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001 Rev.0

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TRANSPORT OF WASTE SIMULANTS IN PJM VENT LINES

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LIST OF ACRONYMS

EDL	Engineering Development Laboratory
PI	Principal Investigator
PJM	Pulse Jet Mixer
PPE	Personal Protective Equipment
UFP	Ultra Filtration Process
WTP	Waste Treatment Plant

1.0 TESTING SUMMARY

1.1 OBJECTIVES

The experimental work was conducted to determine whether there is a potential for waste simulant to transport or “creep” up the air link line and contaminate the pulse jet vent system, and possibly cause long term restriction of the air link line. Additionally, if simulant creep occurred, establish operating parameters for washing down the line. The amount of the addition of flush fluids and mixer downtime must be quantified.

Test Objective	Objective Met (Y/N)	Discussion
1. Determine slurry transport/creep and solids build up rate	Yes	Surface creep occurred for Vent/Drive ratio > 2. No surface creep was observed for V/D=0.5 - 1.3
2. Determine rate of solids carryover in the vent header	Yes	For V/D>2, more that 150 mg/cycle of carryover was measured. For V/D=0.5 - 1.3, the carryover was found to be less than 6 mg/cycle.
3. Determine the required wash amount	Yes	Two wash cycles, 20 gpm for 5 seconds each during drive phase washed the test section effectively

1.2 TEST EXCEPTIONS

Two modifications were made to the test loop as described below.

List Test Exceptions	Describe Test Exceptions
1. Addition of a dome	Initial testing was performed in a 2” vent line. Later, a 14” dia dome was connected to the vent line to simulate PJM tubes
2. Addition of a horizontal loop	Initial testing was performed in a vertical vent line. Later, two horizontal sections were added in the vent line to simulate prototypic conditions.

1.3 RESULTS AND PERFORMANCE AGAINST SUCCESS CRITERIA

Major findings of the test program are given below. More details of test conditions and results are summarized in a summary table provided in section 1.5.

List Success Criteria	Explain How the Tests Did or Did Not Meet the Success Criteria
<p>1. Determination of slurry transport/creep rates in the air supply lines.</p>	<p>For Peak Vent/Drive flow >2, about 4” of surface creep was observed per cycle. This surface creep occurred during the first 5 seconds of the vent phase when the flow rates are very high. No creep was observed during the suction phase. Additionally, large carryover was measured in the filter bag due to droplet and aerosol entrainment (~ 150 mg/cycle)</p> <p>For V/D ratio of 0.5 – 1.3, no significant surface creep occurred. However, waste simulant was carried over by droplet and aerosol entrainment (~ 5 mg/cycle)</p>
<p>2. Determination of wash cycle amount, frequency, flow rates and wash nozzle configuration required to prevent restriction of the air link line and minimize carryover to the vent system.</p>	<p>Initially, water at 20 gpm was used to wash down the surface film without any air flow. This was not effective in cleaning the clear test sections. During later tests, two wash cycles, 20 gpm for 5 seconds each during drive phase were observed to be effective in cleaning the vent line. The buildup in the vent line is in the form of very thin surface film without any noticeable flow restriction even after 1000 cycles. If needed, the water pressure to clean this fine surface film must be greater than the drive air pressure. A simple T configuration for water connection was found to be adequate. These wash cycles were performed after 500 cycles of PJM operation. During Test 4, the wash cycles were performed after 1000 cycles with effective cleaning. Note that the total amount of aerosol carryover in the filter bag increased with the number of PJM cycles.</p>

<p>3. Measurement of the dry solids carryover in the air stream and assessment of particle size distribution.</p>	<p>For large peak vent flow rate (760 SCFM) in 2" vent line caused a large amount of carryover (~150 mg/cycle). For vent rates less than 400 SCFM, the carryover is less than 6 mg/cycle.</p> <p>The carried over particles in the filter bag were in the form of fairly uniform sized powder, mostly imbedded in the filter media. All particles were estimated to be less than 10 micron size.</p>
<p>4. Quantify the effect of addition of a dome in the vent line on waste carryover.</p>	<p>Due to the presence of the dome, the simulat coating on the dome ceiling did not get swept away during the drive phase. However, during the vent phase, the escaping air picked up this additional simulat along. This yielded significant carryover in the form of droplets. Most of the droplets could not make the first turn and got deposited on the outer curved surface of the first elbow. However, two washes after 500 cycles cleared the deposits.</p> <p>The droplet entrainment measured by deposits in the first 90 degree elbow increased with the number of PJM cycles. The percentage flow blockage was calculated to be 1.94%, 2.90% and 4.84% after 100, 180 and 420 cycles of operation, respectively. The uncertainty of flow blockage estimates was determined to be +/- 25% of the value. An extrapolation of this trend yielded an estimated flow blockage of 11% (+/-2.8%) for 10,000 cycles. Note that this extrapolation is approximate since, excessive blockage will result in higher local air velocity levels during venting, possibly limiting the maximum depth of the deposited layer.</p> <p>The droplet entrainment occurred during the first 5 seconds of vent phase where the vent velocity levels peaked. Beyond that, the duration of vent phase had no effect on carryover.</p>

5. Quantify the effect of simulant rheology on the creep phenomenon.	Three kaolin rheologies (30Pa/30cP, 15/15 and 5/5) and one AZ-101 rheology (13/13) were tested. Based on extensive testing with these simulants, it was found that the simulant rheology did not have any significant effect on the overall surface creep phenomenon. However, the carryover per cycle in the filter bag was less for kaolin 30/30 (~ 1.2 mg/cycle versus remaining simulants (~ 5-6mg/cycle). The surface creep was found to occur for large V/D values (peak vent/peak drive flow).
6. Document any effect of air aspiration.	During Test 10, the simulant level in the simulant reservoir dropped, resulting in air aspiration during the draw phase. This resulted in significant carryover of simulant through several clear sections. Two wash cycles were performed, more simulant was added to the reservoir and testing was resumed without any further aspiration or air. This was significant observation that such conditions should not occur in the actual plant operation.

1.4 QUALITY REQUIREMENTS

This work was conducted in accordance with the RPP-WTP QA requirements specified for work conducted by SRNL as identified in DOE IWO M0SRLE60. SRNL has provided matrices to WTP demonstrating compliance of the SRNL QA program with the requirements specified by WTP. Specific information regarding the compliance of the SRNL QA program with RW-0333P, Revision 13, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Subpart 2.7 is contained in these matrices. Additionally, the Test Specification applies 10 CFR 830 Subpart A and does not apply QARD to this work.

1.5 R&T TEST CONDITIONS

The WTP customer directed EDL to perform simulant transport/creep tests using kaolin/clay mixture and AZ-101 simulant over a wide range of peak drive and vent flow conditions. EDL added some initial water runs as a part of system shakedown.

List R&T Test Conditions	Were Test Conditions Followed?	Explanation
1. Validate PJM simulated operation using water as working fluid.	Yes	A series of water runs were performed to validate the PJM operation.
2. Perform creep test using kaolin/clay based slurry as simulant. Use different rheologies.	Yes	A total of 12 test campaigns were run using kaolin/clay as working fluid. The operating conditions were developed in consultation with WTP customer.
3. Perform creep test using AZ-101 simulant	Yes	Two test campaigns were run with AZ-101 simulant as directed by the WTP customer.

Detailed test conditions and key results are summarized in Table 1.

Table 1. Transport/Creep Tests Summary Table

Test Number	Run Date	Simulant	Number of Cycles	Peak Drive Flow (D), SCFM	Peak Vent Flow (V), SCFM	V/D Ratio	Filter Bag Carryover, grams	Carryover per cycle, mg	Comments
1	April 7, 2006	Water	10	320	760	2.38	N/A	N/A	Shakedown Tests
2	April 10-11, 2006	Kaolin/clay 30/30	100	320	760	2.38	15.44	154.00	Slurry creep 4"/cycle for first 25 cycles
3	April 21, 2006	Kaolin/clay 30/30	200	620	380	0.61	0.256	1.28	No surface creep. 2 nd clear section is replaced by a stainless steel section
4	April 24-26, 2006	Kaolin/clay 30/30	1000	620	380	0.61	1.185	1.19	No surface creep, vent line cloudy
5	April 27, 2006	Kaolin/clay 30/30	20	600	300	0.50	N/A	N/A	No surface creep beyond fill line
6	April 27, 2006	Kaolin/clay 30/30	20	600	400	0.67	N/A	N/A	No surface creep beyond fill line
7	April 27, 2006	Kaolin/clay 30/30	20	600	500	0.83	N/A	N/A	No surface creep beyond fill line, clear section fogging up
8	April 27, 2006	Kaolin/clay 30/30	20	600	600	1.00	N/A	N/A	~ 3" surface creep beyond fill line, clear section fogging up
9	April 27, 2006	Kaolin/clay 30/30	50	600	700	1.17	N/A	N/A	surface creep in the entire first clear section. No creep observed in the 3 rd section (2 nd section is Stainless Steel)
10	August 7-10, 2006	Kaolin/clay 30/30	100	310	390	1.26	N/A	N/A	14" Dome Installed. No surface creep. First section cloudy. Deposit in first elbow.
11	August 10, 2006	Kaolin/clay 15/15	100	300	390	1.30	0.502	5.02	No surface creep. First clear section coated white
12	Sept. 26-28, 2006	Kaolin/clay 15/15	500	300	330	1.10	2.213	4.43	No surface creep. First clear section coated white. A few white streaks in second section
13	Oct. 3-4, 2006	Kaolin/clay 5/5	100	300	390	1.30	0.545	5.45	No surface creep. First clear section coated white
14	Oct. 24, 2006	AZ-101, 13/13	100	300	390	1.30			8" Dome installed. No surface creep. The first section vertical is cloudy. The first 2' of second section (horizontal) are cloudy
15	Oct. 24-, 2006	AZ-101, 13/13	400	390	390	1.00	2.314	5.79	No surface creep. Streaks in first section. The next two sections are somewhat cloudy.

