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Principal Authors:
Stefan Miska, Principal Investigator
Nicholas Takach, Co-Principal Investigator
Kaveh Ashenayi, Co-Principal Investigator
Ramadan Ahmed, Research Associate
Mengjiao Yu, Research Associate
Mark Pickell
Len Volk
Mike Volk
Lei Zhou
Zhu Chen
Aimee Washington
Crystal Redden
Sameer Nene
Jagruthi Godugu

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The University of Tulsa
600 South College Avenue
Tulsa, Oklahoma 74104

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ABSTRACT

Final design of the mast was completed (Task 5). The mast is consisting of two welded plate girders, set next to each other, and spaced 14-inches apart. Fabrication of the boom will be completed in two parts solely for ease of transportation. The end pivot connection will be made through a single 2-inch diameter x 4'-8" long 316 SS bar. During installation, hard piping make-ups using Chiksan joints will connect the annular section and 4-inch return line to allow full movement of the mast from horizontal to vertical. Additionally, flexible hoses and piping will be installed to isolate both towers from piping loads and allow recycling operations respectively.

Calibration of the prototype Foam Generator Cell has been completed and experiments are now being conducted. We were able to generate up to 95% quality foam. Work is currently underway to attach the Thermo-Haake RS300 viscometer and install a view port with a microscope to measure foam bubble size and bubble size distribution.

Foam rheology tests (Task 13) were carried out to evaluate the rheological properties of the proposed foam formulation. After successful completion of the first foam test, two sets of rheological tests were conducted at different foam flow rates while keeping other parameters constant (100 psig, 70F, 80% quality). The results from these tests are generally in agreement with the previous foam tests done previously during Task 9. However, an unanticipated observation during these tests was that in both cases, the frictional pressure drop in 2" pipe was lower than that in the 3" and 4" pipes. We also conducted the first foam cuttings transport test during this quarter.

Experiments on aerated fluids without cuttings have been completed in ACTF (Task 10). Gas and liquid were injected at different flow rates. Two different sets of experiments were carried out, where the only difference was the temperature. Another set of tests was performed, which covered a wide range of pressure and temperature. Several parameters were measured during these tests including differential pressure and mixture density in the annulus. Flow patterns during the aerated fluids test have been observed through the view port in the annulus and recorded by a video camera. Most of the flow patterns were slug flow. Further increase in gas flow rate changed the wavy flow pattern to slug flow. At this stage, all of the planned cuttings transport tests have been completed. The results clearly show that temperature significantly affects the cuttings transport efficiency of aerated muds, in addition to the liquid flow rate and gas liquid ratio (GLR).

Since the printed circuit board is functioning (Task 11) with acceptable noise level we were able to conduct several tests. We used the newly designed pipe test section to conduct tests. We tested to verify that we can distinguish between different depths of sand in a static bed of sand in the pipe section. The results indicated that we can distinguish between different sand levels. We tested with water, air and a mix of the two mediums.

Major modifications (installation of magnetic flow meter, pipe fittings and pipelines) to the dynamic bubble characterization facility (DTF, Task 12) were completed. An Excel program that allows obtaining the desired foam quality in DTF was developed. The program predicts the foam quality by recording the time it takes to pressurize the loop with nitrogen.

TABLE OF CONTENTS

Disclaimer ii
Abstract iii
Table of Contents iv
List of Tables vi
List of Figures vi
1. Executive Summary 1
2. ACTF Design and Construction Accomplishments 5
2.1. Construction of Elevation System (Task 5) 5
2.2. Plans for the Next Quarter 9
3. Development of a Foam Generator/Viscometer (Task 9b) 10
3.1. Objectives 10
3.2. Foam Generator 10
3.3. Experimental Study of the Viscosity of Drilling Foams (Foam Viscometer) 13
3.3.1. Project Status 13
3.3.2. Preliminary Tests 13
3.3.3. Main Test 14
3.3.3.1. Test Matrix 14
3.3.3.2. Procedure for Making Foam and Using the RS300 15
3.3.3.3. Rheology Test Results for Foam with Smooth Cup and Rotor 16
3.3.3.4. Discussion 17
4. Study of Cuttings Transport with Foam under EPET Conditions (Task 13) 18
4.1. Objectives 18
4.2. Laboratory Tests of the Proposed Foam System 18
4.3. Flow Loop Setup for Foam Experiments 21
4.4. Experiment on Foam Rheology 22
4.5. Preliminary Experiment on Cuttings Transport with Foam 24
4.6. Future Work 25
5. Study of Cuttings Transport with Aerated Muds under EPET Conditions (Task 10) 26
5.1. Objectives 26
5.2. Experiments on Aerated Fluids under Elevated Temperature and Pressure 26
5.3. Experiments on Cuttings Transport with Aerated Fluids 32
5.4. ACTS Flow Loop Maintenance 34
5.5. Future Work 34
5.6. Deliverables 34
6. Development of Cuttings Monitoring Methodology (Task 11) 35
6.1. Objective 35
6.2. Team Composition 35
6.3. Progress to Date 35
6.4. Approach 36
6.5. Future Work 38

