherever possible.

11.0 Procedure List

Table 11-1 provides a comprehensive list of the procedures that are expected to be leveraged in the execution of testing under this Test Plan. Procedures designated with “QP” are generic Alden QAP procedures that will be used in the execution of the tests and associated post-processing. The project-specific procedures listed here will be included in the revision to this test plan that documents executed testing.

Table 11-1: Procedure list

Procedure ID	Title
QP-3201	DP cell check
QP-3202	Temperature probe check
QP-3203	Filter bag weighing
QP-3205	Debris handling
QP-3206	Chemical handling
QP-3207	Calibration solution handling
QP-3208	Handling and storage of samples and filters
QP-3209	pH meter calibration
QP-3210 and/or QP-3217	Conductivity meter calibration
QP-3214	Filter qualification
QP-3215	Chemical verification
QP-3219	Debris heat treatment
QP-3220	Test water generation
QP-3221	NEI Fiber fines debris generation
QP-3222	Chemical precipitate debris generation
QP-3227	Filter Disc Method for the Size Distribution of Suspended Solids
1156WCGSI-450	Large-scale facility inspection procedure
1156WCGSI-451	Large-scale penetration test procedure
1156WCGSI-452	Large-scale head loss test procedure

12.0 References

[1] 1162WCGSI-200-00, “Wolf Creek GSI-191 Testing Project Plan”.
[2] 1162WCGSI-101-00, “Large-Scale Fibrous Debris Penetration Test Specification for Wolf Creek Generating Station”, ENERCON WCN-021-DSPEC-001, Rev. 0B, March 2016.
[3] 1162WCGSI-102-00, “Large-Scale Head Loss Test Specification for Wolf Creek Generating Station”, ENERCON WCN-021-DSPEC-003, Rev. A, March 2016.
[4] TDI-6003-01, “SFS Surface Area, Flow & Volume”, Rev. 0, October 2006.
[5] 1162WCGSI-103-00, “Wolf Creek Drawing Packet”, February 2015
[6] 1162WCGSI-104-00, “Wolf Creek Test Plan Calculations” , February 2016
[7] Nuclear Energy Institute, “ZOI Fibrous Debris Preparation: Processing, Storage and Handling,” Rev. 1, January 2012
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[10] QP-3203, Filter Bag Weight Determination
[11] QP-3205, Debris Handling.
[12] QP-3206, Chemical Handling.
[13] QP-3214, Filter Bag Qualification.
[14] QP-3220, Test Water Generation.
[15] QP-3221, NEI Fines Debris Preparation.
[16] QP-3222, Chemical Precipitate Debris Generation.
[17] QP-3227, Filter Disc Method for the Size Distribution of Suspended Solids
[18] REF-127, Standard Specification for Reagent Water, ASTM, 2011.
[19] WCAP-16530-NP-A, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191”, Rev. 0, March, 2008, Adams Accession No.: ML081150379.
[20] NUREG/CR-6224, “Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris”, ADAMS Accession: ML083290498.

Appendix A
Inspection Items

A.1 Strainer Modules

Table 12-1: Test strainer tolerances

Dimension	Value	Tolerance	Source of Tolerance
Disk width	19"	1/8"	
Disk thickness	0.558"	1/8"	
Perforated plate	22 ga. ASTM A240 type 304 stainless	0.005"	
Perforated hole diameter	.045"	.005"	
Perforated hole pitch	0.081" (Center to center)	.005"	
Gap between adjacent strainer disks	1"	1/8"	
Gap disk and core tube sleeve diameter	10.063"	1/8"	
Perforated height of gap disk	0.675" out of 1"	1/16"	
Core tube O.D.	7.5"	1/8"	
Gap between adjacent strainer disks for penetration testing	2.558"	1/8"	
Top/bottom perforated band height on penetration testing gap rings	0.338"	Min	
Middle stainless steel band height on penetration testing gap rings	1.883	Max	
Distance between stacks (disk-edge to disk-edge)	4”	1/8”	

