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Drilling Research Projects

Study on Effective Hole Cleaning Using :

"Conventional and Enhanced Sweeps in Horizontal Wellbores"

Thanh Nguyen, University of Tulsa, Drilling Research Projects,

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Abstract:

This is the first report that presents literature review, experimental work and recent developments in this project. The experimental work consists of static tests and preliminary "Enhanced Sweeps". This report includes the first batch of experimental results obtained from the tests conducted on the SSL (Small Sweep Loop) flow loop as well as preliminary successful static test results for oil droplet attachments.

Based on results from preliminary flow loop tests, subsequent "Enhanced sweep" tests were conducted according to a modified Test Matrix. A preliminary analysis of the experimental data obtained is presented. The effects of parameters such as rheology, flow rate, bed heights and pressure drop are presented. The focus of this report will be the results from the "Enhanced Sweep" tests.

The research also shows some interesting behavior of oil droplets attaching to cuttings. Because of the buoyant ability of the oil, it tends to lift the particle in the drilling fluid.

Project Status

Literature Review	85%		
Flow Loop development Training	SWL.	L.P.A.T. (*)	E.P.E.T. (**)
	100 %	95 %	15%
Modeling	05%		
Experiments on SSL.	80%		

(*) SWL (Small Sweep Loop).(**) L.P.A.T. (low pressure ambient temperature loop).
(***) E.P.E.T. (Elevated Pressure Elevated Temperature loop)

PRELIMINARY LITERATURE REVIEW

1)CONVENTIONAL SWEEPS.

a) Fluid Characterization

As documented by Hemphill et al.[2], drilling fluid sweeps generally fall into the following categories:

- High-Viscosity
- High-Density
- Low-Viscosity
- Combinations Sweeps
- Tandem (one type followed by the other)

The characterization of the fluid thus becomes essential to determine the effect that fluid rheology has on the "efficiency" of the sweep. As of now no single rheology model has been proved to describe exactly the shear stress-shear rate relationships of all non-Newtonian fluids over all ranges of shear rate. As a practical consideration there are many situations [22], [23] where a rheology model can be found to approximate the behavior of an actual fluid (within certain ranges) with accuracy commensurate with the reproducibility of measured field data.

Among the existing models, Bingham, Power Law and Yield Power Law have gained widespread usage in the oil industry.

The Power Law

$$\tau = K\gamma^n$$

The Bingham Plastic Model

$$\tau = \tau_y + \mu_p \gamma$$

The Herchel-Bulkley or the Yield Power Law Model:

$$\tau = \tau_y + K\gamma^n$$

Other models such as the Robertson-Stiff Model have found application, specifically in the cementing industry and was shown [24] to provide a good fit of rheology data.

We are using the Chan 3500 and Fann75 viscometers for additional high temperature and pressure fluid characterization tests. Since no consensus could be reached as to the best model to suit our fluids, we have used the above mentioned models individually to characterize the fluid.

b) Rheology of Sweep Fluid:

Much has been written about the role of drilling fluids in the cuttings transport literature[21,22,23]. These studies and others debated high viscosity versus low viscosity and which rheological parameters are most useful for characterizing hole cleaning efficiency. It has been suggested that flow index "n" plays a dominant role for the study of efficient hole cleaning[21] but also that all available rheological parameters (such as n, K and τ_0 in the YPL model) should be considered. The use of density sweeps, sweep fluids having a higher density than the "base" drilling fluid in use, has also been proposed[26,27]. Density sweeps are difficult to study with the available low pressure flow loop as the addition of weighted material may cause clogging and/or degradation of valves and other problems due to the small size of the weighting material. However, at this time weighted sweeps are considered in the 1st stage of Test Matrix.

Studies[24], [25] use the effective viscosity ratio, i.e, the ratio between the displacing phase to the displaced phase to describe the effect of rheology of fluids on the efficiency of displacement. They suggest that high values of this ratio are desirable for good displacement efficiencies, all other variables remaining the same. Large values mean that the displacing phase is more viscous than the displaced phase. They suggest that at low ratios the penetrating front of the displacing phase tends to channel through the center of the flow field, leaving a great deal of the external phase behind.

c) Critical Velocity Concept:

Fluid velocity is an important factor in the hole cleaning process that has been cited by many researchers[28,29,30], in terms of critical velocities. Fluid velocities can disturb the cuttings lying in the cuttings bed and push them up to the main flow stream. However, if the fluid has inadequate carrying capacity, many of the cuttings will fall back into the cuttings bed. Mechanistic models based on critical velocities were developed for the bed erosion process[11]. These model show that both rolling and lifting of bed particles, caused by drag and lift forces, exist simultaneously during solid bed erosion; however one mechanism may dominate over the other. We may develop a mechanistic or regression model to understand the effects of rheological properties of the sweep fluid on bed erosion and its relationship with the critical velocity concept.

d) Fluid-Fluid Displacement:

Generally, in practice the sweep fluids are injected in addition to the drilling mud that is already present in the well-bore. The sweep fluid "displaces" the base fluid out of the drill-pipe as well as the well-bore while contributing to the bed erosion process. The stability of the interface between the base fluid and the sweep fluid is of concern. The stability of the interface may have some influence on the efficiency of sweep as it may affect the rheology of the

sweep fluid due to mixing, etc. Various models [25], [24], [28], [29] allow a careful investigation of individual effects of various parameters that effect the displacement efficiency.

e) Fluid Density:

Studies [24], [30] use the density ratio between the displacing phase to the displaced phase to describe the effect of density on the efficiency of displacement. They suggest that by increasing the density of the displacing phase even slightly the displacement efficiency can be drastically improved even for relatively short displacement times.

f) Fluid yield stress:

Studies [30], [27], [31] have shown that yield stresses are quite critical in the displacement process. A model developed by Beirute et al. [24] for displacement of drilling muds by cement slurries predicts that cement "channeling" through the muds will occur if the yield stress of the mud is significantly less than that of the cement. They also conclude that the possibility of a "static layer" quite similar to the "channeling" is governed by the ratio of the yield stresses of the fluids in question. For axial displacements with density differences the ratio of the buoyancy stress and the yield stress of the displaced fluid also significantly effects this "static layer".

A review of the developed models to describe the fluid-fluid displacement has been conducted during the course of this project. A brief outline of this process is given in the theoretical section of this report.

g) Pipe Rotation:

Pipe rotation influences the cuttings bed erosion significantly [9]**.** Results indicate that rotation results in a velocity profile difference that makes bed erosion easier. Optimizing the use of rotation can also contribute to improvement of drilling efficiency. Sanchez et al.[9] focused on investigating the effects of drillpipe rotation in hole cleaning. This study shows that the effect of drillpipe rotation is promising enough that it should not be neglected. Valuri [15] reported that drill pipe rotation has a significant effect on cutting bed height reduction during sweep experiments.

A method was proposed by Hemphil et al. for the objective analysis of sweep efficiency [2]. Information from pressure-while-drilling (PWD) tools and measured drilling fluid properties were used to determine a mathematical prediction of "cuttings out". Their method was based on the difference in mass "in" and "out". Thus, a more rigorous evaluation of drilling fluid sweep efficiency was provided to minimize ineffective sweeps. Our project will follow the principles mentioned in the approach section to evaluate the sweep efficiency.

h) Sweep Fluid Selection and Performance :

There are several sweep[12] formulation options available for improving hole cleaning performance but often little consideration is given to what the most appropriate sweep for the given conditions will be. Factors that need to be

considered when selecting sweeps include hole angle, fluid density, formation type, cutting diameter, drill pipe rotation and fracture gradient.

i) Interface stability

Nelson [13] suggested that at low flow rates the displacement of a dense fluid by a lighter one leads to a unstable phenomenon known as "buoyant plume". Everything else being constant, the laminar flow displacement of a "thin" fluid by a "thick" fluid will be more efficient than the reverse, which is known to give rise to an unstable interface. The factors that most influence the displacement were suggested to be the ratio of the densities of the fluids in question, the effective viscosity ratios, yield stresses and the flow rates. It has also been suggested[13] that in the study of displacement of drilling mud by spacer and wash fluids, the non-Newtonian nature of the latter fluids must be accurately modeled to accurately determine flow regime and dynamic pressures in the annulus along the entire column of fluid.

2) FLOTATION.

a) Air bubbles attachment:

Yu[1], et al. proposed technology to counteract gravitation force while simultaneously increasing the drag force by attaching gas bubbles to drilled cutting particles with chemical surfactants. The gas bubbles will pull the cuttings upward because of their buoyancy in the drilling mud thereby counteract the gravity force. Furthermore, the gas bubble/cutting aggregation will have a larger surface area than the cutting alone, resulting in an increase in the drag force. This work reported the following conclusions:

- ✓ Air bubble attachment to cutting is possible. Chemical surfactants play a critical role
- ✓ The chemical surfactants are capable of attaching air bubbles to drilled cuttings when added to both water and aqueous polymeric fluids.
- ✓ The structure of the chemical "collector" is very important.

b) Oil droplet attachment:

Because there was concern over the effect of high pressure on the air bubbles, attachment of cuttings to oil droplets was considered next. Phan.[16] showed in preliminary experiments that :

- ✓ A chemical collector is important for the attachment of both air bubbles and oil droplets to drilled cuttings.
- ✓ Attachment to oil droplets helps cuttings to be transported easier.
- ✓ Dynamic tests showed that cuttings attached to oil droplets can be transported easily, however, the strength of the attachment needs to be improved.

- ✓ The concentration of surfactant used in the experiment is low. This helps to make this technology environmentally friendly and cost effective.

c) The Purpose of Oil in Flotation:

Megraw [20] reported that the exact function of oil in flotation is a point that has not yet been definitely settled. The primary function, which has been clear since the inception of flotation process, is that oil serves to reduce the surface tension of water and thus provide for bubbles and froth of more lasting character than could be formed without its use. Furthremore, the flotation processes that are used on the largest scale and the ones that are achieving the greatest success, such as in the mining industry, are those in which oil is used. One of the properties of oil is its preferential adhesion to some minerals rather than to gangue particles.

RESULTS AND DISCUSSION

1) CONVENTIONAL SWEEPS.

a) Sweep Fluid Design & Characterization:

The composition of the "sweep" fluid had been proposed to be a mixture of PAC (Poly-anionic cellulose) and XCD (Xanplex D) in water.

Experiments were conducted to estimate the concentration (in lb/bbl) of PAC and XCD in water to obtain the desired rheological parameters at ambient temperature and pressure. These mixtures were then tested using the Chan 3500 viscometer to measure the rheological properties.

The Table 1.1 and Table 1.2 is based on the test matrix proposed in May, 2006, ABM Progress Report. However, there are some minor changes in sweep volumes, flow rate ranges and number of tests.. Sixty-three sweep tests have been completed to date on the Small Sweep Loop (SSL).

Table 1.1 : Sweep Test matrix

Sweep Test No	Sweep Type	Test Code	Flow rate G.P.M. (gpm)	Test Time (min)	Bed Height	Number of Test	Sweep Volume (bbl)	pH Range
1	Water W01-02-03-04-05	W	5/10/15	3-6-9	50-55% of Pipe	15	0.7	(8-11)
2	High Viscosity HV01-02	HV	5/10/15/20	3-6-9	50-55% of Pipe	16	0.7	(8-11)
3	Low Viscosity LV01-02	LV	5/10/15/20	3-6-9	50-55% of Pipe	16	0.7	(8-11)
4	High Density HD01-02	HD	5/10/15/20	3-6-9	50-55% of Pipe	16	0.7	(8-11)

Table 1.2 : Sweep designation and characterization.

Sweep Test No	Sweep Type	Composition			Fluid Properties				
					API - Bingham Plastic		Yield-Power Law model parameters		
		PAC lb/bbl	XCD lb/bbl	Barite lb/bbl	Plastic Viscosity	Yield Point, Lb/100ft^2	Consitency Index, K Lbf^n / 100ft^2	Flow Behavior Index, n	Density lb/gal
1	Water W01-02-03-04-05	-	-	-	-	-	-	-	8.3
2	High Viscosity HV01-02	1.5	1.5	0	22	39	2.942	0.5	8.3
3	Low Viscosity LV01-02	0.5	0.5	0	9	5	0.381	0.591	8.3
4	High Density HD01-02	1	1.5	100	17	49	2.783	0.504	10

b) Discussion :

Four different fluids were prepared to study the effect of rheology and density on the bed erosion and cutting removal process. Figures 1-4 show that water appears to have the most reduction in bed height and most cuttings removed. That is, of the 4 sweeps studied in this stage, water (Test 1) is overall the best in bringing the largest amount of cuttings out of the pipe test section (in the same time of sweeping) compared to the three other fluids (see Figures 1-4). However, this may have been due to the flow conditions when using water. Tables 1.2 shows that the viscous fluids are in laminar flow as compared to water, which is in turbulent flow. Other than water, which was tested as a "base fluid", tests indicate that increasing the viscosity (see table 1.2 and figure 6) and the density of the sweep efficiently "erodes" the cuttings bed. Test 3 (lower viscosity than Test 2) performed poorly while Test 2 (higher viscosity) and Test 4 (high density) are very good in carrying and moving cuttings out of the hole.

Plots of bed height at flow rates of 5-10-15-20 gpm. All of the figures (Fig.s 1-4) show that increase of the flow rate will have a large effect on the bed height erosion.

The effect of different parameters on pressure are shown in Fig. 5 (plots of measured differential pressure versus time, duration of the sweep, 3-6-9 minutes). Measured differential pressure reflects the frictional pressure drop along the test section. As depicted in the figure, the pressure drop generally increases with increase of flow rate for Test 3 (low viscosity) while this concept is not totally correct for Test 4 (High Density) (see figure 5)

2) ENHANCED SWEEPS.

Static Tests:

Forty-five oil droplet static tests in all were performed in the test tube. The effect of different parameters such as surfactant, polymer, pH value and salt (NaCl) concentration are investigated in these tests. Oil droplet static test proved the concept that when the oil droplet adhered to the cutting then the buoyant tendency of the oil lifts the particle in the fluid to the surface (see figures 7.1 to 7.6). This also demonstrates one of the properties of oil which is its preferential adhesion to some particles. The test number 33-34-35 is the best fluid for floating the particle by increasing the percentage of clear salt from 15 to 25 % by weight when mixed with 10% oil in 400 ml of water.