7. Development of Methods for Characterizing Bubbles in Foams (Task 12) 39
7.1. Introduction 39
7.2. Objective 39
7.3. Project Status 40
7.3.1. Dynamic Bubble Characterization 40
7.3.1.1. Dynamic Imaging 40
7.3.1.2. Dynamic Testing Facility (DTF) 40
7.3.2. Novel Techniques for Bubble Characterization 43
7.3.3. Installation of Bubble Characterization Instrument on ACTF 44
7.4. Planned Activities 44
7.4.1. Dynamic Bubble Characterization 44
7.4.2. Installation of Bubble Characterization Methodology on ACTF 44
8. Safety Program (Task 1S) 45
8.1. Introduction 45
8.2. Objective 45
8.3. Project Status 45
8.4. Planned Activities 45
9. Technology Transfer 46

LIST OF TABLES

Table 1.1 Summary of ACTS project plan performance 4
Table 2.1 Construction Schedule 9
Table 3.1 Test Matrix for Foam Viscometer/Generator 11
Table 3.2 Foam Viscometer/Generator Calibration and Test Schedule 12
Table 3.3 Test matrix 15
Table 4.1 Rheological Data for the Weatherford Base Liquid 19
Table 5.1 Test Set # 1: T=80 ºF and 200 psig 27
Table 5.2 Test Set #2: T=140 ºF and 200 psig 27
Table 6.1 Data received from the sensor board in the form of ASCII characters 38
Table 6.2 Testing Plan 39

LIST OF FIGURES

Figure 2.1 Hydraulic Power Unit with the Pipe Rotation System 5
Figure 2.2 Design Loop Elevation System 6
Figure 2.3 Design Details of Loop Elevation System 6
Figure 2.4 Pivot Connection of Mast Section 7
Figure 2.5 Heim Joints End Points 7
Figure 2.6 Flexible Connections (Chiksan joints) 8
Figure 2.7 Recirculation Line 8
Figure 3.1 Thermo-Haake RS300 Viscometer 10
Figure 3.2 Foam Generator Assembly 10
Figure 3.3 Torque Reading versus Time (number of turns) 13
Figure 3.4 Torque reading versus time (number of turns) 14
Figure 3.5 Shear stress versus shear rate for 0.5% surf conc. at different foam qualities 16
Figure 3.6 Shear stress versus shear rate for 1% surf. solution at different foam qualities 16
Figure 3.7 Shear stress versus shear rate for 2% surf. solution at different foam qualities 17
Figure 3.8 Measured Torque versus Foam Quality with 0.5% surfactant at 200 rpm 17
Figure 4.1 Influence of Polymer Concentration on Foam Properties (MultiMixer) 19
Figure 4.2 Influence of Polymer Concentration on Foam Properties (Waring Blender) 20
Figure 4.3 Surface Tension versus Weatherford Surfactant Concentration 20
Figure 4.4 Simplified Schematics of the ACTF Flow Loop 21
Figure 4.5 Surfactant Injection Metering Pump 22
Figure 4.6 View Port 22
Figure 4.7 Foam Breaker Pump 22
Figure 4.8 Breaker Injection Nozzles 22
Figure 4.9 Wall Shear Stress vs Newtonian Shear Rate for Polymeric Foam 23
Figure 4.10 Wall Shear Stress vs Newtonian Shear Rate for Polymeric Foam 23
Figure 4.11 Densitometer Reading for Foam Cutting Transport Test 25