1.6 SIMULANT USE

WTP project directed SRNL to use two different simulants for the simulant transport/creep tests. The first one is kaolin/clay based simulant of different rheologies covering a wide range of consistencies and yield stresses. The second simulant is AZ-101 simulant used earlier for other WTP tests conducted at SRNL. Rheological properties of these simulants are listed below.

1. Kaolin/clay suspension, 30 Pa, 30 cP (or Kaolin/clay 30/30)
2. Kaolin/clay suspension, 15 Pa, 15 cP (or Kaolin/clay 15/15)
3. Kaolin/clay suspension, 5 Pa, 5 cP (or Kaolin/clay 5/5)
4. AZ-101, 13 Pa, 13 cP (or AZ-101, 13/13), from Gas Holdup and Release Test.

1.7 DISCREPANCIES AND FOLLOW-ON TESTS

The tests performed covered a wide range of working fluids and their rheological properties, hardware configurations and operating conditions. Based upon the results, no follow-on work is anticipated at this time. If the operating conditions change beyond the test envelop, an evaluation of the creep phenomenon will be needed.

2.0 CD-ROM ENCLOSURES

A CD of this report is provided separately.

3.0 DISCUSSION

3.1 TEST PROGRAM OBJECTIVES.

The experimental work was conducted to determine whether there is a potential for slurry to transport or “creep” up the air link line and contaminate the pulse jet vent system, and possibly cause long term restriction of the air link line. Additionally, if slurry creep occurred, establish operating parameters for washing down the line. The amount of the addition of flush fluids and mixer downtime must be quantified.

3.2 BACKGROUND AND PREVIOUS WORK

From the data generated following testing dated back to FY 2001 at the 336 PJM Test Platform, WTP discovered that the simulant (Iron Oxide) had gradually advanced in the air supply line all the way to the control unit which was located about 50’ away from the tank. This phenomenon was attributed to slurry creeping up the piping wall following each cycle of PJM operation. In order to confirm or refute this phenomenon, WTP requested the Engineering Development Laboratory (EDL) of SRNL to perform a range of tests using full scale air supply piping diameter, closely matched simulant rheology to the actual waste (AZ-101) and run the same PJM cycle times and conditions as in the actual plant.

3.3 QA REQUIREMENTS

This work was conducted in accordance with the RPP-WTP QA requirements specified for work conducted by SRNL as identified in DOE IWO M0SRLE60. SRNL has provided matrices to WTP demonstrating compliance of the SRNL QA program with the requirements specified by WTP. Specific information regarding the compliance of the SRNL QA program with RW-0333P, Revision 13, NQA-1 1989, Part 1, Basic and Supplementary Requirements and NQA-2a 1990, Subpart 2.7 is contained in these matrices. Additionally, the Test Specification applies 10 CFR 830 Subpart A and does not apply QARD to this work.

3.4 TEST APPRATUS

In order to investigate simulated waste creep behavior, a mockup of PJM operation was designed to achieve full scale operating conditions and key hardware components. A typical PJM operation in a waste tank involves the following steps.

1. **Drive Phase.** High pressure air (~ 40 psig) is supplied to the pulse jet tube. Air pushes the waste downwards into the waste tank. This phase is about 30 seconds long for tanks with non Newtonian waste as tested earlier. The drive time varies between 4 – 80 seconds depending upon the waste tank and the size of the PJM tubes. Peak air flow to the PJM tube varies in the range 190 – 850 SCFM for different tanks.

2. **Venting Phase.** This phase is initiated by discontinuing high pressure air supply to the PJM tube and opening the vent line until the PJM tube pressure approaches atmospheric pressure. The tank waste enters the tube under hydrostatic head. The vent line peak flow rate varies between 300 – 400 SCFM.
3. **Suction Phase.** The PJM tube is then subjected to a vacuum which draws waste into the tube and a few feet into the 2” vent line connected to the tube. The suction phase is followed by the drive phase to complete the cycle. The total cycle time varies between 19 and 270 seconds depending upon the waste tank to be mixed.

The key concern here is that during every cycle, waste is coated inside the vent line. During the drive phase, the wall coating is swept downwards into the tube. During the vent phase, the remaining wall coating can **creep** downstream. It is important to note that a key parameter that controls the creep phenomenon is the ratio between peak vent flow to the peak drive flow rate.

EDL designed a test facility to mockup the above cycle where different simulants could be tested under a range of drive and vent flow conditions. The EDL’s Creep Test Facility was designed to duplicate the potential creep phenomenon by the following steps.

1. **Simulant Draw Phase.** In this phase, simulant from a holding tank is drawn into a section of a transparent vent line to a desired level. This is achieved by using an air eductor to create vacuum and draw the simulant.
2. **Simulant Drain Phase.** After drawing the simulant to a desired level and holding it for about 5 seconds, the vacuum is released and the simulant is allowed to drain back in the holding tank leaving a coating of simulant in the vent line.
3. **Drive Phase.** The simulant holding tank is then isolated and the vent line is opened to a 28 cu ft volume simulating the volume of a PJM tube. High pressure air at desired pressure is then pushed down in the vent line at a desired flow rate. Air from the 28 cu ft volume is also allowed to bleed at a controlled and adjustable rate to simulate the drive phase of the actual system. During this phase the wall coating in the vent line is swept down and some of the simulant is pushed into the 28 cu ft volume (which is transferred back to the holding tank after every 20 – 25 cycles). The entire 28 cu ft volume is pressurized to the supply air pressure of 38 psig.
4. **Vent Phase.** At the end of the drive phase, air supply and bleed is stopped and the vent line is suddenly opened to atmosphere. The high pressure air from 28 cu ft volume rushes out of the vent line carrying some simulant with it. The amounts and mechanisms of carryover are discussed in details in the results section
5. **Suction Phase.** This follows the vent phase where the vent line and the 28 cu ft volume are subjected to vacuum to mimic the actual process. In these tests, the suction phase did not play any significant role. Initially, prototypic suction phase durations were set. Later, the suction phase duration was shortened to perform more cycles in a given time.

Figure 1 shows the schematic of the test facility originally designed to duplicate the above steps. Note that in this layout, the vent line is directly connected to the 28 cu ft volume via an air operating valve V2. Subsequently, a dome shaped volume was added to represent a more prototypic connection between the vent line and the PJM tube. The modified layout is shown in Figure 2. Description of key components is provided below.

1. **Air Supply.** A 400 gallon air receiver tank was used to supply high pressure air for the drive phase and to operate the vacuum eductor. The air receiver tank is continuously charged with 120 psig air from the building header. The supply air pressure is regulated down to 38 psig to match the PJM pressure during drive phase.
2. **Filter Bag Housing.** The vent line air is discharged through an air filter bag to capture any simulant carry over. The filter bag housing is a large 12" piping and elbow used for a prior UFP suction line tests. The housing is connected to a quick acting solenoid valve to vent the pressurized air from the system.
3. **PJM Tube Volume.** A typical PJM tube has a large volume (5 – 60 cu ft). For the present testing a volume of 28 cu ft was used. This volume was achieved by sections of 12" pipe available from a previous UFP suction line test. For the non Newtonian waste tanks, typical PJM tube volume is around 25 cu ft. The PJM Tube volume was fitted with adjustable and air operated valves to achieve desired flow rates during drive and vent phases.
4. **Simulant Holding Tank.** This tank is just below the vent line test section. During the simulant suction and drain phases, the vent line test section is connected to the holding tank. During the drive, vent and suction phases, the test section is isolated from the holding tank and connected to the PJM Tube Volume via air operated valves. The holding tank is placed in a covered secondary containment to contain any accidental spill.
5. **Test Section.** The vent line was simulated by 6' long multiple sections of 2" clear acrylic tube. Initially, 6 acrylic sections were used to simulate the vent line. During Test No. 3 (see **summary table in results section**), the second clear section from bottom was replaced with stainless steel section to determine the effect of surface finish on the creep phenomenon. This configuration was used up to Test 9. From Test 10 -15, the vent line configuration was modified as shown in Figure 2. Two changes were made. The first one is the addition of a dome shaped volume to closely simulate the connection between the vent line and the PJM tube. The second change is the addition of a loop having two horizontal sections and 4 elbows. As discussed in the results section, presence of an elbow has a significant impact on the droplet carryover mechanism. The plant vent line has multiple elbows. It was deemed necessary to quantify the carryover in the presence of elbows.
6. **Wash System.** In order to flush out the system, the test rig was equipped with building process water connected at the end of the acrylic test section. The water flow rate could be controlled by a throttle valve. A solenoid valve in series controlled the timing of the wash cycle. The wash system was designed for both manual and automatic flushes. The automatic wash was performed during the drive phase since a mixture of rushing air and water is most effective in cleaning while minimizing the total water volume addition.