Table 2 : The static tests for Oil droplet completed up to date are 45 Tests in Lab

No	Water	NaCl	XCD	PAC	Surfactant	Oil	Note
	ml	g	g	g	g	ml	
1	200	0	0	0	0	10	pH - 8.11
2	200	2	0	0	0	10	pH - 7.49
3	200	4	0	0	0	10	pH - 7.6
4	200	6	0	0	0	10	pH - 7.7
5	200	8	0	0	0	10	pH - 7.5
6	200	10	0	0	0	10	pH - 7.04
7	200	12	0	0	0	10	pH - 7.4
8	200	14	0	0	0	10	pH - 7.1
9	200	16	0	0	0	10	pH - 7.2
10	200	6	0	0.5	0	10	pH - 7.16
11	200	6	0	0.6	0	10	pH - 7.13
12	200	6	0	0.7	0	10	pH - 7.1
13	200	6	0	0.8	0	10	pH - 7.07
14	200	6	0	0.9	0	10	pH - 7.0
15	200	6	0	1	0	10	pH - 7.04
16	200	0	0	0	0.005	10	0% of Salt
17	200	2	0	0	0.005	10	1% of Salt
18	200	4	0	0	0.005	10	2% of Salt
19	200	6	0	0	0.005	10	3% of Salt
20	200	8	0	0	0.005	10	4% of Salt
21	200	10	0	0	0.005	10	5% of Salt
22	200	12	0	0	0.005	10	6% of Salt
23	200	14	0	0	0.005	10	7% of Salt
24	200	16	0	0	0.005	10	8% of Salt
25	200	6	0	0.5	0.005	10	3% of Salt
26	200	6	0	0.6	0.005	10	3% of Salt
27	200	6	0	0.7	0.005	10	3% of Salt
28	200	6	0	0.8	0.005	10	3% of Salt
29	200	6	0	0.9	0.005	10	3% of Salt
30	200	6	0	1	0.005	10	3% of Salt
31	200	60	0	0	0	10	30% of Salt
32	400	40	0	0	0	5	10% of Salt
33	400	60	0	0	0	10	15% of Salt
34	400	80	0	0	0	10	20% of Salt
35	400	100	0	0	0	10	25% of Salt
36	400	120	0	0	0	10	30% of Salt
37	400	140	0	0	0	10	35% of Salt
38	400	12	0	0	0	10	3% of Salt
39	400	12	0.5	0	0	10	3% of Salt
40	400	12	0.6	0	0	10	3% of Salt
41	400	12	0.7	0	0	10	3% of Salt
42	400	12	0.8	0	0	10	3% of Salt
43	400	12	0.9	0	0	10	3% of Salt
44	400	12	1	0	0	10	3% of Salt
45	1000	300	0	0	0	50	30% of Salt

COMPARISON OF FLUID TYPES.

A. CONVENTIONAL SWEEP

1. COMPARISON OF FLUID TYPES @ 5 gpm

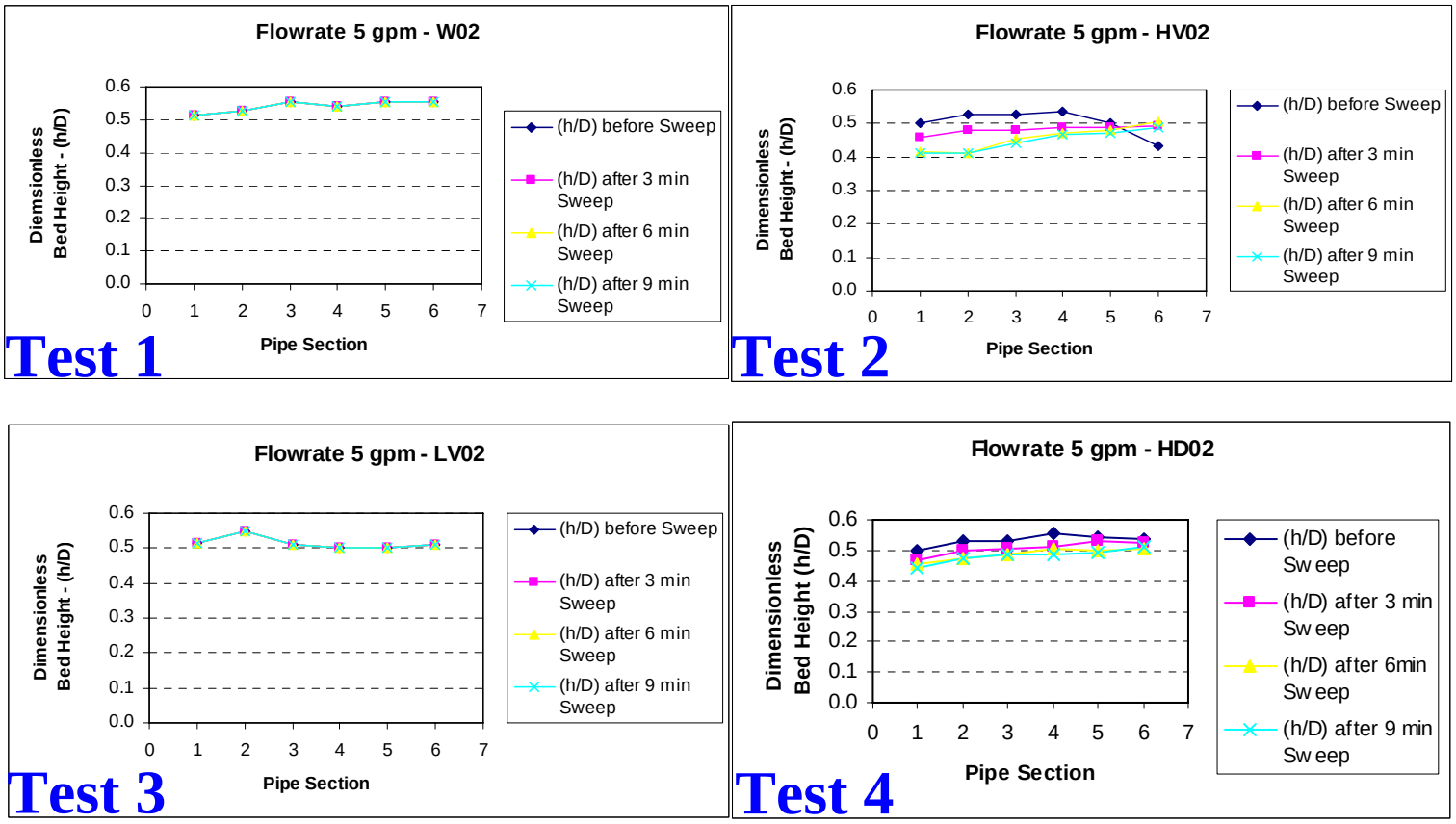
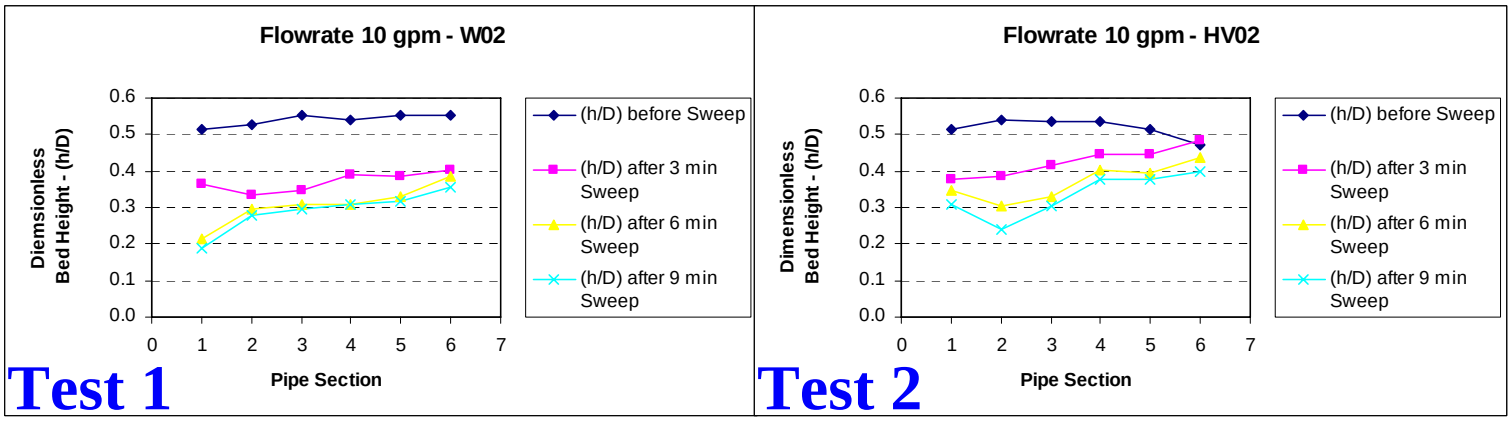


Figure 1 : Comparison of sweep fluids based on dimensionless bed heights of cuttings @ flow rate 5 gpm

2. COMPARISON OF FLUID TYPES @ 10 gpm



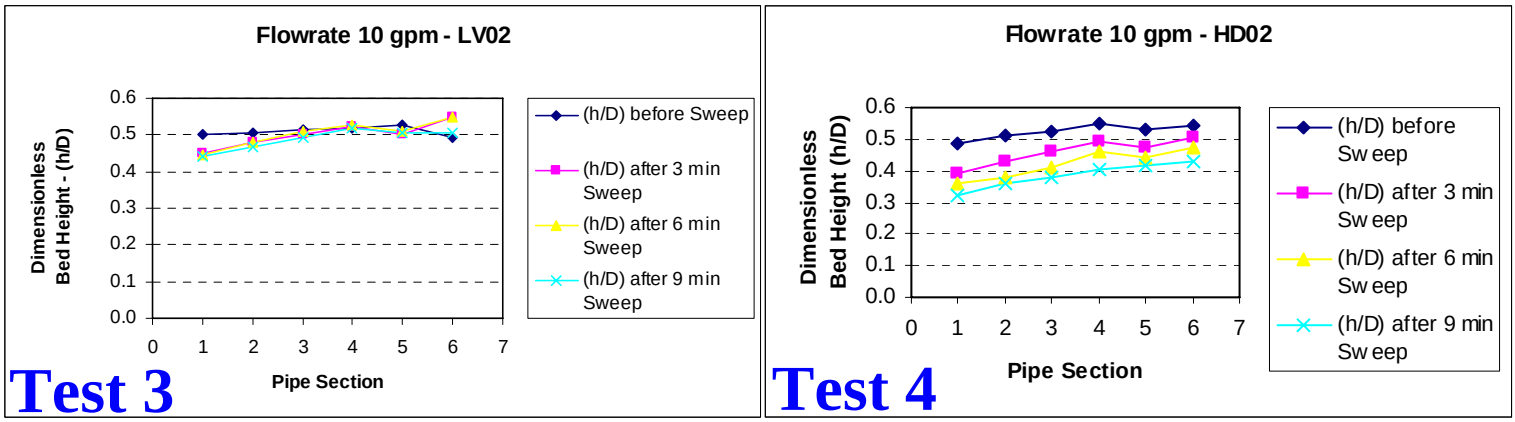


Figure 2 : Comparison of sweep fluids based on dimensionless bed heights of cuttings @ flow rate 10 gpm

3. COMPARISON OF FLUID TYPES @ 15 gpm

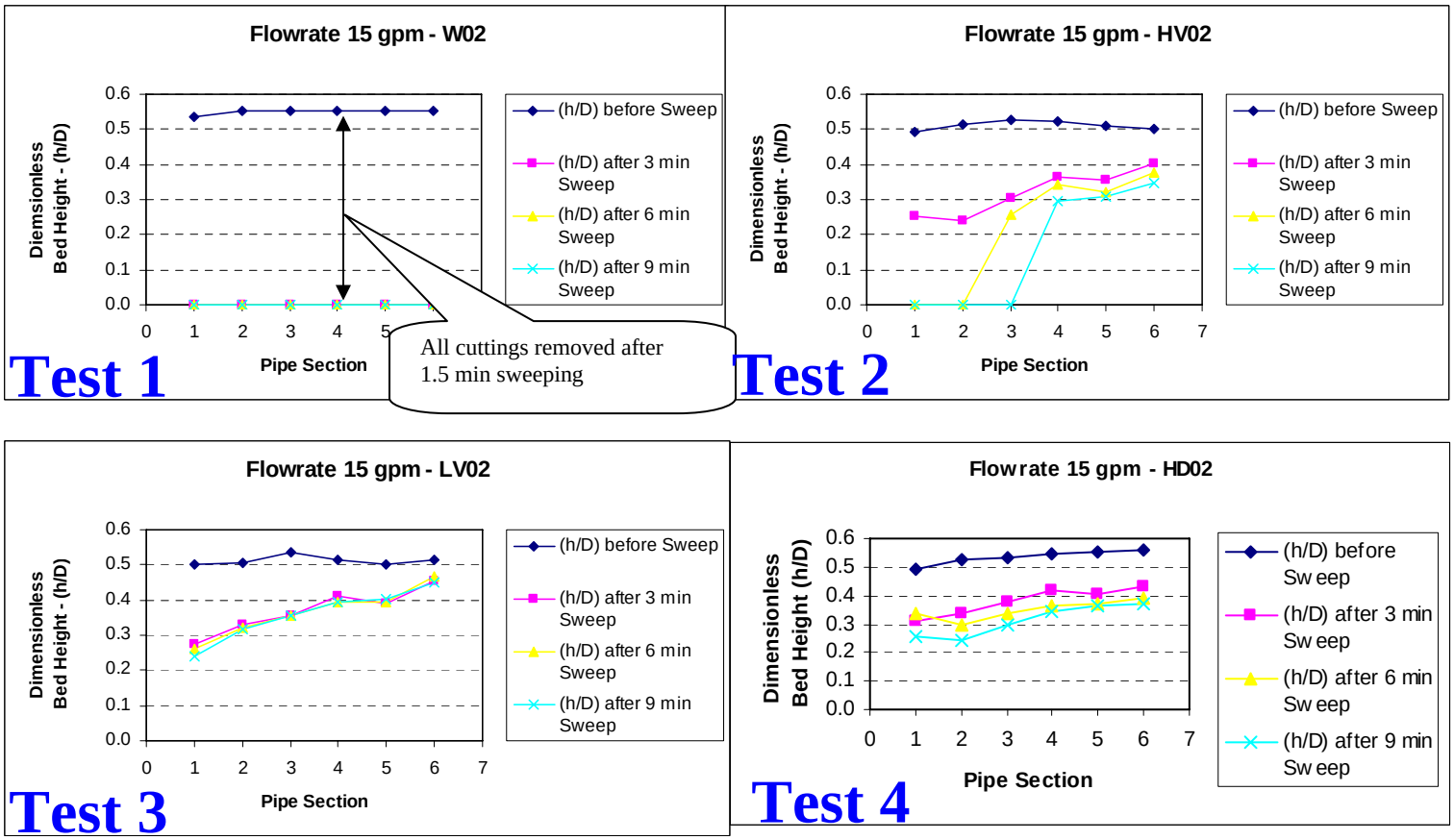
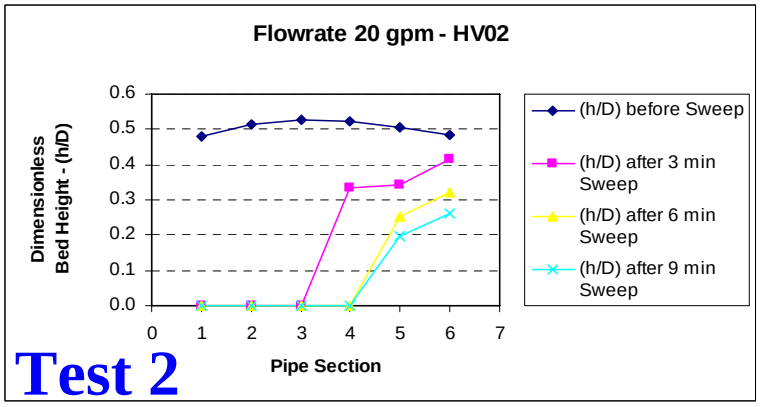