Figure 4.12 Cutting Injections and Collection 25
Figure 5.1 Flow Patterns of Air Water Flow at 80 °F 200 Psig 27
Figure 5.2 Flow Patterns Of Air Water Flow at 140 °F 200 Psig 27
Figure 5.3 Differential Pressure Vs Liquid Flow Rate for Test set #1 28
Figure 5.4 Differential Pressure vs. Liquid Flow Rate for Test set #2 28
Figure 5.5 Comparison of DP for Test set #1 and Test set #2 29
Figure 5.6 Measured DP Vs Predicted DP for Test set #1 29
Figure 5.7 Measured DP Vs Predicted DP for Test #2 30
Figure 5.8 Sample Data of Gamma-Ray Densitometer Readings 30
Figure 5.9 Liquid Holdup for Test set #1 31
Figure 5.10 Measured Holdup versus Predicted Holdup 31
Figure 5.11 Cuttings weight versus Temperature 32
Figure 5.12 Cuttings Volumetric Concentration versus Temperature 32
Figure 5.13 Cuttings weight Vs Temperature 33
Figure 5.14 Cuttings Volumetric Concentration versus Temperature 33
Figure 7.1 Simplified schematic of DTF illustrating foam generation and removal 40
Figure 7.2 Determination of empty and partially liquid filled volume of the DTF 41
Figure 7.3 Development of foam in the DTF 41
Figure 7.4 Change in pressure drop through an orifice as foam quality changes 43
Figure 7.5 Picture taken by the analog Camera 44
Figure 7.6 Picture taken by digital Camera 44

1. Executive Summary

Flow Loop Construction (Tasks 5)

The main feature item for this year's additions is elevation of the drilling section. As has been planned since the inception of this 5-year program that will include a mast section which pivots on the existing concrete pillar and is elevated by two large hydraulic cylinders:

As of the last report we had located several "30 ton" mast sections that came off of a Lorain crane. These mast sections had been surplused by a local cartage company. We traced the masts back to their manufacturer and exhausted all means to retrieve their original design data in order to analyze it for our loading conditions. We were, unfortunately, not successful. Therefore, we were forced to abandon this approach and proceeded to complete our own design, which we have done, and contract to have it made, which, at this writing, is in progress.

The mast is consisting of two 41 x 14, welded plate girders (90.1lb/ft), set next to each other, and spaced 14-inches apart. Fabrication of the boom will be completed in two parts solely for ease of transportation. The end pivot connection will be made through a single 2-inch diameter x 4'-8" long 316 SS bar. At horizontal, the mast centerline will be approximately 10-feet above ground. Heim joint end connection points for the hydraulic cylinders are splayed 20 degrees to accommodate the spread-foot design of nearly 11-feet wide at the base but only 2'-4" at the mast.

During installation, hard piping make-ups using Chiksan joints will connect the annular section and 4-inch return line and allow for full movement of the mast from horizontal to vertical.

Additionally, flexible hoses will be installed to isolate both towers from piping loads which have been blamed for inconsistent readings in the tower load cells

Also, piping will be installed which will allow for closed-loop operations. It was decided that the option to be able to recirculate continuously within the test loop would be advantageous.

Development of a Foam Generator/Viscometer for EPET Conditions (Task 9b)

Calibration of the prototype Foam Generator Cell has been completed and experiments are now being conducted. During initial trials, it was determined that the mixing propeller could not supply sufficient thrust to fully involve the foam. Several propellers and propeller combinations were tried to achieve even mixing. A 3-inch propeller modified for additional thrust seems to perform adequately. We were able to generate up to 95% quality foam. Work is currently underway to attach the Thermo-Haake RS300 viscometer to perform the viscosity measurements and a view cell and microscope to measure bubble size and distribution.

Calibration of the RS300 rheometer was completed for Newtonian fluids. The procedure for running the RS300 and the Dynamic Testing Facility was developed. Two new cups and rotor inserts (sleeves) were machined with 0.025 inches and 0.010 inches surface roughnesses. Foam testing with the Dynamic Testing Facility with the “smooth” cup and rotor were completed.

Study of Cuttings Transport with Foam under Elevated Pressure and Elevated Temperature Conditions (Task 13)

In the last DOE quarterly report, we proposed to use the Weatherford chemicals. By the end of November, all of the chemicals needed for flow loop experiment were donated to the project free of any charge. This includes 160 gallons of Weatherford liquid polymer KLEAN-VISH™, 640 gallons of Weatherford surfactant WFT-FOAM™, and 640 gallons of Weatherford foam breaker WFT-DF-250. After receiving the chemicals, indoor laboratory tests were carried out for preliminary evaluation of the surfactant and viscosifier (HEC polymer).