7. **Data Acquisition/Control System.** The test facility was designed to perform multiple PJM cycles automatically using a desktop computer based control system. This was achieved by several manual, air operated and solenoid valves. The cycle time could easily varied by adjusting times for individual phases. The system was also used to record key measurements.
8. **Instrumentation.** As shown in Figures 1 and 2, the test facility was instrumented with pressure gages, thermocouples and flow meters. Table 2 lists all the instruments installed.

Figure 3 is a photograph of the test facility showing simulant holding tank, secondary containment, filter bag housing, high pressure air supply line and vacuum eductor. Figure 4 shows a photograph of test section connected to the 28 cu ft volume via air operated valve V2.

Figure 7 shows the 14” dome section used for Tests 10 – 13 using kaolin/clay simulant. The overall length is 6 ft and it replaced the first clear acrylic section.

Figure 6 shows the 8” dome installed for AZ-101 simulant testing. This dome was used due to a limited inventory of AZ-101 simulant at hand.

Figure 7 shows a picture of Data Acquisition and Control System.

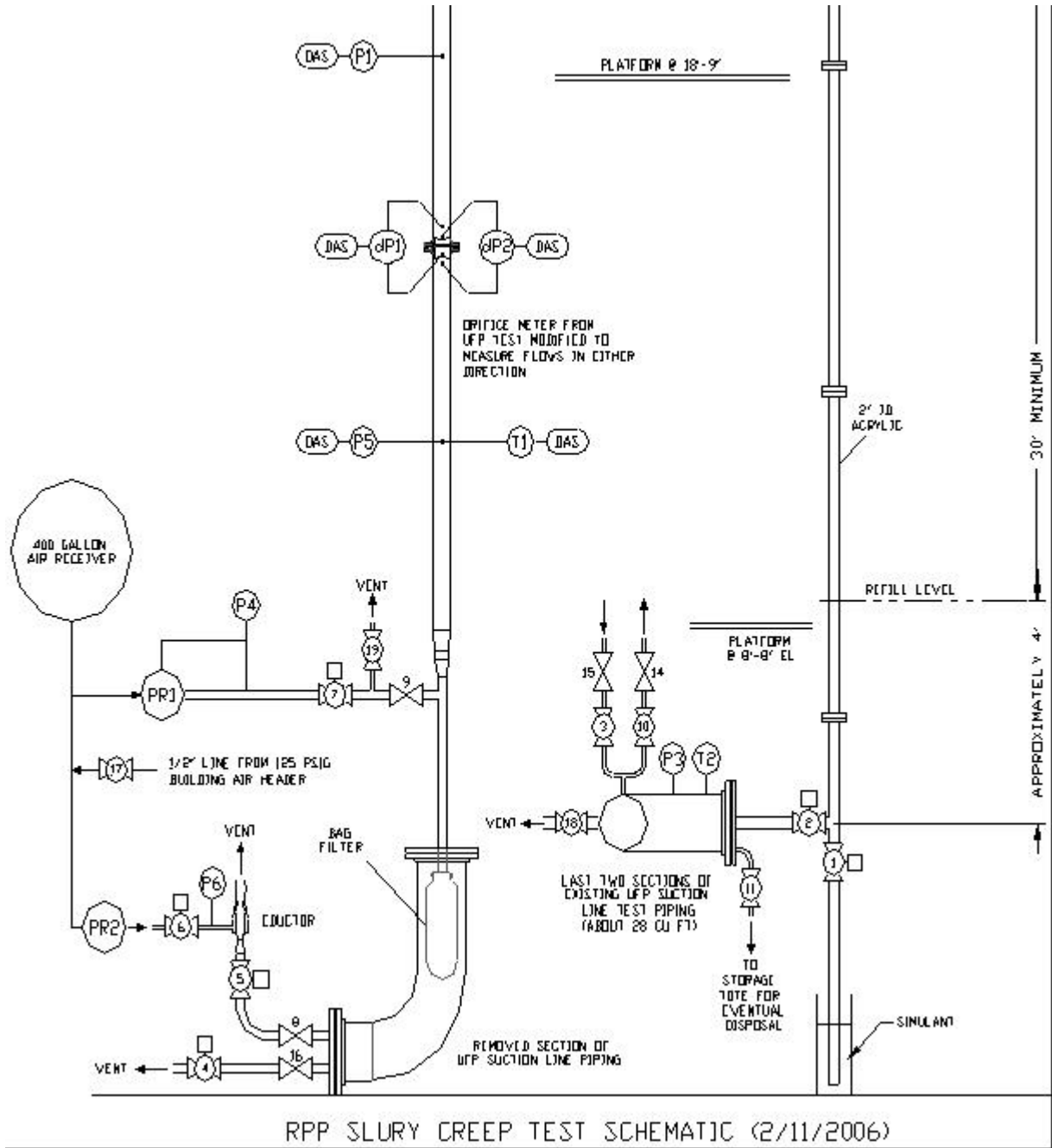


Figure 1. Slurry Creep Test Schematic for Tests 1 – 9

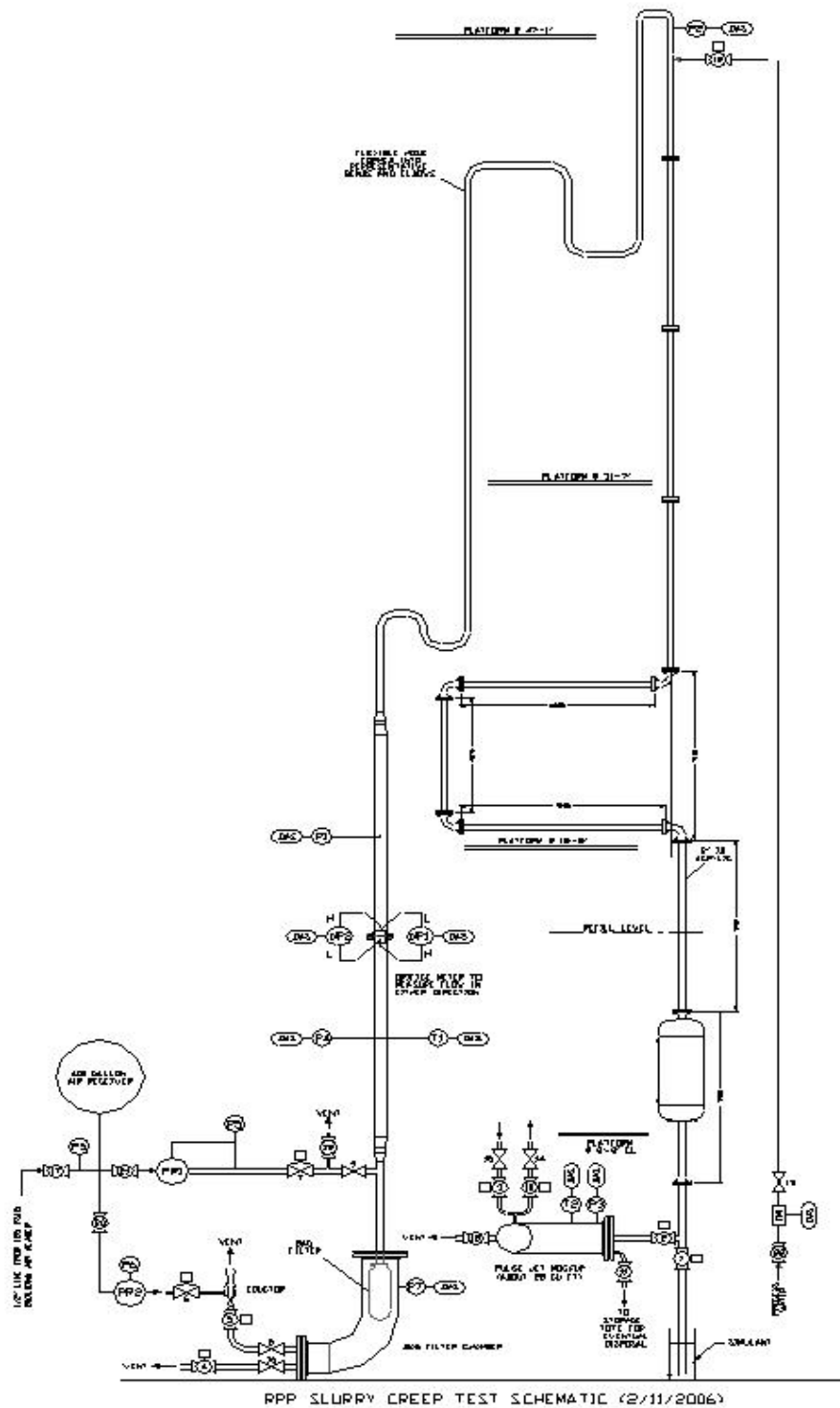


Figure 2. Slurry Creep Test Schematic for Tests 10 - 15



Figure 3. Photograph of Test Facility



Figure 4. Photograph of Test Facility showing connection to 28 cu ft Volume



Figure 5. Photograph of 14” Dome used for Tests 10 – 13



Figure 6. Photograph of Test Section showing 8" Dome used for Tests 14 & 15



Figure 7. Photograph of Data Acquisition and Control System

Table 2. Instrumentation for EDL Creep Test Facility

Instrument	Name	Type	Range	Description	TR#
Flowmeter	FM-1	Fischer Porter Mag Flowmeter	0 – 52 gpm	Cleaning Water Supply Flowmeter	03674
Pressure Transducer	P1	Rosemount	0 – 150 psig	Orifice Plate Vent Pressure	03656
Pressure Transducer	P2	Rosemount	0 – 150 psig	Suction Piping Pressure	03549
Pressure Transducer	P3	Endress and Hauser	0 – 150 psia	PJM Volume Pressure	03738
Pressure Transducer	P5	Rosemount	0 – 160 psig	Pulse Jet Pressure Supply	03781
Pressure Transducer	P4	Rosemount	0 – 150 psig	Orifice Plate Drive Pressure	03792
Pressure Gauge	P6	Pressure Gauge	0 – 150 psig	Eductor Supply Pressure	03748
Differential Pressure Transducer	dP1	Rosemount	0 – 300 inches of water	Orifice Plate DP Drive Flow	03714
Differential Pressure Transducer	dP2	Rosemount	0 – 300 inches of water	Orifice Plate DP Vent Flow	03756
Thermocouple, Type E	T1	Omega	0 – 200 deg. C	Flowmeter Temperature	02956
Thermocouple, Type E	T2	Omega	0 – 200 deg. C	Simulated PJM Volume Temperature	03053
Pressure Transducer	P7	Endress – Hauser	0-120 psia	Bag Filter Vessel Pressure	03735
Pressure Gauge	P8	Pressure Gauge	0-160 psig	House Air Pressure Line	Uncalb

3.5 TEST FACILITY OPERATION

A schematic diagram of the test facility is shown in Figure 1 and Figure 2. The steps below provide initial adjustments, starting conditions for the test, simulate normal operation of the PJM system, and the flushing sequence. It allows observation of the mechanism of creep up the suction line (if such a mechanism exists) and if solids are entrained through the 50 ft of vent piping. Methods of cleaning the vent line of carryover solids, using wash water were tested by opening valve V12 during the drive cycle

3.5.1 Initial Adjustments

1. Close valve 9. Open solenoid valve 7 and adjust pressure regulator PR1 to the maximum desired pressure (about 38 psig). Close valve 7 and then valve 19. Place a tag on PR1 cautioning against adjusting it without PI approval.
2. Open solenoid valve 6 and adjust pressure regulator PR2 to 80 psig. Close valve 6. Place a tag on PR2 cautioning against adjusting it without PI approval.
3. Open solenoid valve 6; wait until the maximum vacuum is achieved, then adjust the position of the eductor nozzle to set the maximum vacuum to the desired level (TBS). Close valve 6. Put a tag on the eductor nozzle, cautioning against adjusting it without PI approval.
4. Open 3" manual ball valve 18 to vent the 12" pipe. (It is expected that opening valve 18 will be sufficient to keep the pressure in the 12" pipe from varying appreciably from atmospheric pressure during the following two steps. If not, open up other existing ports on the 12" pipe that were used during the UFP test and/or remove the blind flange from the end of the pipe as required.)