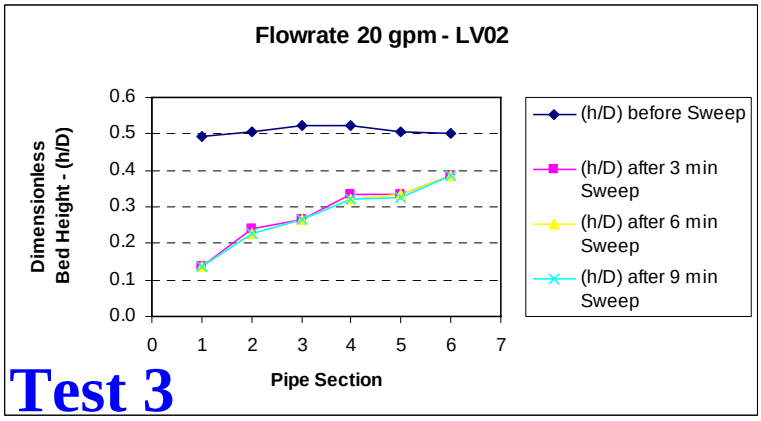
Figure 3: Comparison of sweep fluids based on dimensionless bed heights of cuttings @ flow rate 15 gpm

4. COMPARISON OF FLUID TYPES @ 20 gpm

Test 1 :

@ 15 gpm, water (test1) cleaning all cuttings in the pipe test after 1,5 min sweeping. Therefore, we don't run experiment with water at flow rate 20 gpm





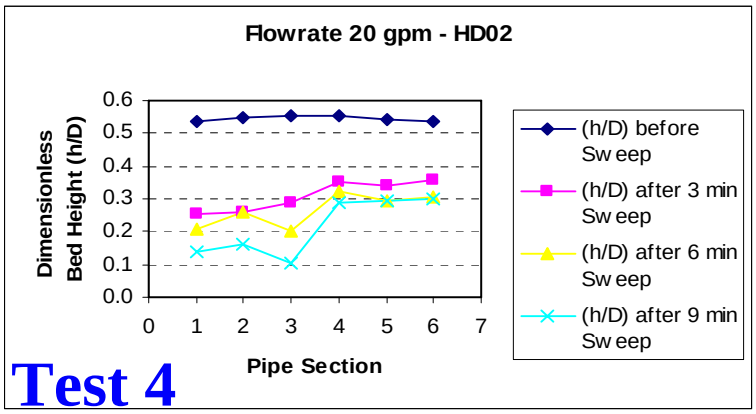
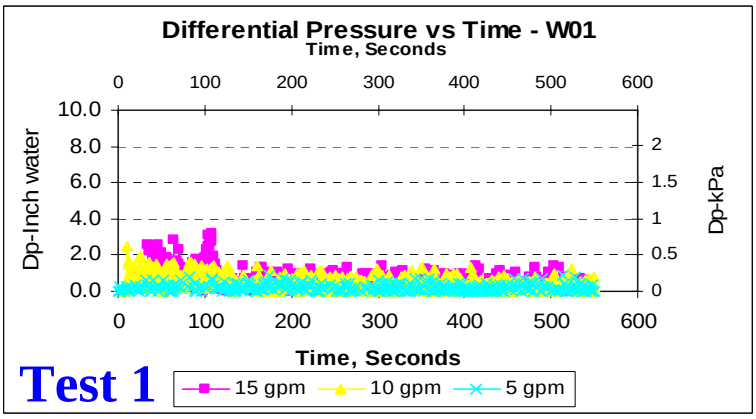
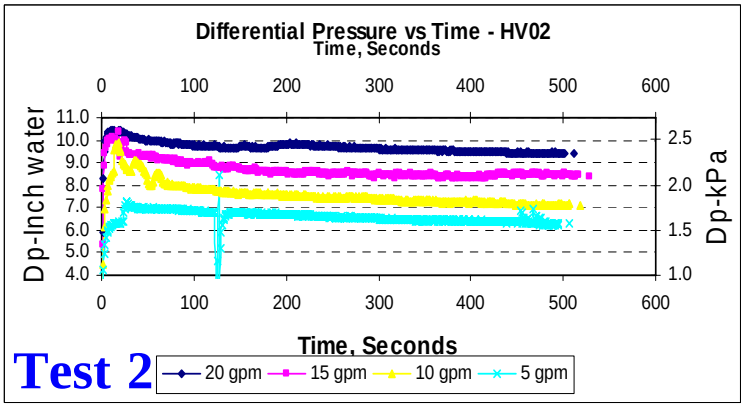


Figure 4: Comparison of sweep fluids based on dimensionless bed heights of cuttings @ flow rate 20 gpm

4. COMPARISON OF dP AT 5-10-15-20 gpm





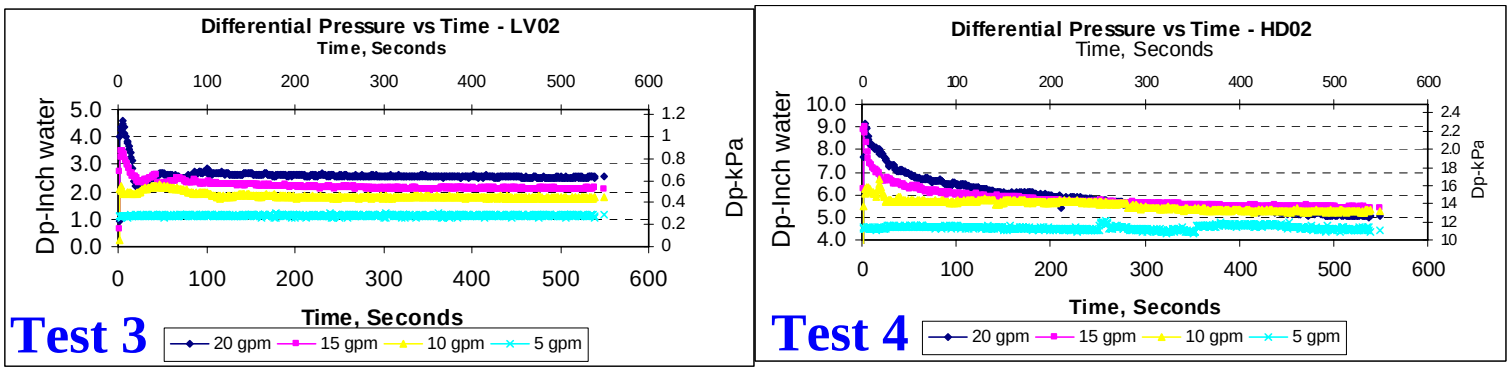


Figure 5 : Comparison of sweep fluids based on differential pressures+. @ flow rate 5-10-15-20 gpm

4. SHEAR STRESS vs SHEAR RATE OF FLUIDS

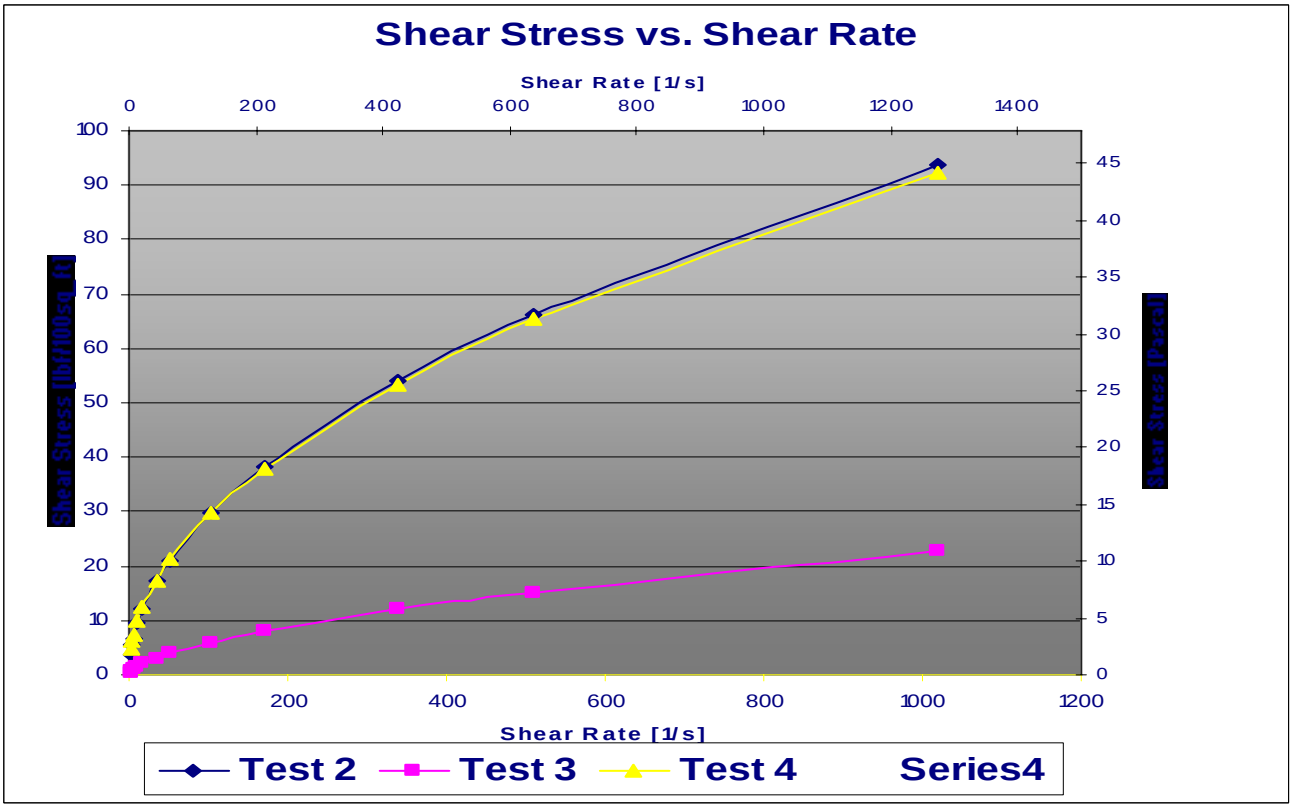


Figure 6 : Shear stress vs Shear rate of fluids

B. ENHANCED SWEEPS

Pictures of Static Test for "Oil Droplet " Proved the Concept

Figure 7.1: Oil droplet attached to the cutting sized 2.83 mm - Test No 34

Figure 7.2 : The cutting floating – Test No 35

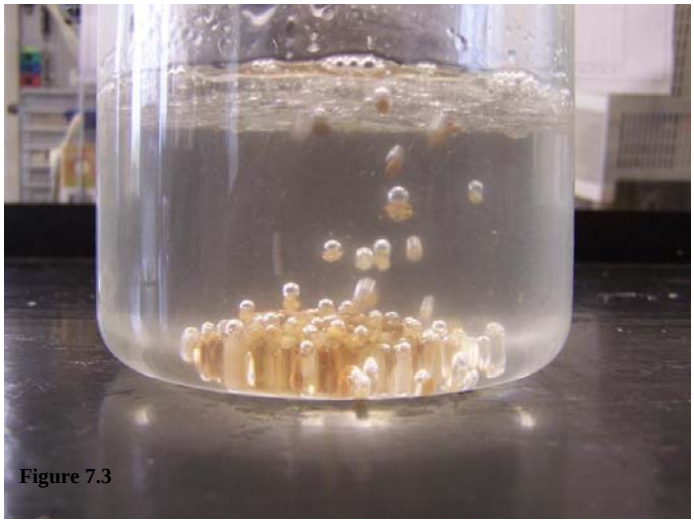


Figure 7.3

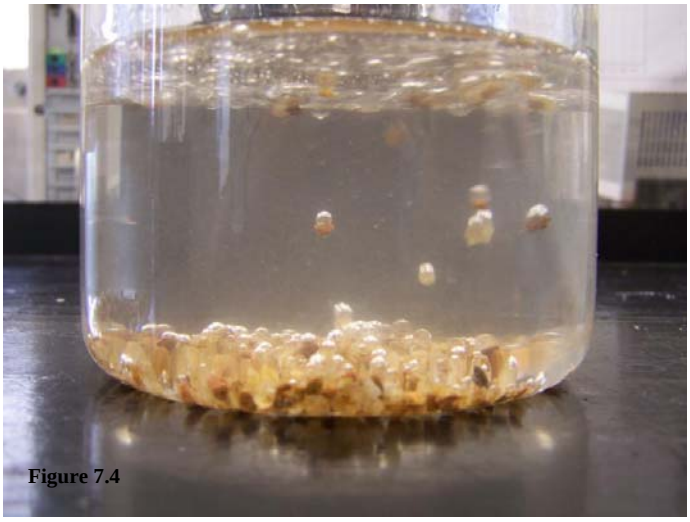


Figure 7.4

Figure 7.3 –7.4 – 7.5 : The cutting lifted up by oil droplet and moving around when stirring it up

Figure 7.5

Figure 7.6

Future Work:

1) Continue the SWL. tests. Once they are completed the second stage of the project, i.e. tests on the LPAT and E.P.E.T. (Elevated Temperature Elevated Pressure – if time permitted) flow loops will be undertaken. (see table 3 proposed next test matrix)

2) Development a Mathematical model.