Foam rheology tests were carried out in the ACTF to evaluate the rheological properties of the proposed foam formulation. After successful completion of the first foam test, two sets of rheological tests were conducted at different foam flow rates while keeping other parameters at constant (100 psig, 70F, 80% quality). The results from these tests are generally in agreement with the results of previous foam tests performed as part of Task 9. However, an interesting observation during these tests was that in both cases, the frictional pressure drop in 2” pipe was lower than that in the 3” and 4” pipes. Though we encountered the unexpected low pressure drop phenomenon in the 2” pipe during foam rheology tests, which needs to be better understood, we did conducted one foam cuttings transport test during this quarter.

Study of Cuttings Transport with Aerated Mud Under Elevated Pressure and Temperature Conditions (Task 10)

Experiments on aerated fluids without cuttings have been completed in ACTF. Gas and liquid were injected at different flow rates. Two different sets of experiments were carried out, where the only difference was the temperature. Another set of data was collected which covered wide range of pressures and temperatures. Several parameters were measured during these tests including differential pressure and mixture density in the annulus.

Flow patterns during the aerated fluids test have been observed through the view port in the annulus and recorded by a digital video camera. Most of the flow patterns were in a slug flow. Only at very low gas and liquid flow rates, the stratified flow was observed. As the gas flow rate increases unstable wavy surface on the interface was observed. Further increase in gas flow rate changed the wavy flow pattern to slug flow.

A mechanistic model was developed to predict the aerated mud flowing pressure loses and mixture density (liquid holdup). It is based on existing two-phase pipe flow model and extended to concentric annular geometry.

At this stage, all of the planned cuttings transport tests have been completed. The following data were collected: i) cuttings weight in the annulus (the volumetric cuttings concentration or cuttings bed height); ii) liquid holdup; and iii) pressure losses. The results clearly show that temperature significantly affects the cuttings transport efficiency of aerated muds in addition to the liquid flow rate and gas liquid ratio (GLR). This conclusion is essential for practical field design applications.

Research on Instrumentation to Measure Cuttings Concentration and Distribution in a Flowing Slurry (Task 11)

Since the printed circuit board is functioning with acceptable noise level we were able to conduct several tests. We used the newly designed pipe test section to conduct tests.

We tested to verify that we can distinguish between different depths of sand in a static bed of sand in the pipe section. The results indicated that we can distinguish between different sand levels. We tested with water, air and a mix of the two mediums.

The data acquisition software development is continued. The preliminary results indicate that we are able to distinguish between different sand concentrations. To account for the nonlinear nature of the fluid flow we will use neural network to analyze the data being collected. We identified and purchased a commercial neural network development package.

Development of Foam Bubble Size and Distribution Monitoring System (Task 12)

The Hatachi KP-F120 progressive scan digital camera has been installed on the Nikon microscope associated with the dynamic testing facility (DTF), however we are attempting to resolve a few programming difficulties that occur during image capturing. In-house attempts continue in the application of existing software to recognize and measure bubble sizes and distributions.

Major modifications (installation of magnetic flow meter, pipe fittings and pipelines) to the DTF were completed. An Excel program that allows obtaining the desired foam quality in DTF was developed. The program predicts the foam quality by recording the time it takes to pressurize the loop with nitrogen.

Safety Program for the ACTS Flow Loop (Task 1S)

There has been limited activity on Task 1S during this quarter. A hazard review will be conducted on the ACTF once it attains a stable configuration and schematics can be drawn. In the meantime, progress on the ACTF construction is being monitored with respect to safety.

SUMMARY OF CURRENT TASKS FOR ACTS PROJECT

This is the second quarterly progress report for Year-5 of the ACTS Project. It includes a review of progress made in: 1) flow loop construction and development; 2) research tasks; and 3) instrumentation development during the period of time between October 1, 2003 and December 31, 2003. This report presents a review of progress on the following specific tasks:

a) Design and development of an Advanced Cuttings Transport Facility (Task 5): Design of articulated mast has been completed.

b) Additional research project (Task 9b): “Development of a Foam Generator/Viscometer for Elevated Pressure and Elevated Temperature (EPET) Conditions”.

c) Research project (Task 10): “Study of Cuttings Transport with Aerated Mud Under Elevated Pressure and Temperature Conditions”.

d) Research on Instrumentation Tasks to Measure Cuttings Concentration and Distribution in Flowing Slurry (Task 11).

e) Development of Foam Bubble Size and Distribution Monitoring System (Task 12).

f) Viscosity of Foam under EPET conditions (Task 9b).

g) New Research project (Task 13): “Study of Cuttings Transport with Foam under Elevated Pressure and Temperature Conditions”.

h) Development of a Safety program for the ACTS Flow Loop. Work continues on a comprehensive safety review of all flow-loop components and operational procedures (Task 1S).

i) Activities towards technology transfer and developing contacts with petroleum and service company members, and increasing the number of JIP members.

j) Table 1.1 presents the summary of ACTS project plan performance.