5. Open solenoid valves 7 and 2. Adjust manual throttle valve 9 to set the maximum flow rate (TBS) when the 12" pipe is un-pressurized. Close valves 7 and 2. Place a tag on valve 9 cautioning against adjusting it without PI approval.
6. Open solenoid valves 2, 5 and 6. Adjust manual throttle valve 8 to set the maximum flow rate (TBS) when the 12" pipe is vented. Close valves 2, 5 and 6. Place a tag on valve 8 cautioning against adjusting it without PI approval.
7. Close 3" manual ball valve 18 (and close any other ports on the 12" pipe that were opened and reinstall the blind flange if it was removed). Close manual valve 11.
8. Open solenoid valves 2 and 7 and wait until the pressure in the 12" pipe reaches the set point of pressure regulator PR1. Open solenoid valve 10 and adjust manual throttle valve 14 to set the maximum flow rate (TBS) when the 12" pipe is pressurized. Close valves 2, 7, and 10. Place a tag on valve 14 cautioning against adjusting it without PI approval.
9. Adjust position of throttle valve 16 as follows:
 - a. Open manual throttle valve 16 slightly. Open solenoid valve 2.
 - b. Open solenoid valve 7 and wait until the pressure in the 12" pipe reaches the set point of pressure regulator PR1. Close valve 7.
 - c. Open solenoid valve 4 for about a second then close it. Determine the maximum flow rate when valve 4 is first opened.
 - d. If the flow rate obtained matches the desired maximum vent flow rate (TBS) continue with step 8e. Otherwise open or close manual valve 16 slightly (as appropriate) and go back to step 8b.
 - e. Open valve 4 until the system is fully vented. Close valves 2 and 4. Place a tag on valve 16 cautioning against adjusting it without PI approval.
10. Open solenoid valves 2, 5, and 6 and wait until the vacuum reaches the value set in step 1 above. Open solenoid valve 3 and adjust manual throttle valve 15 to set the maximum flow rate (TBS) when the 12" pipe is evacuated. Close valves 2, 3, 5, and 6. Place a tag on valve 15 cautioning against adjusting it without PI approval.

11. Open valve 18 to ensure the 12” pipe is vented. Open valve 2, waiting sufficient time (about 2 seconds) for it to be fully open. Open valve 11 and route the discharge to a storage tote. Open solenoid valve 12 and adjust manual throttle valve 13 to allow 20 gpm of water to flow into the unpressurized acrylic pipe. Close valve 12. Open solenoid valve 1 and drain any residual water into a bucket and transfer it to the storage tote. Close valves 1 and 2. After all water has drained from the 12” pipe close valve 11 and valve 18.

3.5.2 Starting Conditions for Normal Operation

All solenoid valves closed, air receiver at 125 psig with supply valve open so it will refill automatically after each use, pressure regulator PR1 set to about 37 psig, pressure regulator PR2 set to about 80 psig, and 12” pipe at atmospheric pressure. Manual throttle valves 8 and 16 adjusted to predetermined positions to control the air flow through valve 5 and 16, respectively, whenever they are opened. (The position of valves 8 and 16 will have to be determined during shakedown to provide maximum air flow rates that are expected for the “typical” pulsejet described above.) Manual throttle valve 13 should be adjusted to provide 20 gpm flow whenever valve 12 is opened and the system is unpressurized.

3.5.3 Simulate Normal PJM Operation

(The following steps will be automated via the DCAS.)

1. Open valve 4, wait until pressure P2 is 0 psig, then close valve 4.
2. Open valves 1, 5, and 6 for a preset time (TBD but about 2 sec) to draw a column of simulant into the acrylic pipe, then close valves 5 and 6.
3. Open valve 4, allow sufficient time for most of the simulant to drain back into the simulant tank (TBD but about 2 seconds), then close valves 1 and 4.
4. Open valve 2 and wait sufficient time for it to fully open (TBD but about 2 sec). Open valves 7 and 10 to establish the Drive Phase.
5. After a predetermined interval (TBS), close valve 10, wait one second, then close valve 7.
6. Open valve 4 to establish the Vent Phase.
7. Monitor pressure P3. When it reaches a predetermined pressure (TBS but near 0 psig), close valve 4 then open valves 3, 5, and 6 to establish the Suction Phase.
8. After a predetermined interval (TBS), close valves 5 and 6. Close valve 2 and wait sufficient time for it to fully close (TBD but about 2 sec). Close valve 3.
9. Repeat steps 2 through 9 as often as required to investigate the creep phenomena or coat the pipe prototypically prior to a cleaning test.