Table 3: Proposed next test matrix

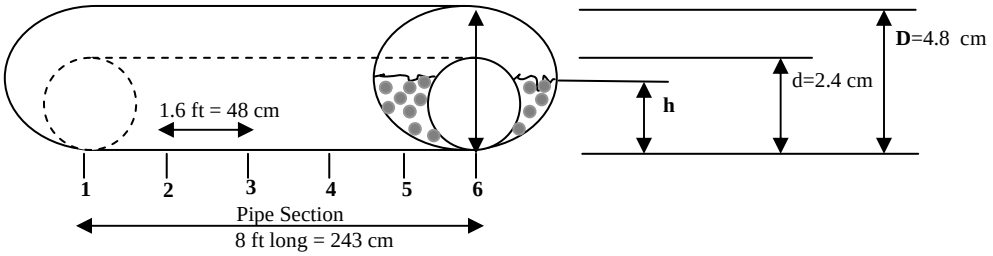
Sweep Type	Flow rate G.P.M. (gpm)	Test Time (min)	Bed Height	Number of Test	Sweep Volume (bbl)	PH Value
Dynamic Flotation Test	5/10/15/20	3-6-9	50-55% of Pipe	5	0.7	(8-11)
High Viscosity 1 (2XCD+2PAC)	5/10/15/25/30	3-6-9	40-50% of Pipe	5	0.7	(8-11)
High Viscosity 1 (3XCD+3PAC)	5/10/15/25/30	3-6-9	40-50% of Pipe	5	0.7	(8-11)
High Density 1 (12 lb/gal)	5/10/15/25/30	3-6-9	40-50% of Pipe	5	0.7	(8-11)
High Density 2 (14 lb/gal)	5/10/15/25/30	3-6-9	40-50% of Pipe	5	0.7	(8-11)
High Density 3 (16 lb/gal)	5/10/15/25/30	3-6-9	40-50% of Pipe	5	0.7	(8-11)
High Density 4 (18 lb/gal)	5/10/15/25/30	3-6-9	40-50% of Pipe	5	0.7	(8-11)
Low Density 1	5/10/15/25/30	3-6-9	40-50% of Pipe	5	0.7	(8-11)

Preliminary Time Table

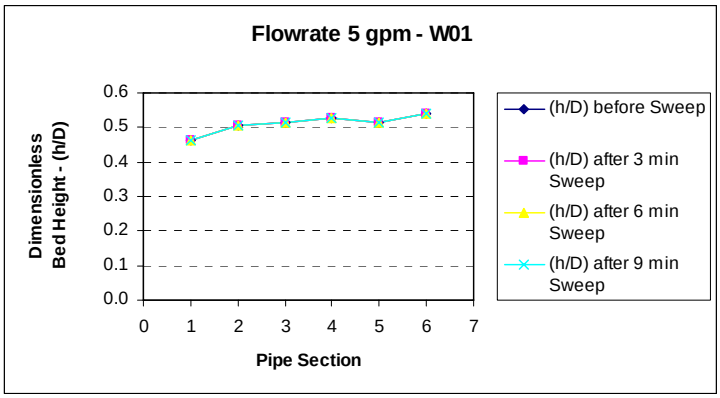
	2006			2007		
	Spring	Summer	Fall	Spring	Summer	Fall
Literature Review and SSL set up						
Literature Review & Experiments on SSL						
Experiments on LPAT and ETEP (if time permitted)						
Test data analysis and Modeling						
Final Report						

Appendix :

Pipe Test



Appendix A . THE RESULT OF DIMENSIONLESS BED HEIGHT (h/D) FOR WATER – TEST 1



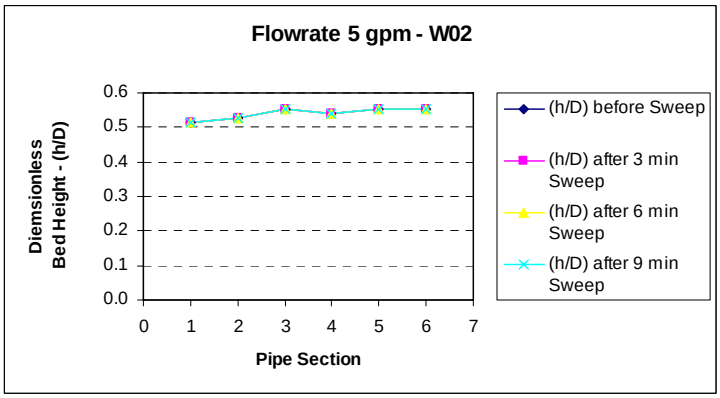
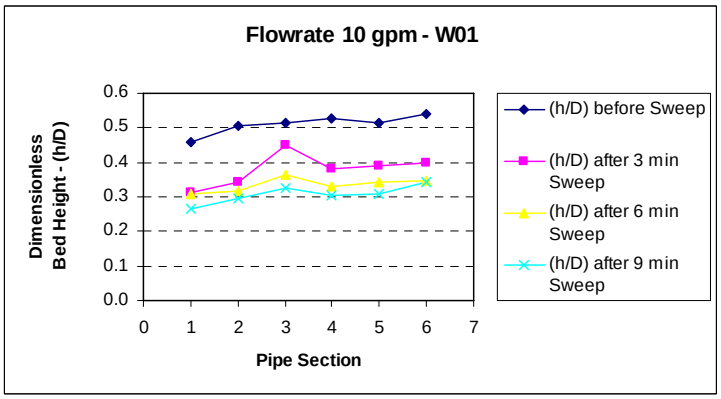


Figure A.1 Test 1 –Sweep type :Water Code W01-02 @ Flowrate 5 gpm



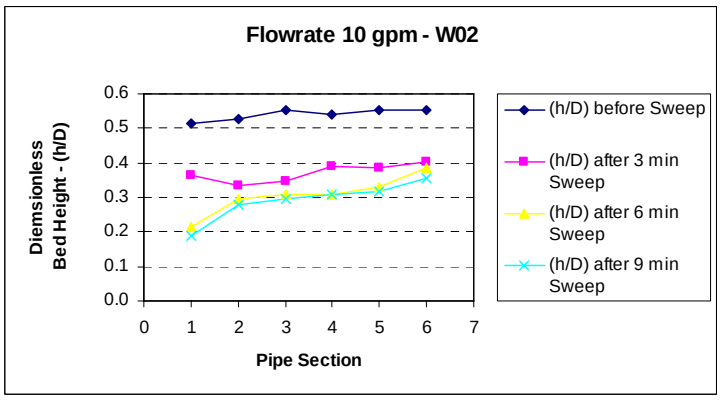
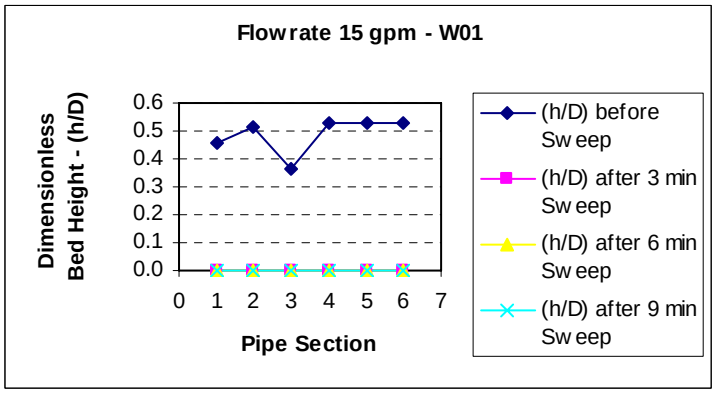


Figure A.2Test 1 –Sweep type :Water Code W01-02 @ Flowrate 10 gpm



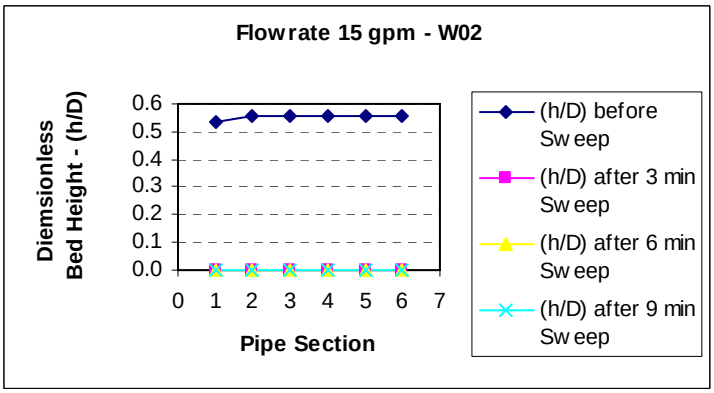
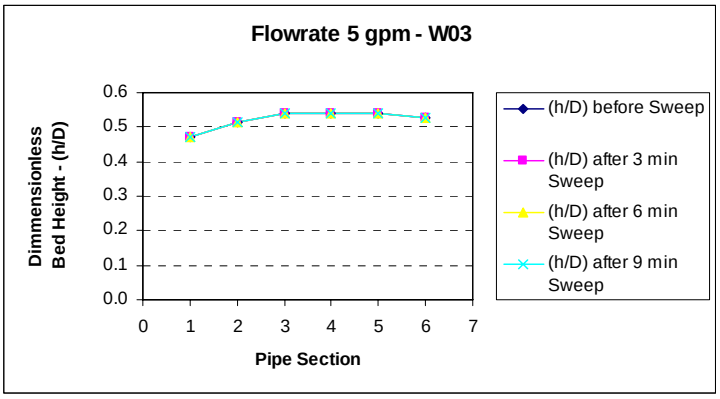


Figure A.3 Test 1 –Sweep type :Water Code W01-02 @ Flowrate 15 gpm



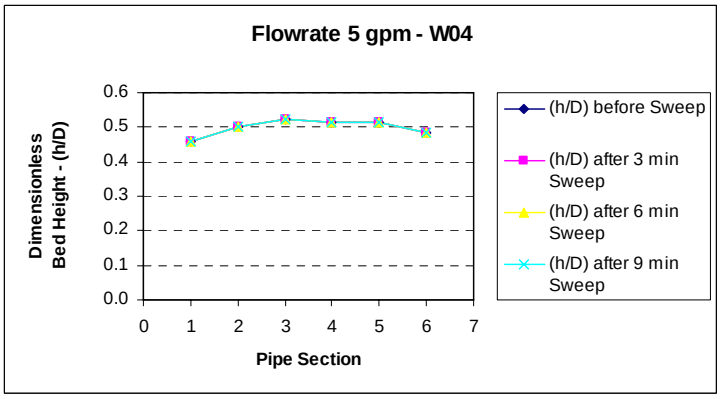
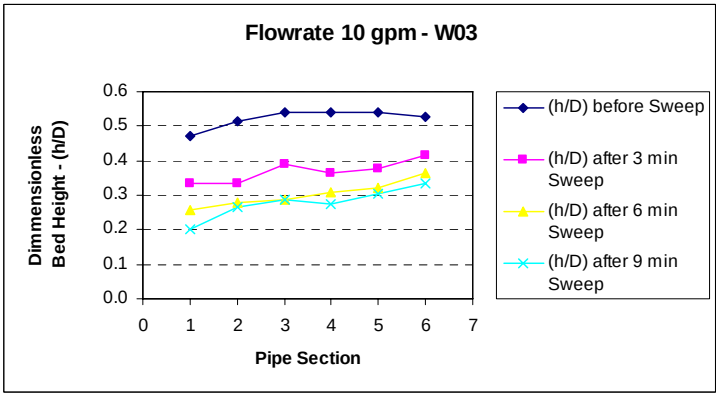


Figure A.4 Test 1 –Sweep type :Water Code W03-04 @ Flowrate 5 gpm



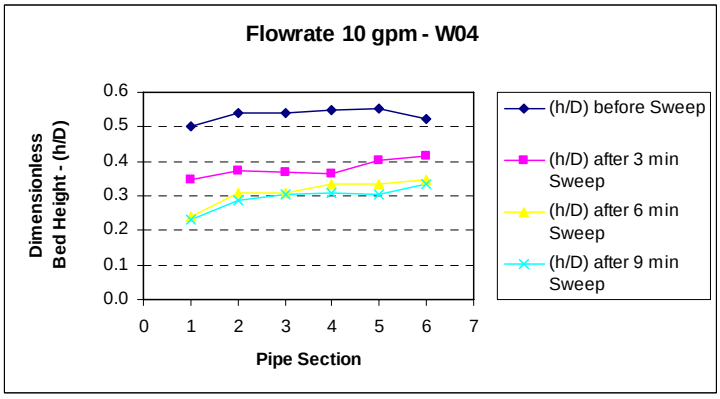
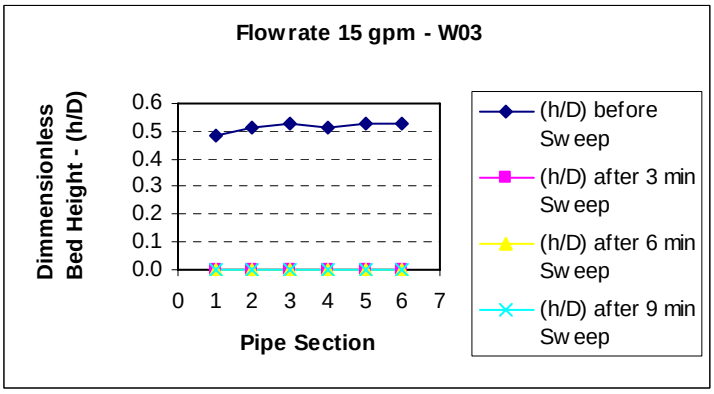