A.2 Test Tank

Table 12-2: Test tank tolerances

Dimension	Value	Tolerance	Source of Tolerance
Overall strainer height	71 -13/16"	1/2"	
Upstream Tank Width	27"	0.25"	
Upstream Tank Wall Height	36"	Min	
Upstream tank Length	96"	0.25"	
Pit Depth (base plate to flume floor)	58"	1/8"	

Dimension	Value	Tolerance	Source of Tolerance
Pit width during penetration testing	27"	1/4"	
Pit length during penetration testing	50"	1/4"	
Pit width during head loss testing	24"	1/4"	
Pit length during head loss testing	48-1/2"	1/4'	

Appendix B
Collected Requirements

B.1 Test Loop Requirements

- Loop is set up as in Figure 4-2.
- Test solution temperature will be set to 120 °F ± 5 °F for the duration of testing with the only exception during the head loss temperature sweeps.
- No sudden area changes in piping from strainer suction take off to the filter bag assemblies for penetration testing.
- No sudden area changes in piping from the strainer suction take off to the mixing line discharge for head loss testing.
- All non-vertical piping downstream of the plenum has an ID less than 14.6".
- Drain must be downstream of total flow meter.
- The total flow through the test strainer must be measured.
- Two filter housings (or sets of housings) installed in parallel and separately isolatable.
- For head loss testing a bypass branch must be available to prevent filtration of the recirculation flow.
- Tap locations must be documented in facility inspection and should avoid the top and bottom of piping.
- The test loop must be water solid prior to testing.
- The test loop must be thoroughly cleaned before all tests.

B.2 Isokinetic Sampler Requirements

- Sample nozzle(s) inner diameter > 0.2" (larger than longest expected debris penetration fiber).
- Sample nozzle(s) extends more than 3 inner nozzle diameters upstream from vertical penetration.
- Sample nozzle(s) is (are) visually parallel to the pipe it is installed in.
- System must contain a minimum of two valves, one to throttle the flow and one to function as a shut-off.
- The sample nozzle should not remove more than 10% of the flow in the pipe.

B.3 Test Strainer Requirements

- Two type A stacks.
- Gap spacing is appropriately maintained to account for removed strainer disks during penetration testing.
- Approach velocity of test strainer must match that of the actual strainer modules at the plant.

B.4 Penetration Test Requirements

- Must experimentally quantify fibrous debris penetration.
- Must provide data that shows debris penetration as a function of time.
- The only debris introduced will be Nukon fines.
- Strainer disks will be removed in an every other disk scheme.
- Isokinetic samples must be taken at 2 PTOs after each debris batch addition and at 1 PTO after the completion of each debris addition.
- Must have a fiber filtering system that meets the following requirements:
    - Two parallel filter housings to facilitate filter bag changes.
    - One filter bag housing must be online at all times.

  - All filter bags must meet the requirements below in the "filter bag requirement" section.
- Test parameters listed in Table 5-1 and Table 5-2.
- Can achieve a maximum flow rate of 570 gpm.
- Batch sizes in Table 5-3.
- Target debris introduction times must match that of Table 5-4.
- Filter bags will be changed in accordance with Table 5-5.
- Loop must be documented to be visually clean before putting control bag online.