When sufficient cycles has been accumulated (Contact the Task Leader), the Flushing operation will be conducted manually, as follows:

3.5.4 Execute “Air-Driven” Flushing Sequence

(This sequence may be manual.)

1. Open valve 4, wait until pressure P2 is 0 psig, then close valve 4.
2. Open valves 1, 5, and 6 for a preset time (TBD but about 2 sec) to draw a column of simulant into the acrylic pipe, then close valves 5 and 6.
3. Open valve 4, allow sufficient time for most of the simulant to drain back into the simulant tank (TBD but about 2 seconds), then close valves 1 and 4.
4. Open valve 2 and wait sufficient time for it to fully open (TBD but about 2 sec). Open valves 7, 10, and 12 to establish the Drive Phase with simultaneous water addition.
5. After a predetermined interval (TBS), close valve 10 and 12, wait one second, then close valve 7.
6. Inspect the acrylic pipe and record observations.
7. Open valve 4 to establish the Vent Phase.
8. Monitor pressure P3. When it reaches a predetermined pressure (TBS but about 0 psig), close valve 4 then open valves 3, 5, and 6 to establish the Suction Phase.
9. After a predetermined interval (TBS), close valves 5 and 6. Close valve 2 and wait sufficient time for it to fully close (TBD but about 2 sec). Open valve 11 and drain the wash water into a storage tote.
10. Verify all water has drained from the 12” pipe then close valves 3 and 11.
11. Inspect the acrylic pipe and record observations.
12. Repeat steps 2 through 12 as often as required to clean the pipe above the normal fill elevation.

3.5.5 Operation of Data Acquisition and Control System (DACS)

The DACS uses a Dell computer and Labview software. The software logs data from the flow meters, pressure gages, and thermocouple. No changes to this program are to be made without obtaining the concurrence of the Principal Investigator. A file folder named “Suction Line Creep Testing” is to be created and placed on the computer desktop. All file folders containing the data files pertaining to testing of the first resin are to be stored in this folder. The DACS should log the data from each day’s test to an ASCII data file, which in turn should be filed in the appropriate folder. The data file name should be related to the date and test cycle number. This data file name will be recorded in the lab notebook. The frequency of data collection will be determined after the first few tests, where data will be sampled at a high frequency, e.g. 1 sample/sec.

The DACS software also controls opening and closing of test rig valves. Delay times for valve opening and closing with respect to a reference starting time are input into the DACS Labview program.

3.6 CREEP TEST CAMPAIGNS

Fifteen different test campaigns were run using the EDL Creep Test Facility. Each campaign was run under different conditions as summarized in **Table 2**. Below are the detailed conditions for each campaign.

3.6.1 Test 1. Water Shakedown Runs

Peak Vent flow rate, V	= 760 SCFM
Peak Drive flow rate, D	= 320 SCFM
V/D	= 2.38
Number of cycles	= 10
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Any leakage in or out of system.
- iii) Operation of wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.6.2 Test 2. Kaolin/clay 30/30

Peak Vent flow rate, V	= 760 SCFM
Peak Drive flow rate, D	= 320 SCFM
V/D	= 2.38
Number of cycles	= 100
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of two wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.6.3 Test 3. Kaolin/clay 30/30

Peak Vent flow rate, V	= 380 SCFM
Peak Drive flow rate, D	= 620 SCFM
V/D	= 0.61
Number of cycles	= 200
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of two wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.6.4 Test 4. Kaolin/clay Long Term

Peak Vent flow rate, V	= 380 SCFM
Peak Drive flow rate, D	= 620 SCFM
V/D	= 0.61
Number of cycles	= 1000
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of two wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.6.5 Test 5. Kaolin/clay 30/30

Peak Vent flow rate, V	= 300 SCFM
Peak Drive flow rate, D	= 600 SCFM
V/D	= 0.5
Number of cycles	= 20
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.

3.6.6 Test 6. Kaolin/clay 30/30

Peak Vent flow rate, V	= 400 SCFM
Peak Drive flow rate, D	= 600 SCFM
V/D	= 0.67
Number of cycles	= 20
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.

3.6.7 Test 7. Kaolin/clay 30/30

Peak Vent flow rate, V	= 500 SCFM
Peak Drive flow rate, D	= 600 SCFM
V/D	= 0.83
Number of cycles	= 20
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.

3.6.8 Test 8. Kaolin/clay 30/30

Peak Vent flow rate, V	= 600 SCFM
Peak Drive flow rate, D	= 600 SCFM
V/D	= 1.0
Number of cycles	= 20
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.

3.6.9 Test 9. Kaolin/clay 30/30

Peak Vent flow rate, V	= 700 SCFM
Peak Drive flow rate, D	= 600 SCFM
V/D	= 1.17
Number of cycles	= 50
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.

3.6.10 Test 10. Kaolin/clay 30/30

Peak Vent flow rate, V	= 390 SCFM
Peak Drive flow rate, D	= 310 SCFM
V/D	= 1.26
Number of cycles	= 100
Simulant Draw time	= 15s
Simulant Drain time	= 15s
Drive time	= 15s
Vent time	= ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time	= 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.

3.6.11 Test 11. Kaolin/clay 15/15

Peak Vent flow rate, V = 390 SCFM
Peak Drive flow rate, D = 300 SCFM
V/D = 1.3
Number of cycles = 100 (or more that can be completed in a day)
Simulant Draw time = 15s
Simulant Drain time = 15s
Drive time = 15s
Vent time = ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time = 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of two wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.6.12 Test 12. Kaolin/clay 15/15 Long Term

Peak Vent flow rate, V = 330 SCFM
Peak Drive flow rate, D = 300 SCFM
V/D = 1.1
Number of cycles = 500
Simulant Draw time = 15s
Simulant Drain time = 15s
Drive time = 15s
Vent time = ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time = 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of wash cycles (water @ 20 gpm, 5s wash time per cycle). The number of wash cycle frequency will be determined based upon the creep observations.

3.6.13 Test 13. Kaolin/clay 5/5

Peak Vent flow rate, V = 390 SCFM
Peak Drive flow rate, D = 300 SCFM
V/D = 1.3
Number of cycles = 100
Simulant Draw time = 15s
Simulant Drain time = 15s
Drive time = 15s
Vent time = ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time = 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of two wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.6.14 Test 14. AZ-101 Simulant

Peak Vent flow rate, V = 390 SCFM
Peak Drive flow rate, D = 300 SCFM
V/D = 1.3
Number of cycles = 100 (or more that can be completed in a day)
Simulant Draw time = 15s
Simulant Drain time = 15s
Drive time = 15s
Vent time = ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time = 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of two wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.6.15 Test 15. AZ-101 Simulant

Peak Vent flow rate, V = 390 SCFM
Peak Drive flow rate, D = 390 SCFM
V/D = 1.0
Number of cycles = 400
Simulant Draw time = 15s
Simulant Drain time = 15s
Drive time = 15s
Vent time = ~ 20s (note this time is not set, the system waits until the pressure is below 15 psia)
Suction time = 10s

Data Acquired:

- i) Pressure and temperatures at various locations.
- ii) Creep rate per cycle as measured in the transparent section
- iii) Overall creep for the entire test.
- iv) Mass of carryover material caught in the filter bag.
- v) Effectiveness of two wash cycles (water @ 20 gpm, 5s wash time per cycle)

3.7 CREEP TEST RESULTS

A total of fifteen creep test campaigns were successfully completed on the creep test facility. Table 3 summarizes these 15 tests with operating conditions and brief results.

Before presenting the results, it is important to elaborate on different mechanisms of simulant transport in the vent line. Three distinct mechanisms were observed during these tests as described below.

1. **Surface Creep.** In this mechanism, the simulant film on the wall moves due to fast moving air in a direction parallel to the wall. The film movement is characterized by many factors such as viscosity and surface tension of the simulant, air velocity and wall roughness. For the present tests, the surface creep is defined by any surface film movement beyond the initial fill line.
2. **Droplet Entrainment.** The moving air over the simulant film results in surface waves. The crust of these waves can break away into small droplets that are transported with moving air. Some droplets hit the wall again and cause surface streaks. Additionally, due to their high momentum, the droplets cannot make sharp turns and impinge upon the outer curved surface of a bend.
3. **Aerosol Entrainment.** Some droplets break into fine particles and get dried with the surrounding dry air. Some of these particles stick to the test section walls to make the surface cloudy. The remaining particles are carried along with the venting air. The filter bag at the downstream end of the vent line captured these fine particles.

Observations and quantification of the above three distinct mechanisms were made during the test campaigns. Results from each test are described below.