Figure A.5 Test 1 –Sweep type :Water Code W03-04 @ Flowrate 10 gpm



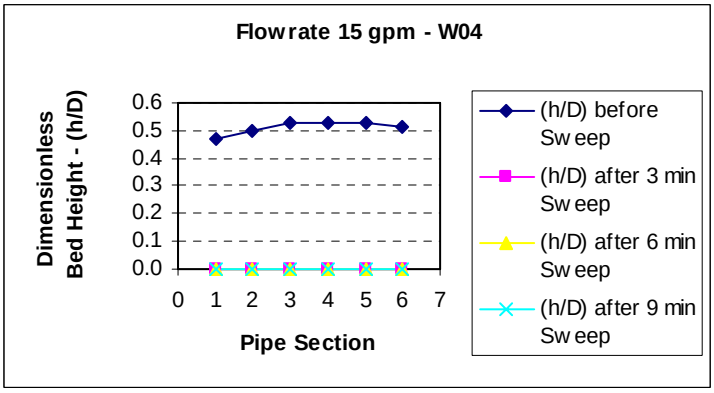


Figure A.6 Test 1 –Sweep type :Water Code W03-04 @ Flowrate 15 gpm

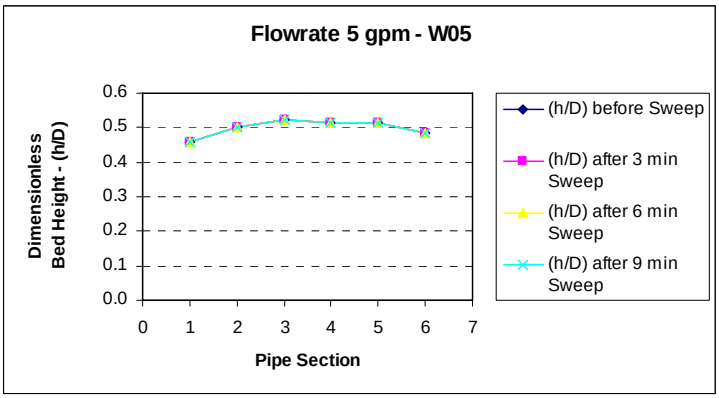


Figure A.7 Test 1 –Sweep type :Water Code W05 @ Flowrate 5 gpm

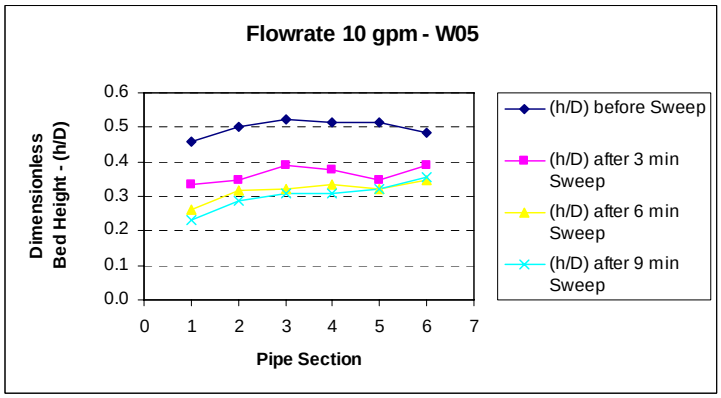


Figure A.8 Test 1 –Sweep type :Water Code W05 @ Flowrate 10 gpm

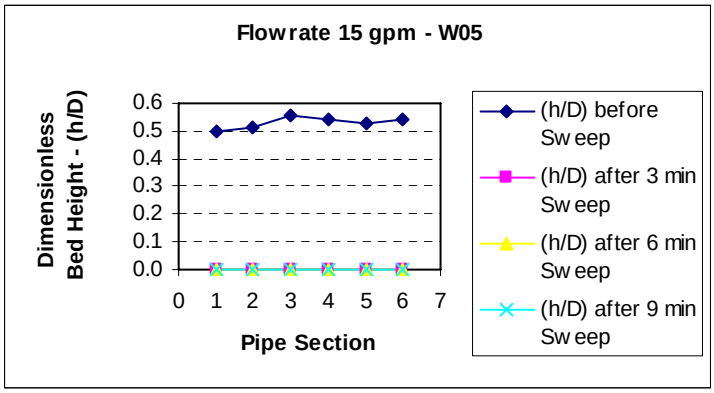
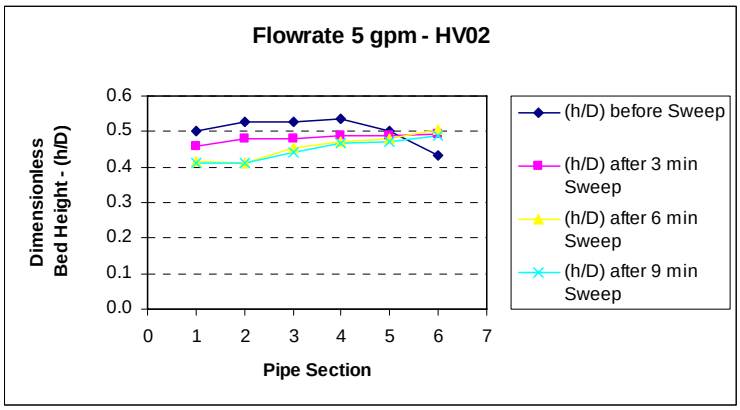
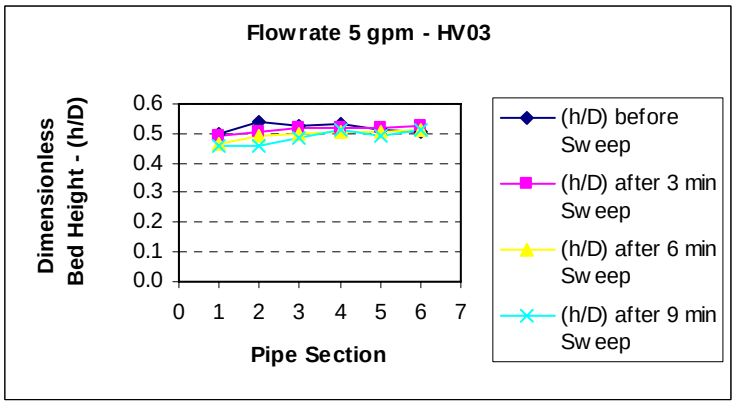


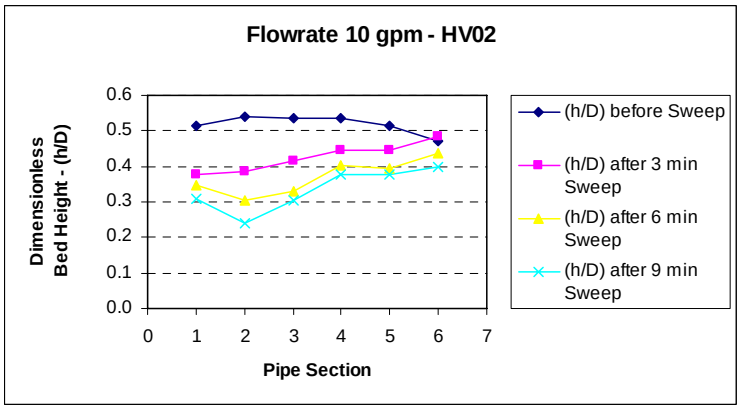
Figure A.9 Test 1 –Sweep type :Water Code W05 @ Flowrate 15 gpm

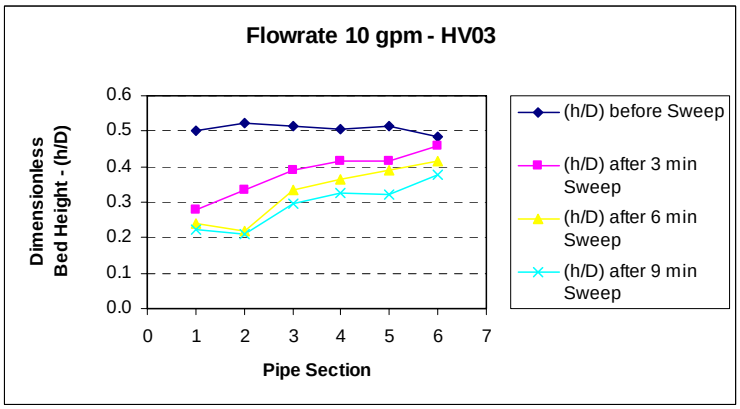
Appendix B: THE RESULT OF DIMENSIONLESS BED HEIGHT – TEST 2

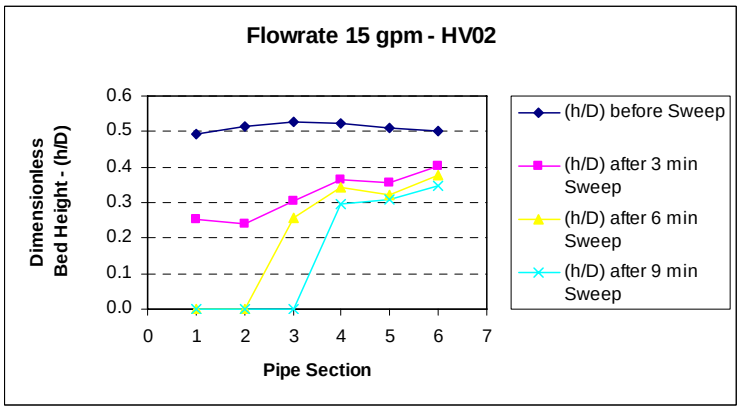
Figure B: Test 2 –Sweep type :High Viscosity Code HV02-03 @ Flowrate 5-10-15-20 gpm

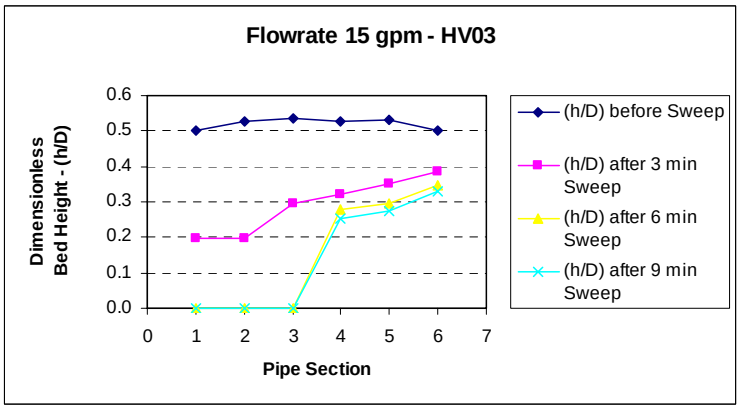


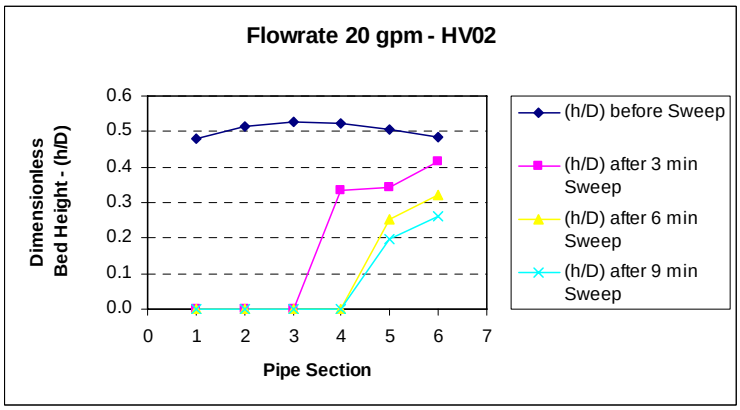


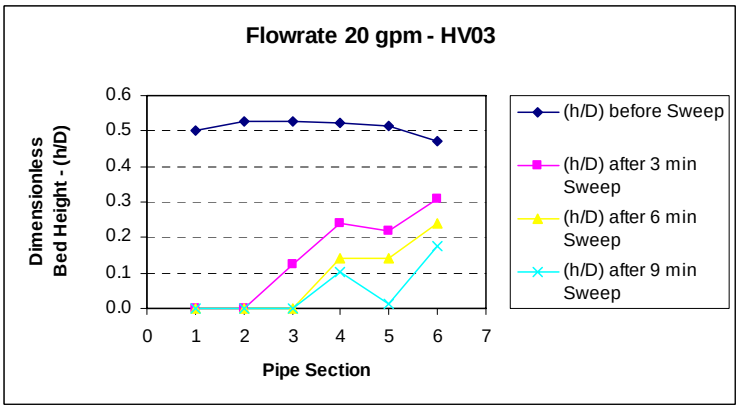






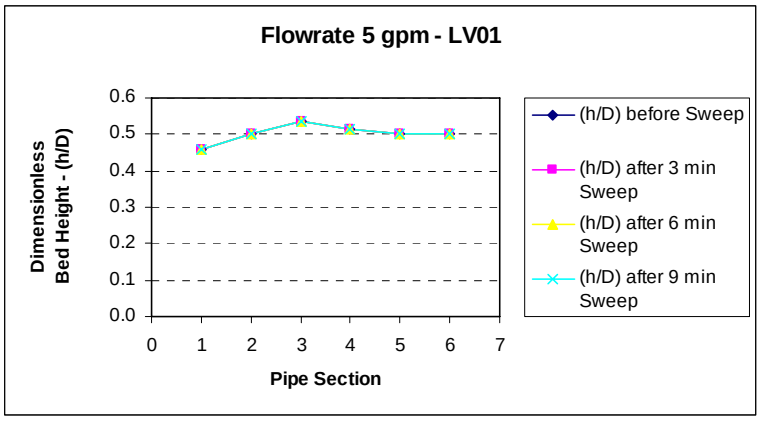


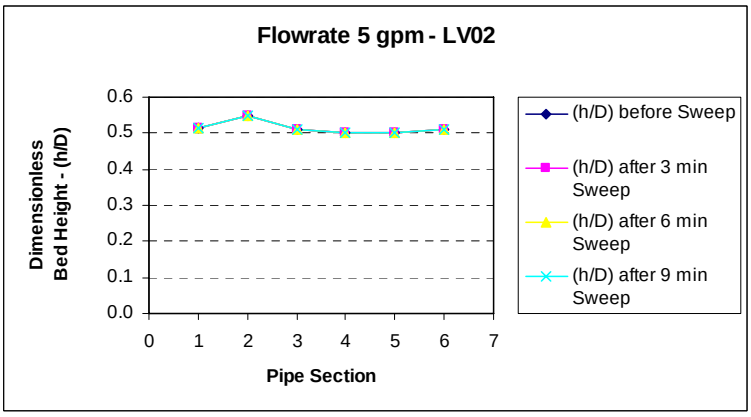


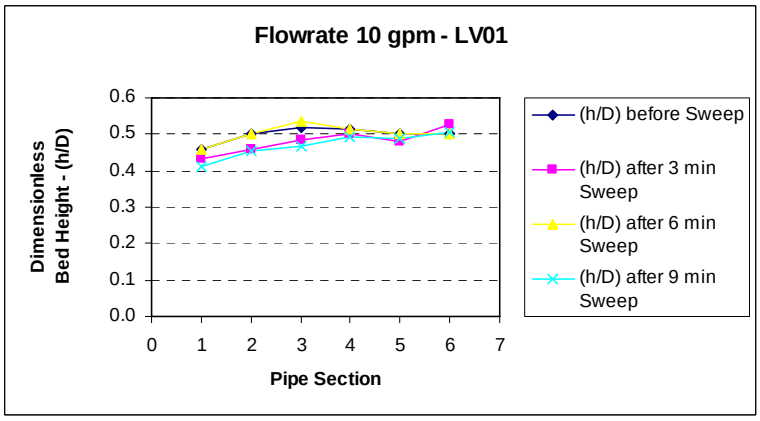


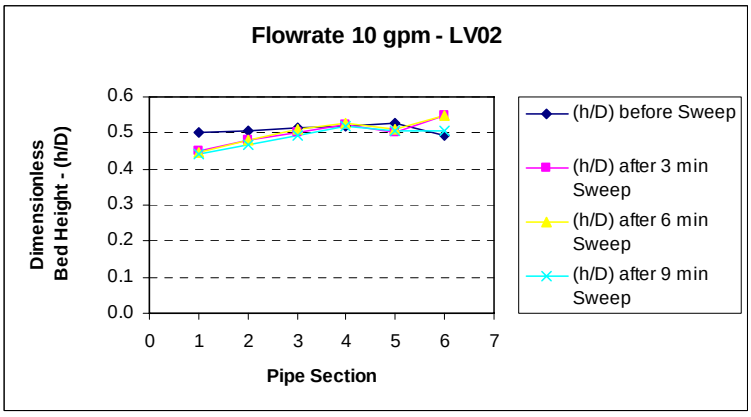
Appendix C: THE RESULT OF DIMENSIONLESS BED HEIGHT – TEST 3

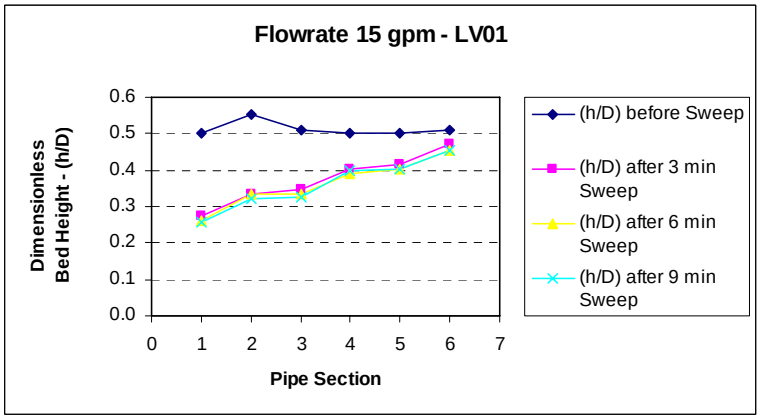
Figure C: Test 3 –Sweep type :Low Viscosity Code LV01-02 @ Flowrate 5-10-15-20 gpm