B.5 Head Loss Testing Requirements

- Variation of clean strainer head loss with flow must be characterized during the test sequence.
- Can achieve a maximum flow rate of 1090 gpm.
- Test parameters listed in Table 5-6 and Table 5-7.
- Maximum acceptable test strainer head loss for conventional debris is the NPSH margin, 3.862 ft.
- Maximum acceptable test strainer head loss for chemical debris is the strainer structural design limit, 2.38 psi.
- Loop must be demonstrated to be visually clean prior to debris introduction.
- Each strainer stack matches prototypical type-A dimensions.
- Full Debris Load Test
  - See Section 3.1.3.8.1 for test requirements, Section 5.2.6.4.1 for debris batching guidance, and Section 8.8.1.1 for a summary of the test procedure.
- Thin Bed Test
  - See Section 3.1.3.8.1 for test requirements, Section 5.2.6.4.2 for debris batching guidance, and Section 8.8.1.2 for a summary of the test procedure.
- Chemical Debris
  - Shall be prepared to the instructions in WCAP-16530-NP (See Section 5.2.6.3 for further details and exact chemical quantities).
  - All chemical debris introductions will be the same for each head loss test.
  - Increment of addition will be determined based on debris bed response.
  - The following chemical precipitates will be used:
    - Aluminum Oxy Hydroxide (See Table 5-8 for generation recipe).
  - Introduced using transition tank, see Section 4.11 and Section 8.8.1.5.

B.6 Debris Characteristics and Preparation Requirements

- Heat treatment of all fibrous debris must be verified.
- See Section 8.4 for particulate preparation details.
- All fibrous debris will be prepared under QP-3221 using the appropriate test water.
  - Fines: mainly class 2.
  - Smalls: even distribution between class 3 and pieces up to 6" in length.
- The creation of fibrous shards must be avoided.
- Processed fiber must be easily transportable.
- Photographic documentation of each batch.

B.7 Debris Introduction System

- Designed to minimize splashing.
- Must not significantly affect the total flow rate of the system.
- Flow through the hopper must be controllable.

- Must facilitate debris introduction to mixing region of the test tank away from the test strainer.
- Valves at the inlet control the flow rate.
- Visually verify hopper does not contain residual debris after debris introduction period ends.

B.8 Test Tank Requirements:

- The curb that surrounds the sump will not be modeled.
- Mixing lines:
  - Maintain velocity of 1-2 ft/s in mixing region.
    - Can be satisfied by four 6” lines for penetration testing.
    - Can be satisfied with four 8” lines for head loss testing.

B.9 Chemical debris introduction requirements:

- Transition tank setup as in Figure 4-2.
- Branch A and B have similar lengths and same number of fittings.
- Branch B discharge elevation is between lower and upper test tank water levels.

B.10 Filter Bag Requirements:

- Each filter bag must be uniquely labeled and verified to free from damage.
- Must have capture efficiency above 97%.
- All filter bags must dried and weighed prior to testing to determine a steady state baseline weight.
- Prior to use all filter bags must be properly stored until testing.
- Debris-laden bags are rinsed with deionized water prior to drying.
- Drying cycles in clean and debris-laden conditions at temperatures below rating for filter bags.
- Weight convergence to 0.05 g on successive weights.

B.11 Test Solution Generation Requirements:

- Start with test water determined to have a conductivity of less than 5 micro-S/cm at 25^{o}C to meet ASTM Standard D1193.
- Chemical purity >97%.

B.12 Instrumentation Requirements:

- See Table 6-1.

Appendix C

Alden Condition Reports

This section contains Table 12-3 which provides an overview of all the relevant Alden Condition Reports (CRs) that have been issued within the last year. This overview table will include only relevant CRs and will not include CRs that relate to, for example, any inspection items found out of tolerance prior to testing, errors in supporting procedures (QPs) or M&TE that were damaged and decommissioned.

At the time of issuance of the present document, the following documents relevant to the CR have not been written:

- Facility inspection procedure
- Debris penetration test procedure
- Head loss test procedure

These documents will be written under consideration of Table 12-3.

Table 12-3: Alden Condition Reports summary

CR # [CR-0##]	Description of CR	Actions specifically taken to prevent reoccurrence	Sections of test plan or other documents relevant to the CR
56	Several instruments used during testing did not meet the uncertainty requirements from the associated test plan.	A step in each test procedure will require verification that all the instrumentation deployed meet the uncertainty requirements of the test plan	- Section 6.0
59	Several filter bag weights were collected and recorded without proper procedural documentation.	The filter bag weight determination procedure now requires a spot check of all filter bag weights. This spot check will also safeguard against poor procedural documentation.	- Section 6.6 - QP-3203, Filter Bag Weight Determination [10]
63	A tank used for testing was not able to meet the temperature requirement without cracking or leaking.	Care will be taken in the design of the test tank especially for components that are affected by large temperature swings such as acrylic viewing windows. Additionally, procedural steps will	- Section 4.3