Table 1.1 Summary of ACTS Project Plan Execution

ID	Task Name	Completed
Task 1	Construction of Elevated Temperature Facility	100%
Task 2	Construction of Aeration System	100%
Task 3	Construction of Cuttings Injection/Separation Facility	100%
Task 4	Construction of Drill Pipe Rotating Facility	100%
Task 5	Construction of Loop Inclination Facility	50%
Task 6	Research on Cuttings Transport with Foam at LPAT Conditions	100%
Task 7	Research on Cuttings Transport with Aerated Mud at LPAT conditions	100%
Task 8	Research on Synthetic Drilling Fluids at EPET Conditions	100%
Task 9	Research on Foam flow under EPET Conditions	100%
Task 9b	Development of a Foam Viscometer for EPET Conditions	75%
Task 10	Research on Cuttings Transport with Aerated Mud at EPET conditions	90%
Task 11	Development of Cuttings Monitoring System	70%
Task 12	Development of Foam Bubble Size and Distribution Monitoring System	80%
Task 13	Research on Cuttings Transport with Foam at EPET Conditions	25%
Task S1	Development of a Safety Program	In Progress

2. ACTF DESIGN AND CONSTRUCTION ACCOMPLISHMENTS

2.1 Construction of Elevation System (Task 5)

The feature item for this year's additions is elevation of the drilling section. As has been planned since the inception of this 5-year program that will include a mast section which pivots on the existing concrete pillar and is elevated by two large hydraulic cylinders as shown in Figure 2.1.