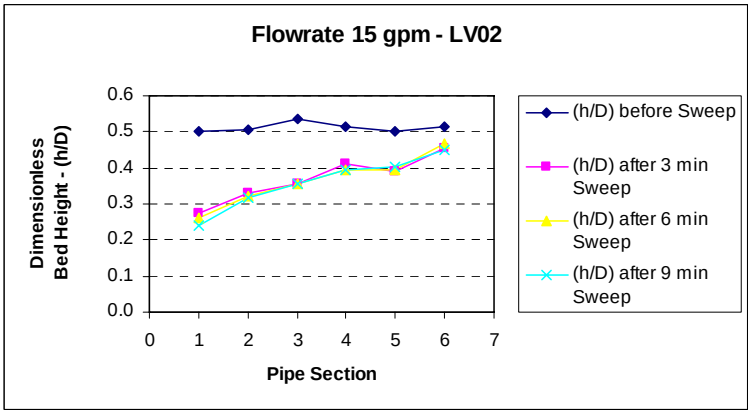


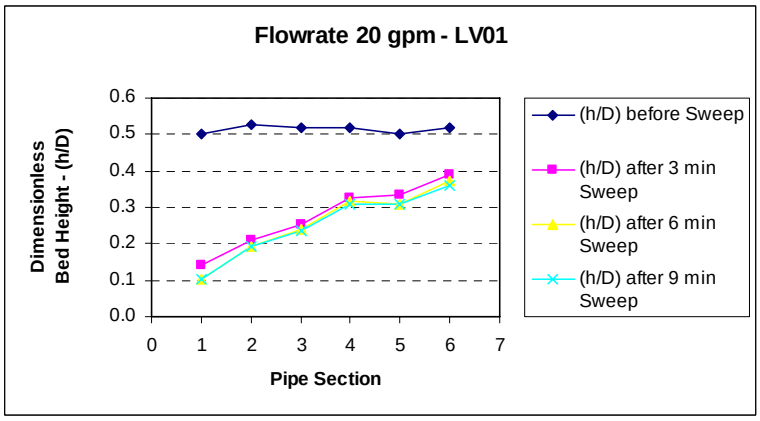


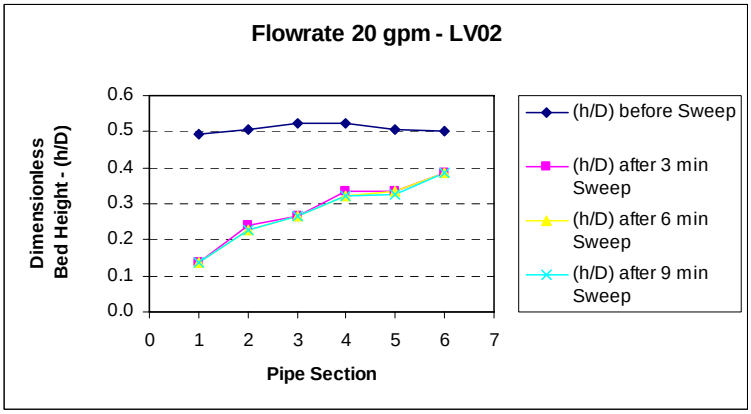






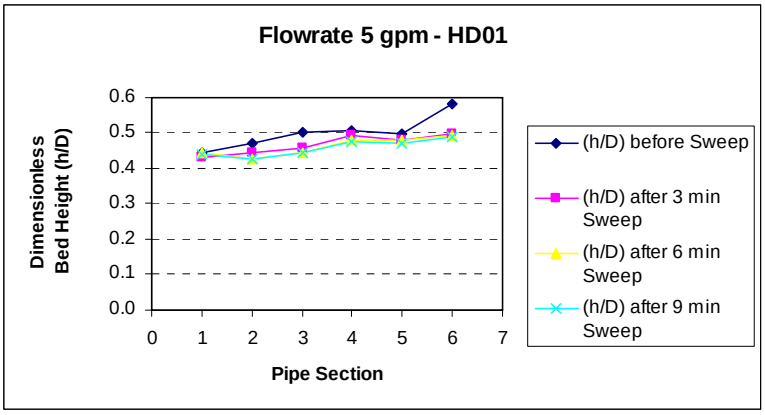


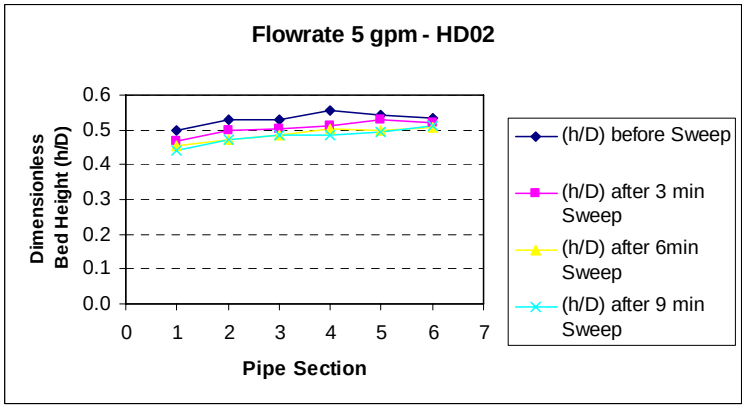


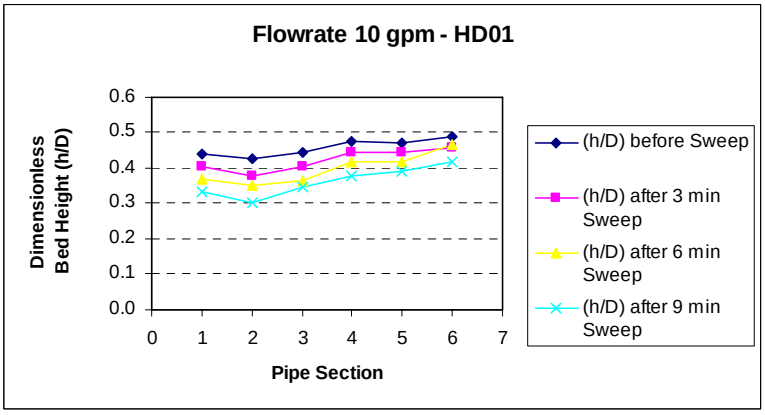


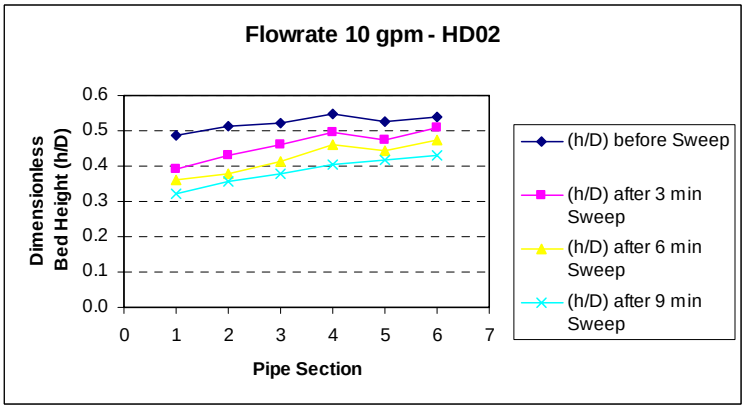
Appendix D: THE RESULT OF DIMENSIONLESS BED HEIGHT – TEST 4

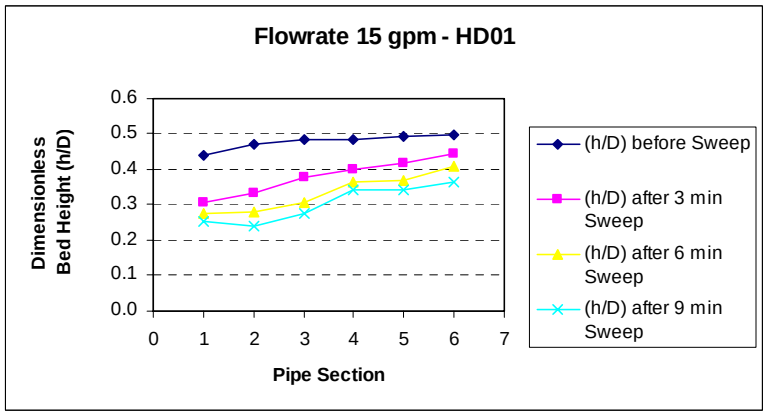
Figure D: Test 4 –Sweep type :High Density Code HD01-02 @ Flowrate 5-10-15-20 gpm

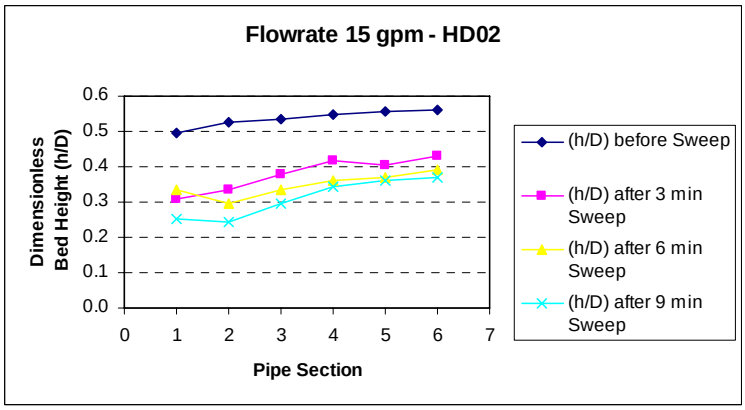


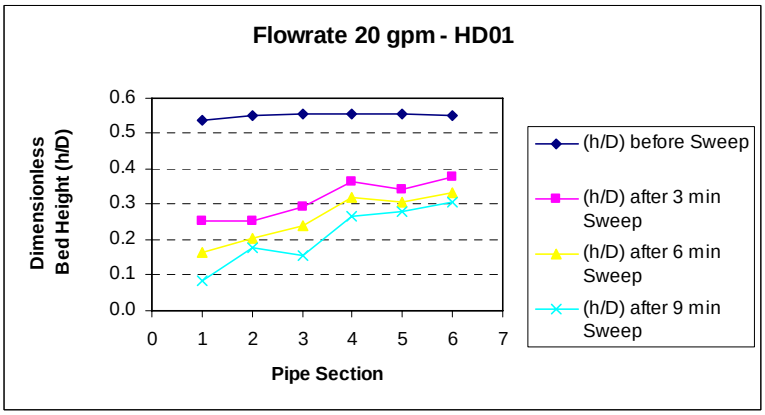


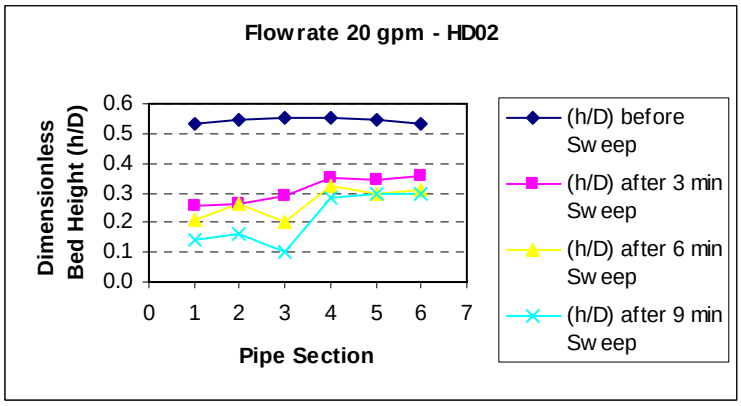












Appendix E: THE RESULT OF DIFFERENTIAL PRESSURE – TEST 1

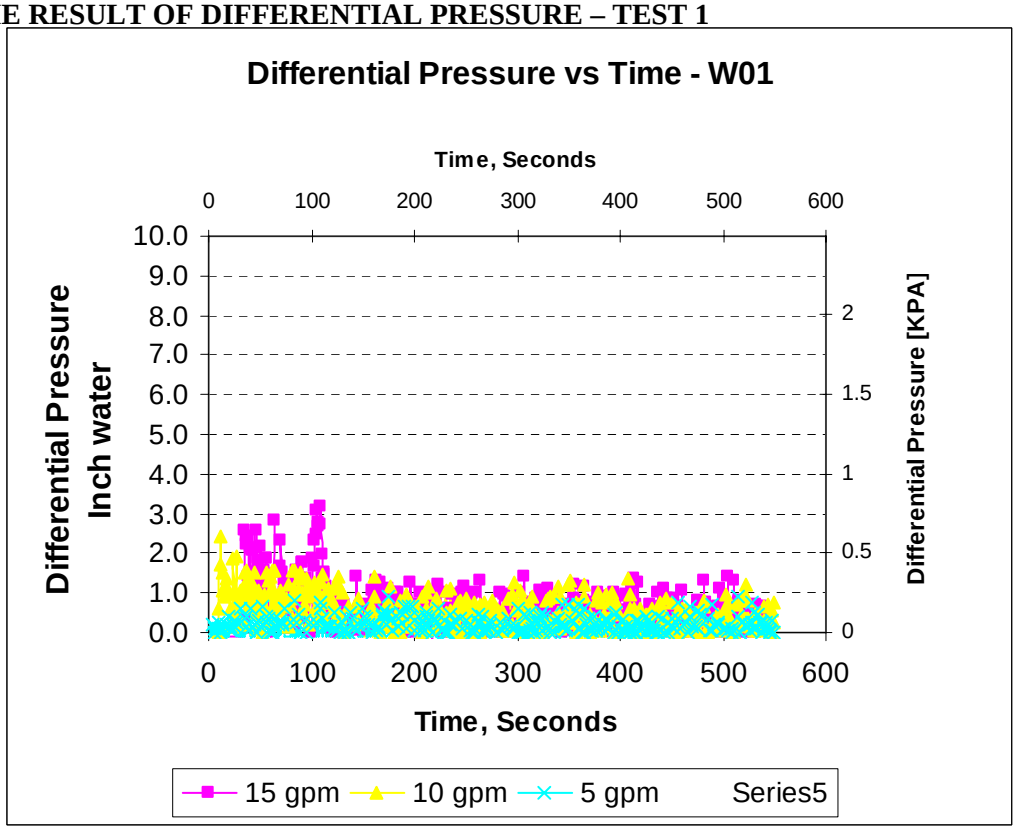
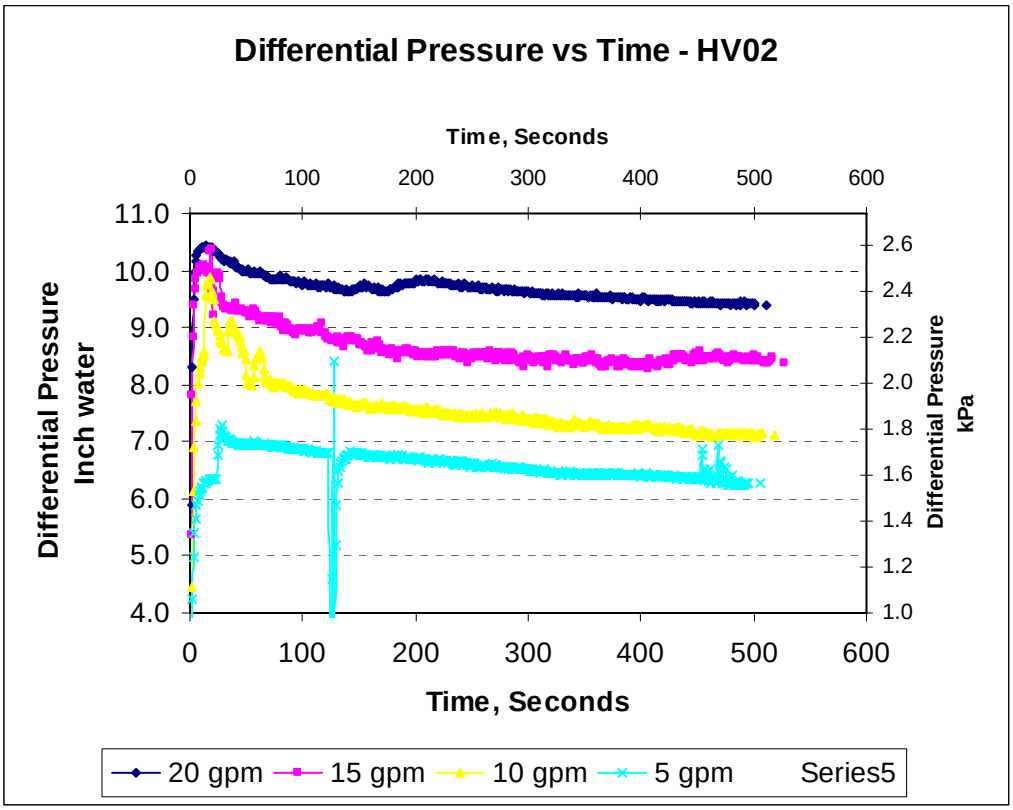