3.7.1 Test 1. Water Shakedown Runs

The water shakedown runs confirmed the integrity of the test facility under pressure and suction conditions. A few threaded and flanged joints had some leakage that was easily fixed. Additionally, some glitches in the automatic control system were also fixed. The air operated valves take about 1 – 2 seconds to fully open or close. The water runs were helpful in fine tuning the delay between different valve opening or closing. For example valve V1 must be fully closed before opening V2 and starting the drive cycle. If valve V1 is partially open for some short time then high pressure air will splash through the simulant holding tank. Similarly, other valve timings were also adjusted for automatic operation of the facility.

Table 3. Summary of Creep Test

Test Number	Run Date	Simulant	Number of Cycles	Peak Drive Flow (D), SCFM	Peak Vent Flow (V), SCFM	V/D Ratio	Filter Bag Carryover, grams	Carryover per cycle, mg	Comments
1	April 7, 2006	Water	10	320	760	2.38	N/A	N/A	Shakedown Tests
2	April 10-11,2006	Kaolin/clay 30/30	100	320	760	2.38	15.44	154.00	Slurry creep 4"/cycle for first 25 cycles
3	April 21, 2006	Kaolin/clay 30/30	200	620	380	0.61	0.256	1.28	No surface creep. 2nd clear section is replaced by a stainless steel section
4	April24-26/2006	Kaolin/clay 30/30	1000	620	380	0.61	1.185	1.19	No surface creep, vent line cloudy
5	April 27, 2006	Kaolin/clay 30/30	20	600	300	0.50	N/A	N/A	No surface creep beyond fill line
6	April 27, 2006	Kaolin/clay 30/30	20	600	400	0.67	N/A	N/A	No surface creep beyond fill line
7	April 27, 2006	Kaolin/clay 30/30	20	600	500	0.83	N/A	N/A	No surface creep beyond fill line, clear section fogging up
8	April 27, 2006	Kaolin/clay 30/30	20	600	600	1.00	N/A	N/A	~ 3" surface creep beyond fill line, clear section fogging up
9	April 27, 2006	Kaolin/clay 30/30	50	600	700	1.17	N/A	N/A	surface creep in the entire first clear section. No creep observed in the 3rd section (2nd section is Stainless Steel)
10	August 7-10, 2006	Kaolin/clay 30/30	100	310	390	1.26	N/A	N/A	14" Dome Installed. No surface creep. First section cloudy. Deposit in first elbow.
11	August 10, 2006	Kaolin/clay 15/15	100	300	390	1.30	0.502	5.02	No surface creep. First clear section coated white
12	Sept. 26-28, 2006	Kaolin/clay 15/15	500	300	330	1.10	2.213	4.43	No surface creep. First clear section coated white. A few white streaks in second section
13	Oct. 3-4, 2006	Kaolin/clay 5/5	100	300	390	1.30	0.545	5.45	No surface creep. First clear section coated white
14	Oct. 24, 2006	AZ-101, 13/13	100	300	390	1.30			8" Dome installed. No surface creep. The first section vertical is cloudy. The first 2' of second section (horizontal) are cloudy
15	Oct. 24-, 2006	AZ-101, 13/13	400	390	390	1.00	2.314	5.79	No surface creep. Streaks in first section. The next two sections are somewhat cloudy.

3.7.2 Test 2. Kaolin/clay 30/30

For this test the peak vent flow rate (V) and the peak drive flow rate (D) were set at 760 and 320 SCFM, respectively. This resulted in a very high V/D ratio of 2.38. Since the vent flow rate was very high, a great deal of surface creep was observed. For the first 25 cycles, the wall film crept up by about 100" from the initial fill level. The remaining clear test sections became cloudy as testing progressed. Note that for this test all 6 acrylic sections were vertical without any bend. Additionally, the test section did not have any dome representing connection between the vent line and the PJM tube. A total of 100 cycles were performed under these conditions. At the end of this test, the filter bag was removed, dried and weighed. A total of 15.44 grams of fine particles were collected. Some of the particles fell to the bottom of the filter bag. Most of them were imbedded in the filter medium. As shown on Table 3, this test resulted in highest amount of filter bag carryover per cycle. Both surface creep and aerosol entrainment mechanisms were observed in this test.

The surface creep was observed during the first 5 seconds of the vent phase when the vent flow rate peaked. The surface creep diminished as the vent flow rate gradually dropped. No creep was observed during the suction phase that followed the vent phase.

In order to wash down the surface film, water at 20 gpm was used under downward flow conditions without any pressurized air. This did not effectively clean the vent line. The subsequent cycles were performed with 20 gpm water during the drive phase. The air-water mixer was observed to be much more effective in cleaning the vent line. It was determined that only 5 second water injection during the drive phase was very effective in cleaning. A second wash during the next drive phase was used to completely clean the transparent vent line.

3.7.3 Test 3. Kaolin/clay 30/30

In view of the results of Test 2, WTP directed EDL to operate under lower V/D ratios. For a given PJM tube, the V/D ratio is in the range 0.4 – 1.3. Test 3 was run with peak vent flow of 380 SCFM and peak drive flow of 620 SCFM, resulting in V/D of 0.61. A total of 200 cycles were completed under these conditions. The first 50 cycles were performed with all 6 acrylic sections. No surface creep was observed. At this time the second acrylic section (from bottom) was replaced with stainless steel section. The idea was that for subsequent tests with higher V/D ratios we would like to see the effect of wall surface on the creep phenomenon. The remaining 150 cycles were completed with this modification. No surface creep was observed. A total of 0.256 grams of aerosol was collected in the filter bag. On per cycle basis, this amounts to 1.28 mg which is far less than 154 mg/cycle measured in Test 2. This clearly demonstrated the effect of lower V/D.

3.7.4 Test 4. Kaolin/clay 30/30 Long Term

The test conditions in this test are the same as in Test 2. The objective was to determine long term buildup of simulant in the vent line. A total of 1000 cycles were completed. No surface film creep was observed. A total of 1.185 grams of kaolin was captured in the filter bag. On per cycle basis, the carryover is 1.19 mg which is very close to the carryover of 1.28 mg/cycle for Test 2.

Two automatic wash cycles were performed at the end of this test. Each wash used 20 gpm water at 80 psig for 5 seconds during the drive phase. The two wash cycles were effective in cleaning the test section.

3.7.5 Test 5. Kaolin/clay 30/30

In view of the preceding tests, WTP directed EDL to perform a series of tests where the peak drive flow is held constant at 600 SCFM and gradually vary the peak vent flow over a range. Test 5 used peak vent flow rate of 300 SCFM to yield V/D ratio of 0.5 for 20 cycles. No surface creep was observed beyond the initial fill line under these conditions. The remaining test section remained clear. The filter bag was not removed for this test.

3.7.6 Test 6. Kaolin/clay 30/30

This test used the same conditions as in Test 5 except for the peak vent flow was increased to 400 SCFM, yielding V/D of 0.67. No surface creep was observed beyond the initial fill line under these conditions. The remaining test section remained clear. The filter bag was not removed for this test.

3.7.7 Test 7. Kaolin/clay 30/30

For this the peak vent flow rate was increased to 500 SCFM, giving V/D of 0.83. No surface creep was observed beyond the initial fill line under these conditions. The first test section started to fog up gradually. Additionally, a few streaks (<1mm wide), about 2-4" long were observed beyond the initial fill line. The second section is stainless steel, so no observation could be made. The third section and beyond remained clear. The filter bag was not removed for this test.

3.7.8 Test 8. Kaolin/clay 30/30

For this test the peak vent flow rate was increased to 600 SCFM resulting in V/D=1. A total of 20 cycles were run. During the first few cycles, the slurry crept up by as much as 5" beyond the initial fill line. As the cycles progressed the surface film remained below the initial fill line. The first clear section fogged up. The third section and beyond remained clear. The filter bag was not removed for this test.

3.7.9 Test 9. Kaolin/clay 30/30

This test was run with V/D ratio of 1.17 by increasing the peak vent flow of 700 SCFM and peak drive flow of 600 SCFM. A total of 50 cycles were completed. Under these conditions, surface creep was observed in the entire first acrylic section. However, no creep was observed in 3rd clear section. Some droplets were found splattered over the bottom 3 feet of the 3rd section. Note that no observation was made in the second section (stainless steel).

3.7.10 Test 10. Kaolin/clay 30/30

Prior to Test 10, two hardware changes were made to the test facility. The first one is the addition of a dome shaped volume to closely simulate the connection between the vent line and the PJM tube. A 14" pipe dome was used for Tests 10-13. A smaller dome (8") was installed for Tests 14 & 15. The second change is the addition of a loop having two horizontal sections and 4 elbows. As discussed earlier, presence of an elbow has a significant impact on the droplet carryover mechanism. The plant vent line has multiple elbows. It was deemed necessary to quantify the carryover in the presence of elbows. The second section (stainless steel) was removed and all the sections beyond the dome were acrylic. WTP directed EDL to run the remaining tests keeping V/D ratio between 1 and 1.3.