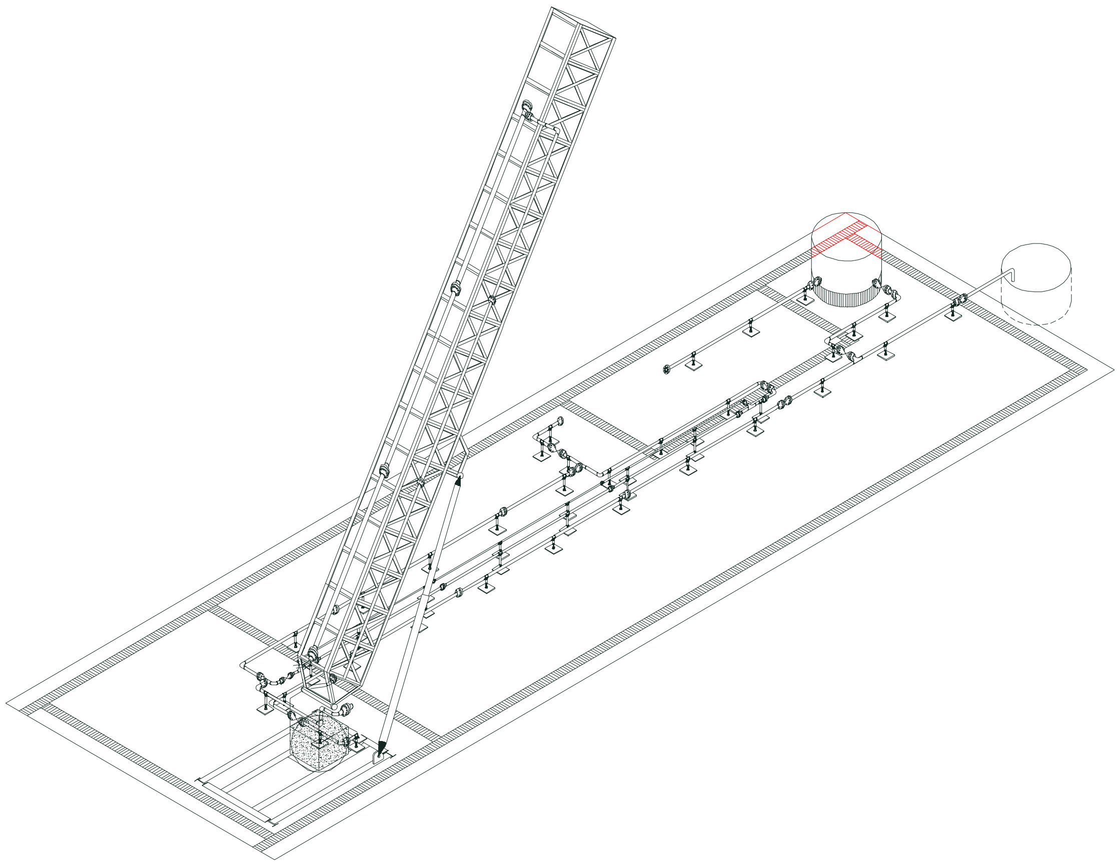


Fig. 2.1 Hydraulic Power Unit with the Pipe Rotation System

As of the last report we had located several "30 ton" mast sections that came off of a Lorain crane. The mast sections have been surplused by a local cartage company. We traced the masts back to their manufacturer and exhausted all means to retrieve their original design data in order to analyze it for our loading conditions. We were, unfortunately, not successful. Therefore, we were forced to abandon this approach and proceeded to complete our own design, which is presented in Fig. 2.2. This design has been completed and given to a contractor for manufacturing.

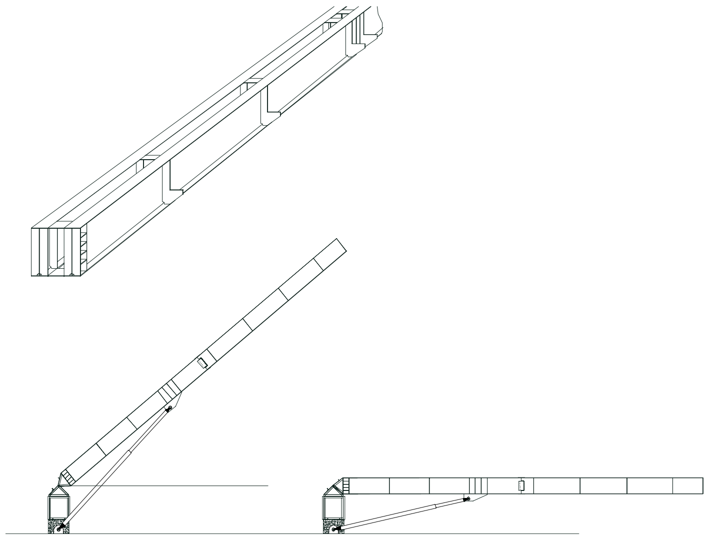


Fig. 2.2 Design Loop Elevation System

Figure 2.3 shows details of the mast design. The mast is consisting of two 41 x 14 welded plate girders (90.1 Ib/ft), which are set next to each other and spaced 14-inches apart. Fabrication of the boom will be completed in two parts solely for ease of transportation.