Figure E: Test 1 – Dp Sweep type :Water Code W01 @ Flowrate 5 gpm

Appendix F: THE RESULT OF DIFFERENTIAL PRESSURE – TEST 2



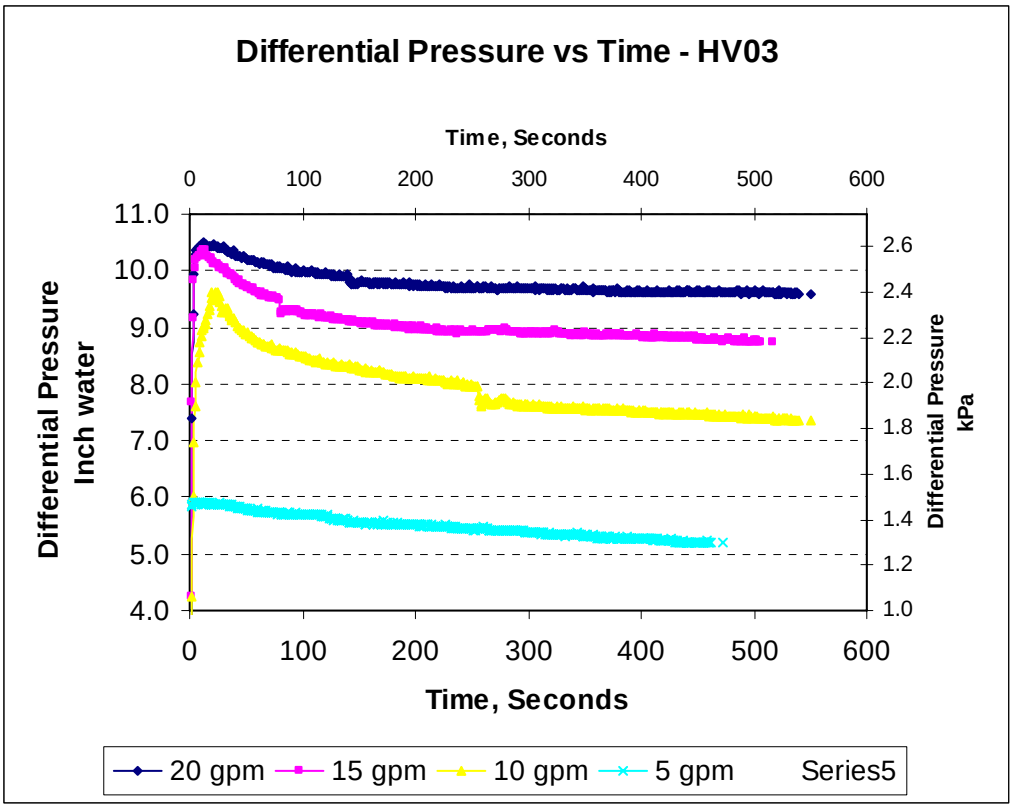
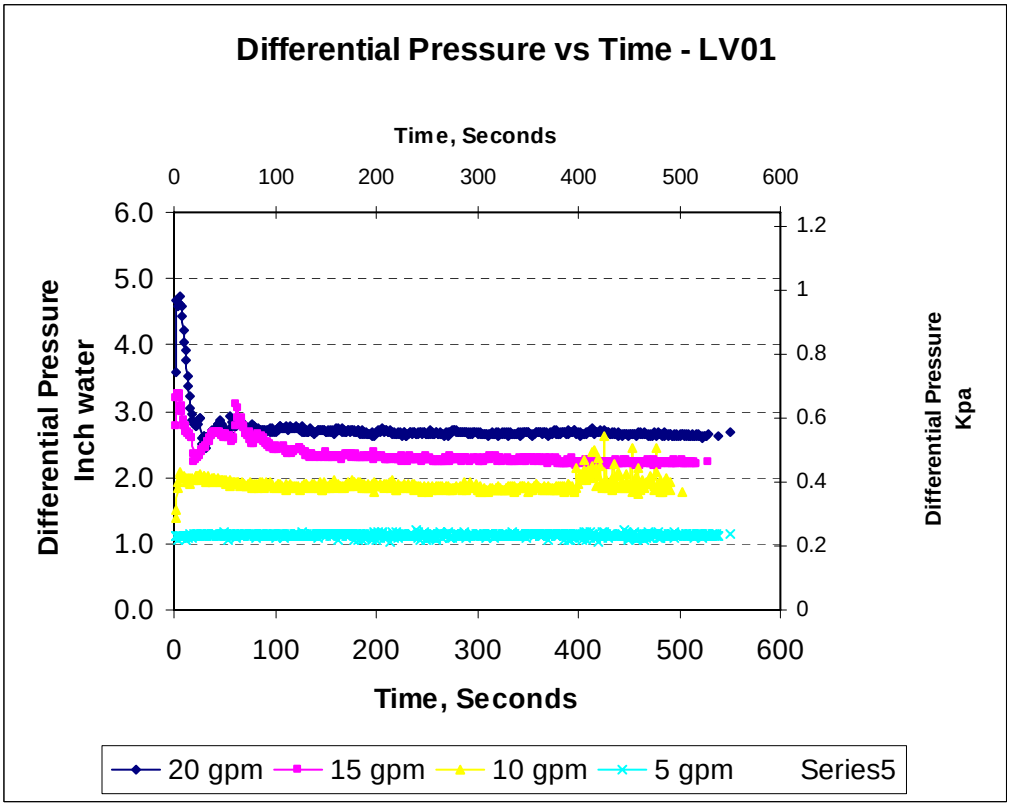


Figure F: Test 2 – Dp Sweep type :High Viscosity Code HV01-02 @ Flowrate 5-10-15-20 gpm

Appendix G: THE RESULT OF DIFFERENTIAL PRESSURE – TEST 3



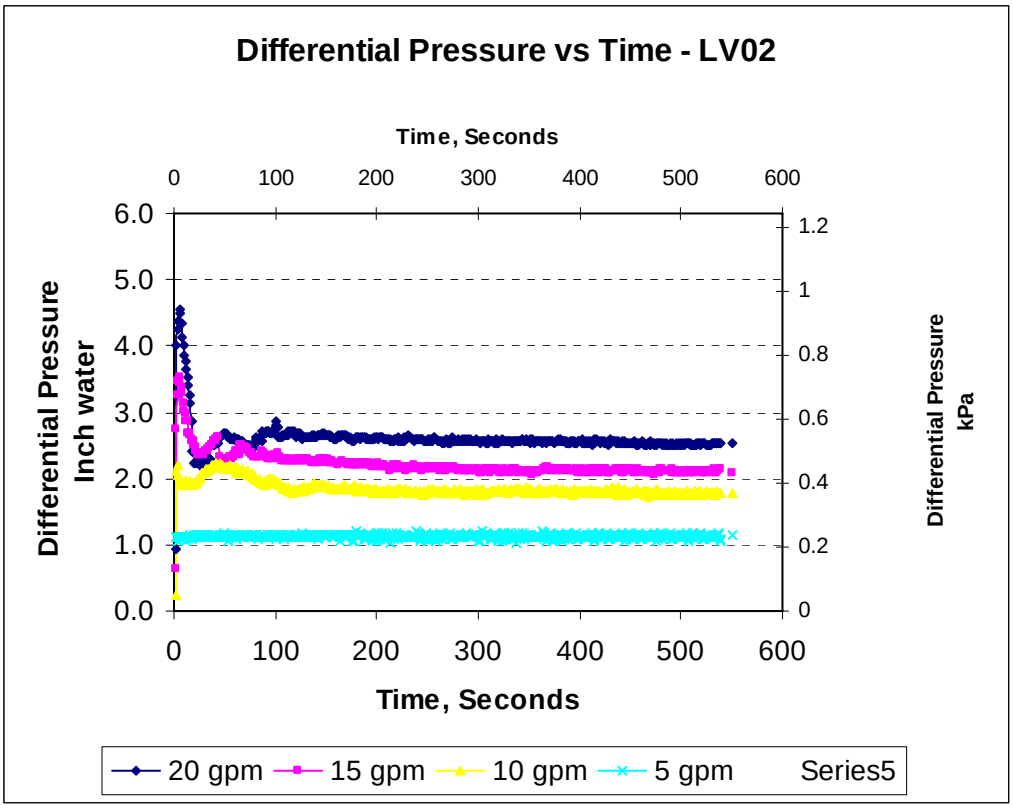
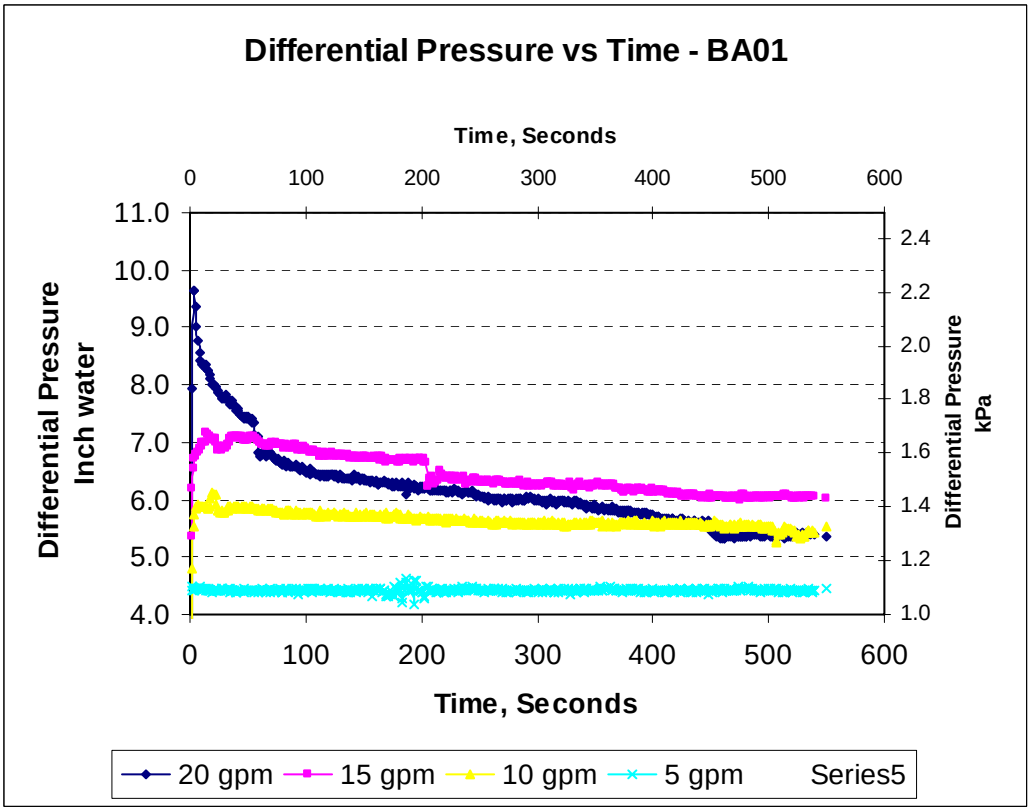


Figure G: Test 3 – Dp Sweep type :Low Viscosity Code LV01-02 @ Flowrate 5-10-15-20 gpm

Appendix H: THE RESULT OF DIFFERENTIAL PRESSURE – TEST 4



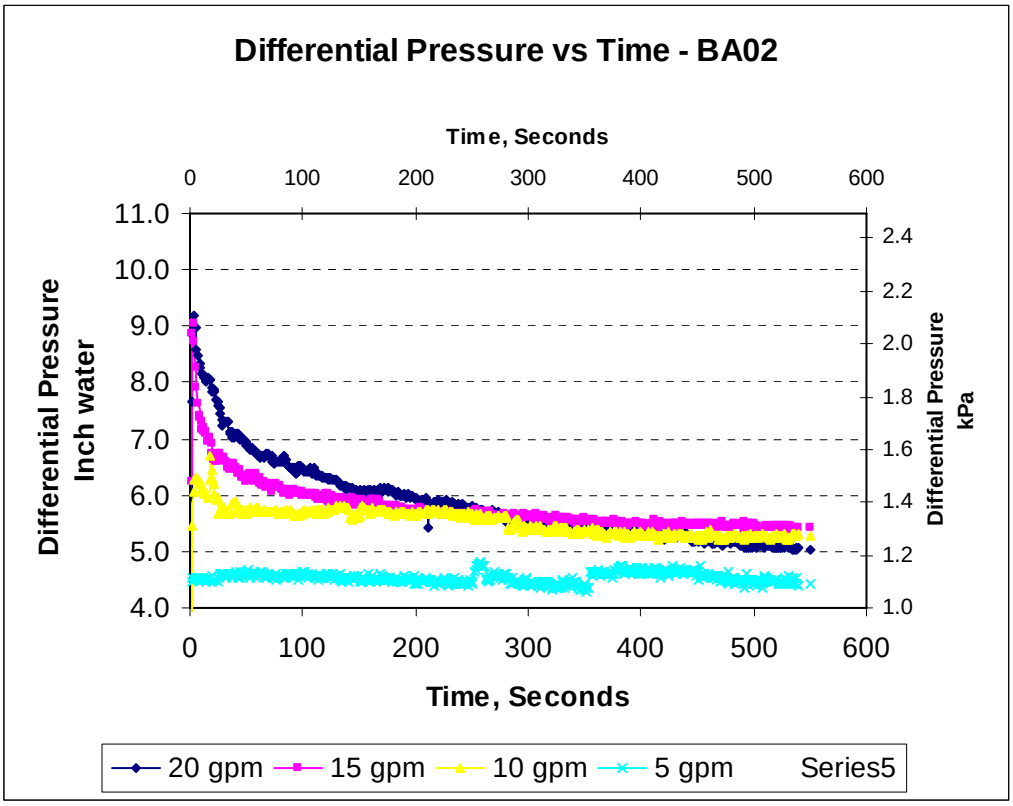


Figure H: Test 4 – Dp Sweep type :High Density Code HD01-02 @ Flowrate 5-10-15-20 gpm