Test 10 was run with D=310 SCFM and V=390 SCFM resulting in V/D=1.26. A total of 100 cycles were completed. No surface creep was observed beyond the initial fill line. Note that although the V/D for Test 10 is higher than for Test 9 (1.26 vs. 1.17), the peak vent flow rate is far less for Test 10.

Due to the presence of the dome, the simulant coating on the dome top surface does not get swept away during the drive phase. However, during the vent phase, the escaping air picks up this additional simulant along. This yields significant carryover in the form of droplets. Most of the droplets cannot make the first turn and get deposited on the outer curved surface of the elbow. At the end of the test, the first elbow was disassembled and photographed. Figure 8 shows the buildup of kaolin/clay inside the elbow. The surface coating was estimated to be ~2 -3 mm thick. Beyond the first elbow, the test section remained practically clear.

At the beginning of this test with 20 cycles complete, the simulant level in the simulant reservoir dropped resulting in air aspiration during the draw phase. This resulted in significant carryover of simulant through several clear sections. Two wash cycles were performed, more simulant was added to the reservoir and testing was resumed without any further aspiration or air. This was significant observation that such conditions should not occur in the actual plant operation.



Figure 8. Kaolin/clay Buildup in the First Elbow in the Test Section during Test 10

3.7.11 Test 11. Kaolin/clay 15/15

Test 11 was done with 15/15 kaolin/clay simulant. Peak vent and drive flow rates were set at 390 and 300 SCFM, respectively ($V/D = 1.3$). The results were similar to those in Test 10. A lot of buildup was observed inside the first elbow but no surface creep in the first section. The second section (after the elbow) showed a few streaks after 60 cycles as shown in Figure 9. The remaining test sections remained clear.

The filter bag collected 0.502 grams of kaolin/clay over 100 cycles, yielding 5.02 mg per cycle. Note that this carryover is much higher than the previous layout where there was no dome and the carryover was around 1.2 mg/cycle. This increase in carryover is attributed to the dome that results in excessive droplets and aerosol. Most of the droplets are deposited inside the first elbow. However, the aerosol is transported all the way to the filter bag.

Figure 10 shows the kaolin/clay buildup inside the first elbow after 100 cycles.



Figure 9. Droplet Streaks in the First Horizontal Section after 60 Cycles



Figure 10. Kaolin/clay Buildup inside First Elbow for Test 11

3.7.12 Test 12. Kaolin/clay 15/15 Long Term

Test 12 was performed to determine creep and carryover under long term testing conditions. For a V/D ratio of 1.1, a total of 500 cycles were performed over three days.

Figure 11 shows the fill line and streaks of the simulant in the clear test section after first two cycles.



Figure 11. Simulant Fill Line and Streaks During Test 12 after 2 Cycles

Figure 12 shows the droplet streaks in the first section after 10 cycles. As testing progressed, the clear section became increasingly coated with kaolin/clay.

Figure 13 shows creep of kaolin/clay film downwards during a drive phase. The surface waves are clearly visible as air rushes past the liquid film.

Figure 14 shows surface film behavior under vent phase.



Figure 12. Simulant Fill Line and Streaks During Test 12 after 10 Cycles



Figure 13. Simulant Surface Coating During a Drive Phase



Figure 14. Simulant Surface Film Behavior under Vent Phase for Test 12

As described in Section 3.7, three distinct mechanisms of simulant transport are surface creep, droplet entrainment and aerosol entrainment. During this test of 500 cycles, no surface creep was observed. However, the droplet entrainment mechanism was present but almost all the droplets were deposited in the first elbow in the vent line. In order to quantify the droplet deposition rate, the elbow was removed for inspection after 100, 180 and 420 cycles. The droplets deposited on the outer curved surface of the elbow since they could not make 90 degree turn along with venting air. The deposited layer was found to be thin around the deposit area and thick in the middle. The maximum depth was measured and an averaged depth around 180 degrees of circumference was determined. This yielded an estimate of total flow blockage at the most constricted cross section of the elbow. The percentage flow blockage was calculated to be 1.94%, 2.90% and 4.84% after 100, 180 and 420 cycles of operation, respectively. The uncertainty of flow blockage estimates was determined to be +/- 25% of the value.

Figure 15 shows the flow blockage data on a semi-log plot. The equation that represents the flow blockage trend is given below.

$$B = 4.67 \log_{10}(N) - 7.47$$

where B = percentage flow blockage
N = number of PJM cycles.

Figure 15 also shows an extrapolation of flow blockage trend (dashed line) for larger number of cycles. Based upon this extrapolation it is estimated that the flow blockage will be around 11.21% (+/-2.80%) after 10,000 cycles. Note that this extrapolation is approximate since, excessive blockage will result in higher local air velocity levels during venting, possibly limiting the maximum depth of the deposited layer.

At the conclusion of 500 cycles, two wash cycles were performed with 20 gpm water for 5 seconds during the drive phase. The first elbow was removed for inspection to determine the effectiveness of the wash cycles. Most of the deposit was washed out and a few small patches of thin kaolin were observed.

The filter bag was also removed, dried and weighed. A carryover of 4.43 mg/cycle was measured for this long term test. This value is very close but less than 5.02 mg/cycle measured for Test 11. Note that Test 11 has V/D ratio of 1.3 vs 1.1 for Test 12.

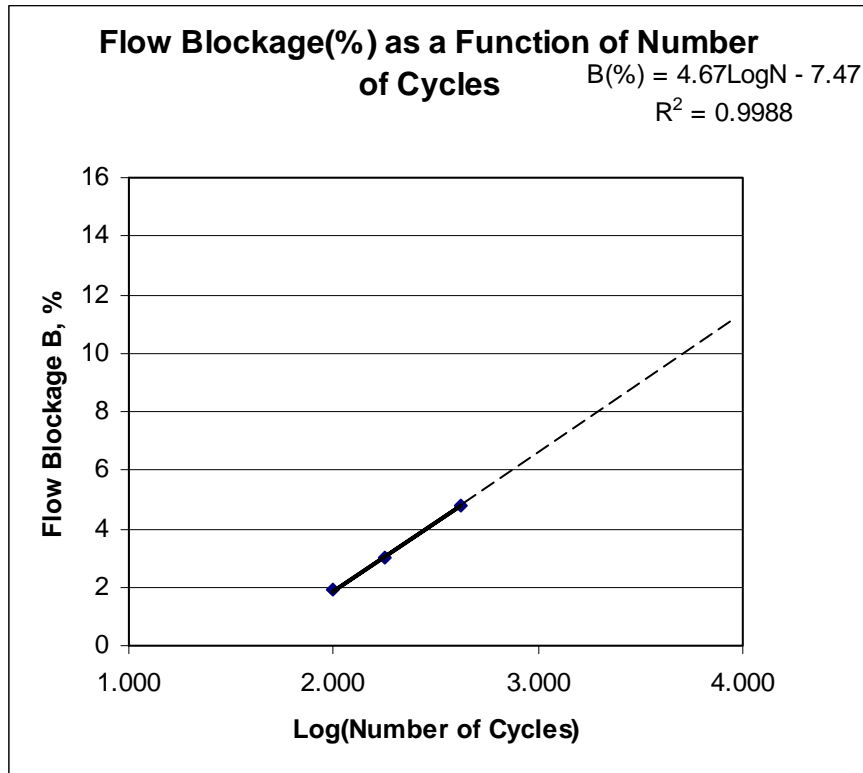


Figure 15. Elbow Flow Blockage as a Function of PJM Cycles During Test 12

3.7.13 Test 13. Kaolin/clay 5/5

For this test, kaolin/clay mixture was diluted to achieve a rheology of 5 Pa and 5 cP. The peak vent and drive flow rates were set at 390 and 300 SCFM, respectively. A total of 100 cycles were run. No surface creep was observed. However, the first clear section was coated white with kaolin due to droplet and aerosol entrainment.

The carryover in the filter bag was measured to be 5.45 mg/cycle. This compares very well with the prior tests.

3.7.14 Test 14. AZ-101 Simulant

For Test 14 and 15, the 14" dome was replaced by a smaller 8" dome due to limited inventory of AZ-101 simulant. The remaining test facility configuration was unchanged.

Test 14 was conducted under the same operating conditions as in Test 13 ($V/D = 1.3$). No surface creep was observed after 100 cycles. However, the first clear section became very cloudy due to droplet and aerosol entrainment as shown in Figure 16.



Figure 16. Test Section after 100 Cycles of AZ-101 Simulant, Test 14

Figure 17 shows the AZ-101 deposit on the first horizontal section immediately after the first elbow. The filter bag was not removed after this test. The AZ-101 carryover in the filter bag was measured in the long term test 15.