		be included to ensure that the test fluid is heated and cooled slow enough to prevent cracking. Operational inspection will not be conducted concurrently with start of an actual test.	
69	The wrong cell was referenced in a spreadsheet resulting in an incorrect output.	All associated spreadsheets will be properly reviewed and logged prior to issuing the test plan and test procedures.	- Supporting calculation spreadsheet [6]
70	Videos documenting baseline test conditions could not be found on the server.	Testing documentation will be saved to the Alden server at the completion of each test.	- Section 9.3
71	A calibrated meter section was dismantled and reconfigured.	All of the flow meters that could be dismantled will have a tag affixed stating the following "Calibrated meter section, do not dissemble".	- Section 6.3
72	The debris generation procedure was not properly followed. Specifically, debris with incorrect heat treatment was used for debris generation.	A step will be included in both penetration and head loss test procedures to require debris batches to be checked in by the lead test executor.	- Section 8.3 - Debris penetration test procedure - Head loss test procedure
73	Carbon steel was used to build strainer components rather than stainless steel.	All metal test components that will have a wetted surface inside the test tank will be ensured to be fabricated from stainless steel. The inspection procedure functions to ensure the test setup is correct prior to the start of testing.	- Sections 4.1, 4.3, and 4.4

75	Individuals did not document training to the Test Plan prior to issuing the test procedure and preforming testing.	Verification steps will be added to all test procedures to ensure proper training documentation.	- Facility inspection procedure - Debris penetration test procedure - Head loss test procedure
77	Incorrect coefficients were used in the Data Collect configuration file.	The head loss and penetration test procedures for WCGS will contain a hold point requiring an engineer to complete an independent review of all DataCollect coefficients.	- Debris penetration test procedure - Head loss test procedure
80	A strainer was not completely assembled and allowed for flow to by-pass the strainer.	The test procedures will include verification steps to ensure that all the critical components of the test setup have be properly installed.	- Debris penetration test procedure - Head loss test procedure
82	The incorrect value was read from the test plan and inadvertently the amount of chemical used during chemical precipitate generation was incorrect.	The procedure used to generate chemical precipitates was revised with a hold point that requires an independent review of chemical quantities need to ensure accuracy prior to the generation of the precipitates.	- QP-3222, Chemical Precipitate Debris Generation [16]
83	Two filter bags were incorrectly swapped between two different set resulting in incorrect filter weight gains.	An independent spot check of all the filter bag weights has been implemented into the filter bag weighing procedure to safeguard against reoccurrence	- Section 6.6 - QP-3203, Filter Bag Weight Determination [10]
84	A set of filter bags that were supposed to be removed from the filter housings were not. The now debris laden filter bags were inadvertently brought back online.	The penetration test procedure will be written such that steps must be executed in order. Additionally, test protocol has been updated to clarify the	- Debris penetration test procedure

		responsibilities of all test personnel.	
85	A calculation error was made when setting up a debris batching schedule.	Diligence will be taken when calculating and reviewing debris batching schedules	- Section 5.1.3.1 - Section 5.2.5
88	During testing the tank wall deflected significantly due to a significant head loss condition.	The tank walls will be sufficiently reinforced to prevent deformations during high head loss conditions. Basic calculations should be done to ensure the integrity of the design.	- Section 4.3
89	The data collection software froze during the overnight monitoring of a test.	Manual logs will be kept to document test activities in the event that the electronic software fails. Ensure manual data recording occurs in a timely fashion.	-None
90	An incorrect sequence of valve position changes on a filter bag swap resulted in a pressure wave that disturbed the debris bed.	The penetration test procedure will be written such that the specific steps of a filter bag swap are explicitly defined.	- Debris penetration test procedure