Appendix I : THE RESULT OF RHEOLOGY TEST 2-3-4 COMPARISON

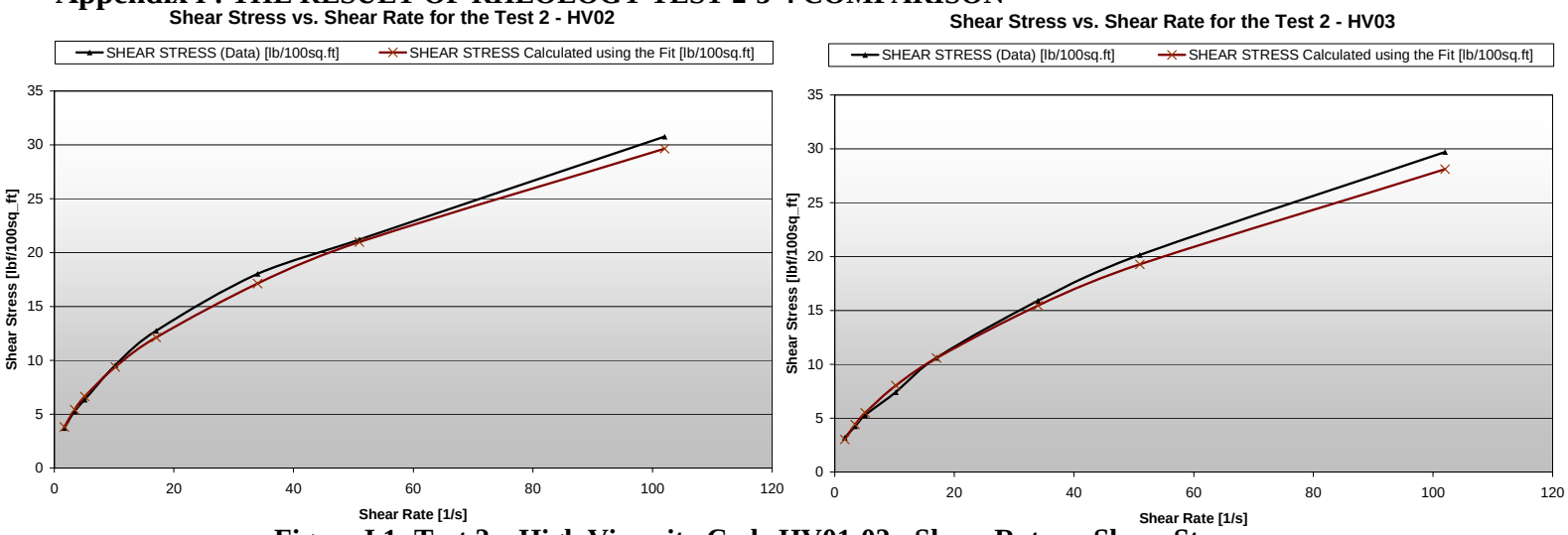


Figure I.1: Test 2 – High Viscosity Code HV01-02 - Shear Rate vs Shear Stress

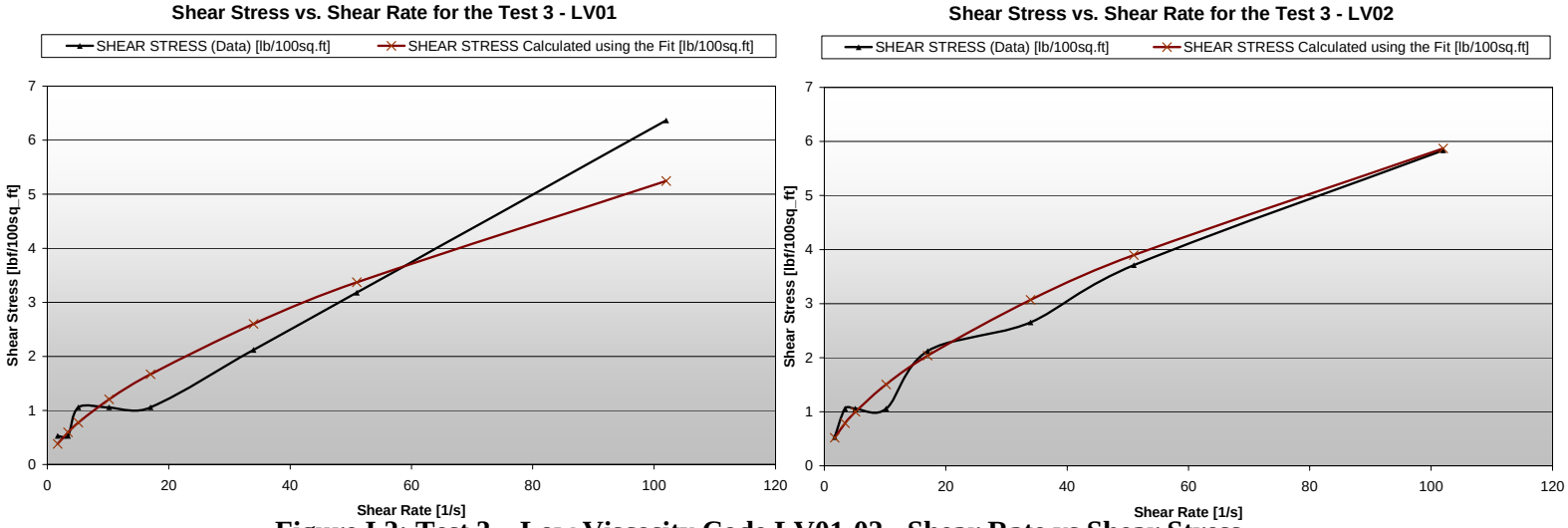


Figure I.2: Test 3 – Low Viscosity Code LV01-02 - Shear Rate vs Shear Stress

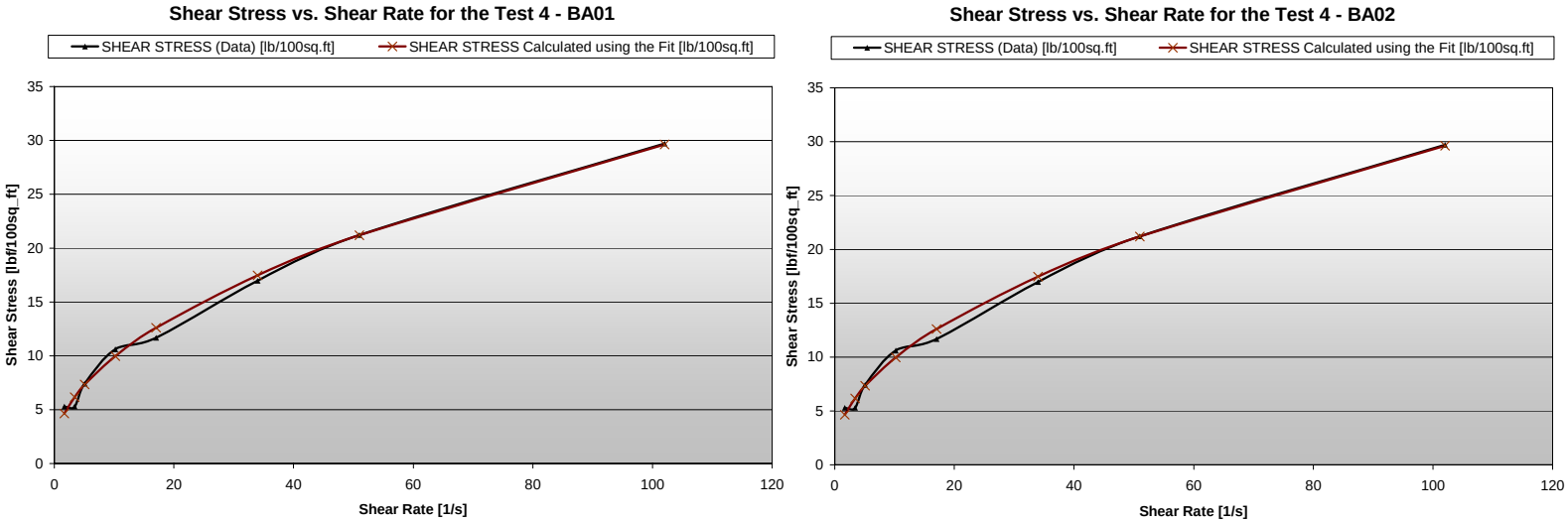


Figure I.3: Test 4 – High DensityCode HD01-02 - Shear Rate vs Shear Stress

Appendix J :

Figure J. Small Sweep Loop

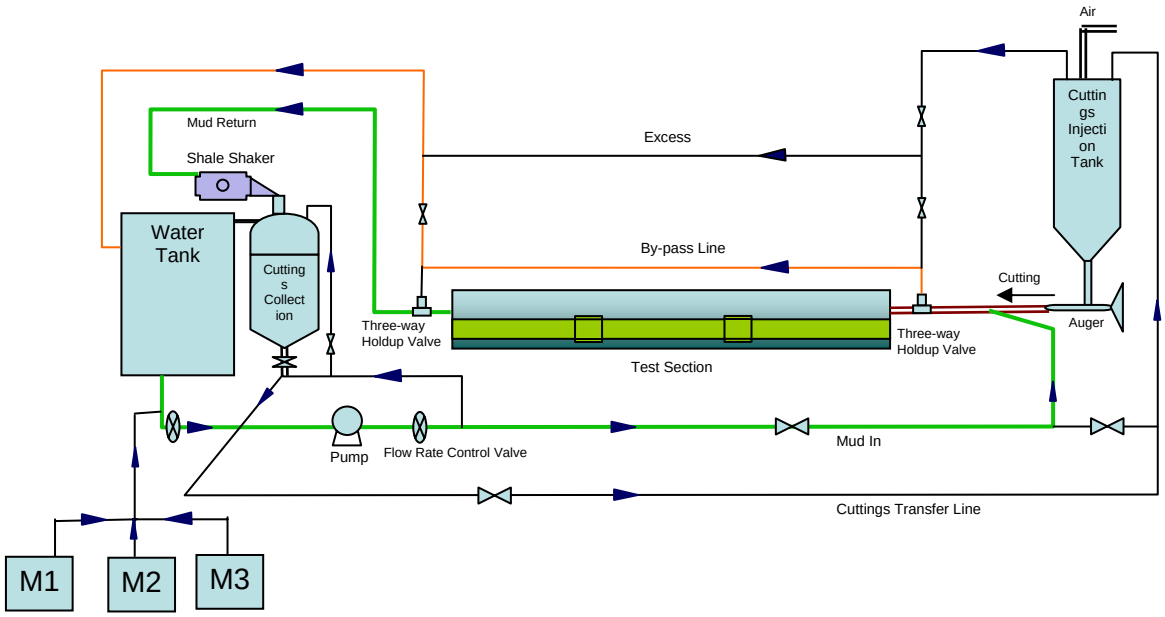


Figure: K- Schematic Drawing of Current LPAT Flow Loop

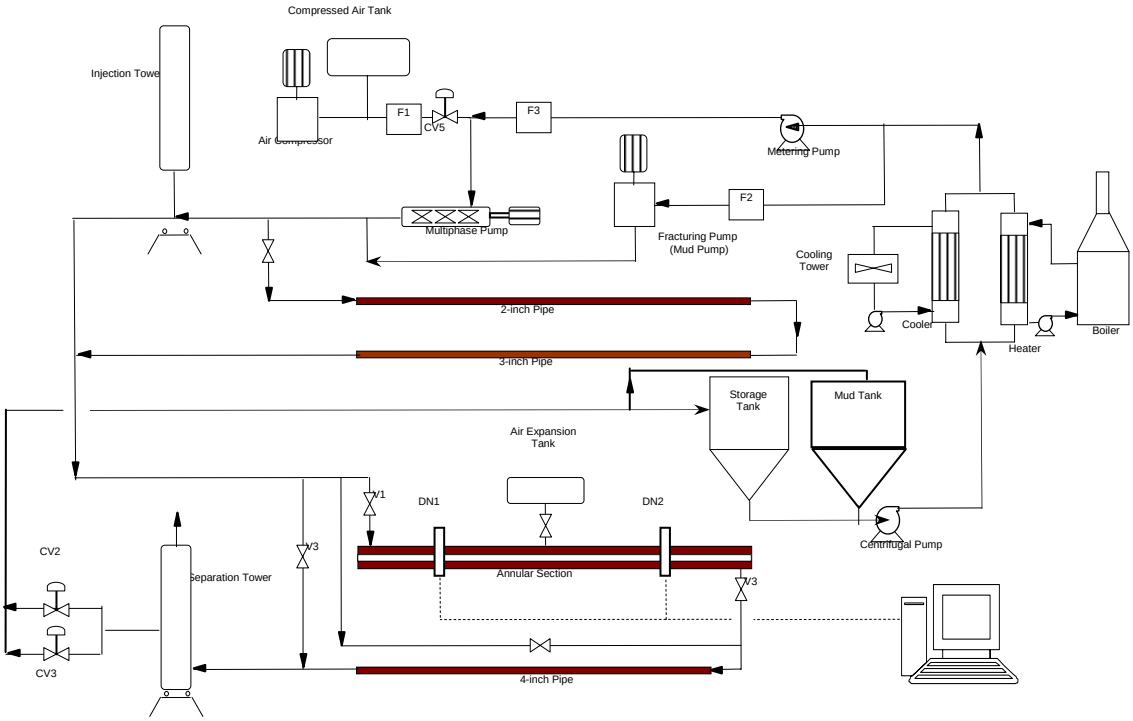


Figure: L- Schematic of the EPET flow loop.

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