Figure 17. Test Section after 100 Cycles of AZ-101 Simulant, Test 14

3.7.15 Test 15. AZ-101 Simulant

This test was performed to quantify the long term behavior of simulant transport. A total of 400 cycles were performed under $V/D = 1$ condition. Both peak vent and drive flow rates were set at 390 SCFM.

No surface creep was found in this long term test. The primary transport mechanism were droplet and aerosol entrainment.

Figure 18 shows the streaks of AZ-101 droplets after 10 cycles.

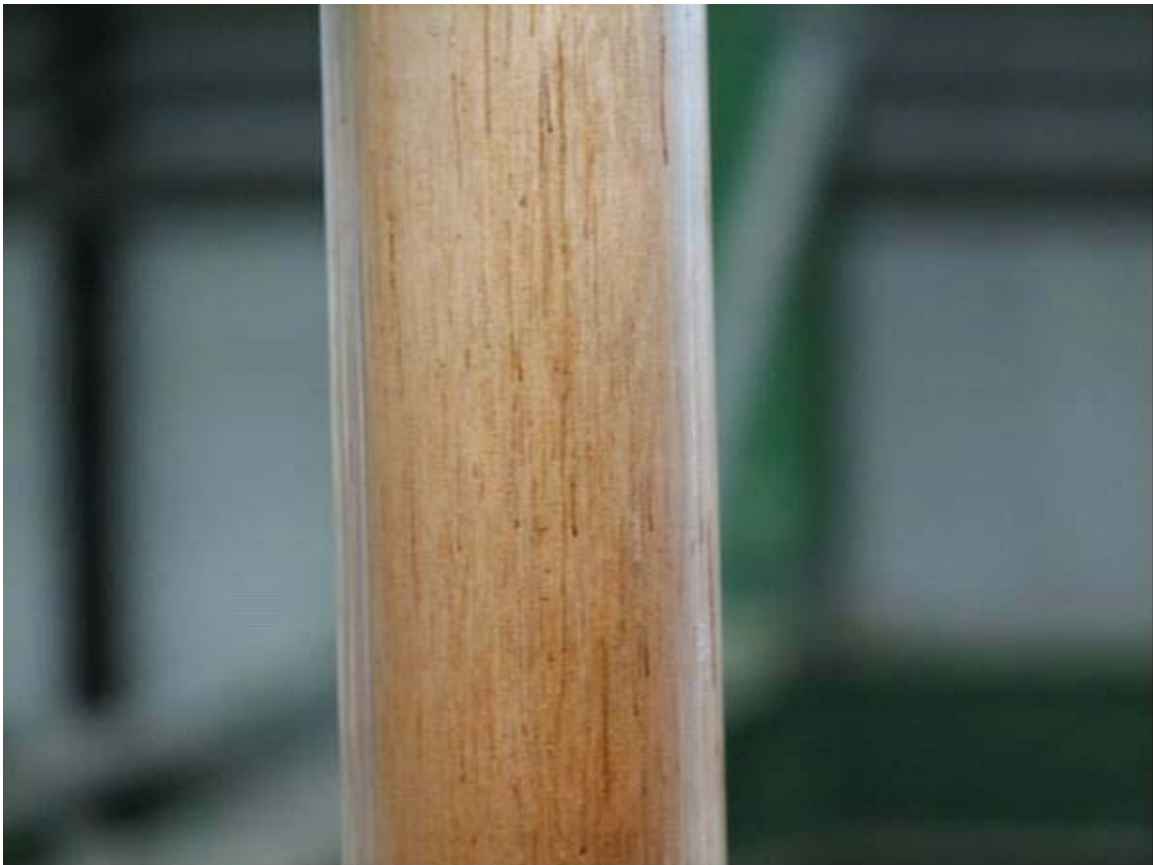


Figure 18. First Clear Section after 10 Cycles of AZ-101

Figure 19 shows the first clear section at the end of 400 cycles. The entire section is full of simulant streaks. The primary mechanism of this deposit is due to droplets entrained in the dome.



Figure 19. First Section after 400 Cycles of AZ-101, Test 15

Figure 20 shows the first horizontal section after the first elbow. It is clear that almost all the droplets were separated out by the first bend and the test section has some discoloration due to aerosol deposits.



Figure 20. First Horizontal Section after the First Elbow after 400 Cycles, Test 15

Figure 21 shows the discoloration of 3rd clear section after 400 cycles of AZ-101 run. Clearly, no streaks or surface film was observed. The discoloration is due to AZ-101 aerosol deposit.



Figure 21. Third Clear Section After 400 Cycles of AZ-101, Test 15

At the conclusion of 400 cycles, two automatic wash cycles were performed. Figure 22 shows the first clear section after one wash. Note that the dark area in the middle is the simulant fill line during each cycle and consequently had a heavier coating.



Figure 22. First Clear Section After One Wash

Figure 23 shows the same section after two wash cycles. Note that except for the fill line area, the remaining test section fairly clean.



Figure 23. Test Section After 2 Wash Cycles

Figure 24 shows the same test section near its connection to the dome. It shows that two wash cycles are effective in cleaning out most of the test section.



Figure 24. Test Section Near the Dome After 2 Wash Cycles

4.0 CONCLUSIONS

A total of 15 test campaigns were run on the EDL Creep Test Facility using water, kaolin/clay simulant and AZ-101 simulant as working fluid. Based upon the results of the tests, the following conclusions are drawn.

1. Three distinct mechanism of simulant transport were observed during a PJM operation. These mechanisms are *Surface Creep*, *Droplet Entrainment* and *Aerosol Entrainment*.
2. Surface Creep occurred under very large Vent/Drive Flow ratios ($V/D > 2$) and large peak vent flow value of 700 SCFM in 2" vent line. Additionally, the other two entrainment mechanisms were also present. A large amount of carryover (~150 mg/cycle) was measured in the filter bag. For Peak Vent/Drive flow > 2 , about 4" of surface creep was observed per cycle. This surface creep occurred during the first 5 seconds of the vent phase when the flow rates are very high. No creep was observed during the suction phase. For V/D ratio of 0.5 – 1.3, no significant surface creep occurred. However, waste simulant was carried over by droplet and aerosol entrainment.
3. For prototypic values of V/D (0.5 – 1.3), no significant surface creep was observed in all test. However, droplet entrainment and aerosol entrainment were present in all tests. Almost all the droplet entrainment was separated out at the first bend in the vent line. For a given rheology, the aerosol transport increased with increasing values of V/D .
4. The presence of a dome (connection between PJM tube and vent line) caused larger amounts of droplet entrainment as well as aerosol entrainment. The droplets were mostly deposited inside the first elbow. The aerosol was captured by the filter bag. The droplet deposit and buildup in the elbow after 500 cycles and 1000 cycles did not cause any measurable flow restriction.
5. The effect of simulant rheology was found to be insignificant on the overall transport. For a given value of $V/D = 1.3$, kaolin 5/5 experienced about 9% more aerosol transport per cycle as compared to kaolin 15/15.
6. The droplet entrainment measured by deposit in the first 90 degree elbow increased with the number of PJM cycles. The percentage flow blockage was calculated to be 1.94%, 2.90% and 4.84% after 100, 180 and 420 cycles of operation, respectively. The uncertainty of flow blockage estimates was determined to be +/- 25% of the value. An extrapolation of this trend yielded an estimated flow blockage of 11% (+/-2.8%) for 10,000 cycles. Note that this extrapolation is approximate since, excessive blockage will result in higher local air velocity levels during venting, possibly limiting the maximum depth of the deposited layer.

7. Initially, water at 20 gpm was used to wash down the surface film without any air flow. This was not effective in cleaning the clear test sections. Later tests showed that two wash cycles at 20 gpm for 5 seconds during the drive phase were effective in cleaning the test section. Note that the surface buildup was primarily in the form of very thin surface film without any flow blockage in the vent line. Even after 500 cycles of PJM operation, the flow in the vent line was observed to be unobstructed. However, a two cycle flushing operation will be sufficient to clean out any waste buildup in the vent line if required.
8. During one test, the simulant level in the simulant reservoir dropped, resulting in air aspiration during the draw phase. This resulted in significant carryover of simulant through several clear sections. This was significant observation that such conditions should not occur in the actual plant operation.
9. In all creep tests, the suction phase did not play any significant role. Initially, prototypic suction phase durations were set. Later, the suction phase duration was shortened to perform more cycles in a given time.

5.0 FUTURE WORK

The tests performed covered a wide range of working fluids and their rheological properties, hardware configurations and operating conditions. Based upon the results, no follow-on work is anticipated at this time. If the operating conditions change beyond the test envelop, an evaluation of the creep phenomenon will be needed.

6.0 REFERENCES

1. Test Plan: WSRC-TR-2005-00362, SRNL-RPP-2005-00045 REV 0
2. Test Specification: 24590-PTF-TSP-RT-05-001 Rev.0
3. Test Exceptions: 24590-PTF-TEF-RT-05-00015 Rev.1
4. Scoping Statement: S-200