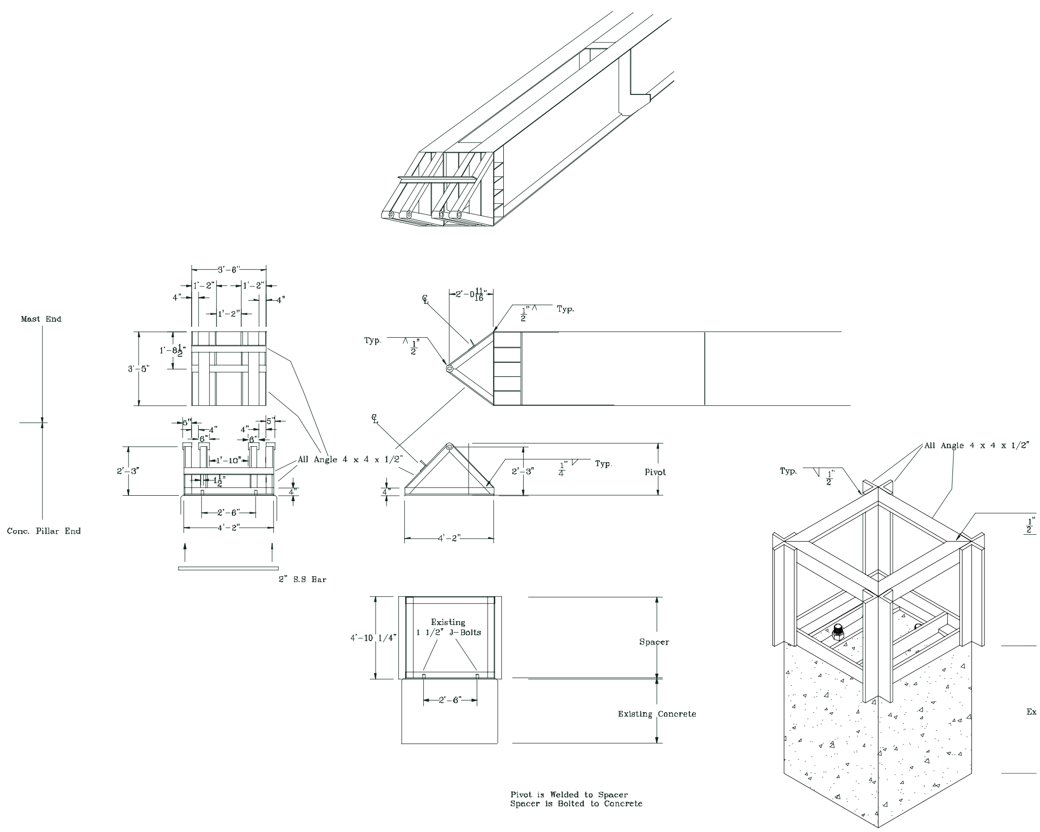


Fig. 2.3 Design Details of Loop Elevation System

The end pivot connection shown in Fig. 2.4 will be made through a single 2-inch diameter by 4'-8" long 316 SS bar. In horizontal position, the mast centerline will be approximately 10-feet above ground. Figure 2.5 shows heim joint end connection points of the hydraulic cylinders. These points are splayed 20 degrees to accommodate the spread-foot design of nearly 11-feet wide at the base but only 2'-4" at the mast.

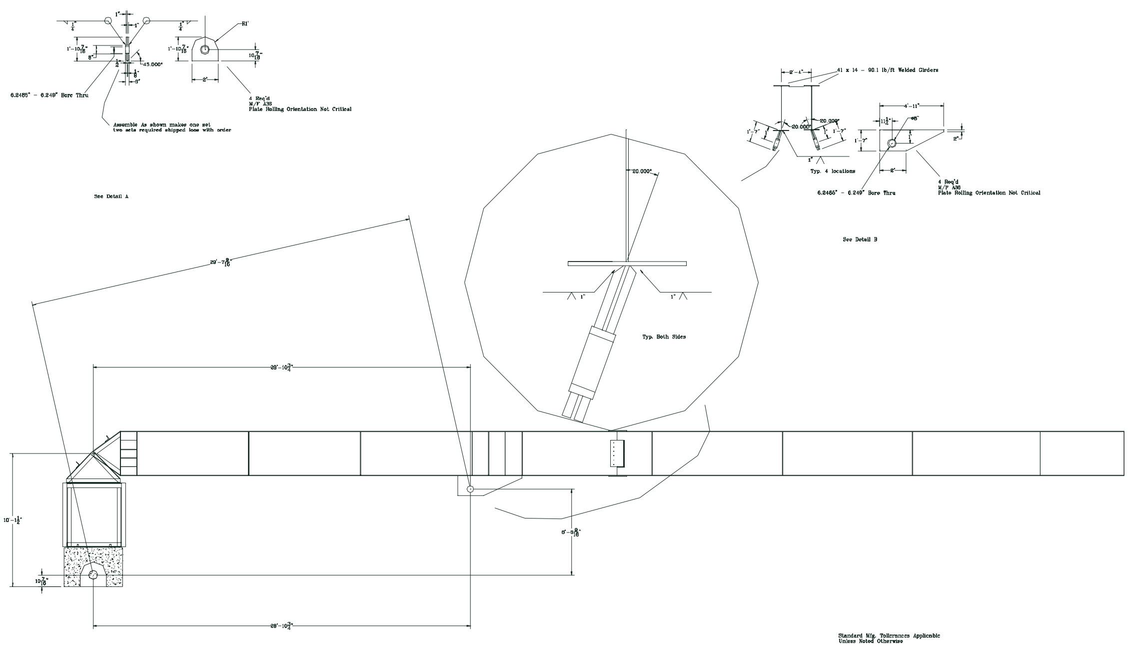


Fig. 2.4 Pivot Connection of Mast Section

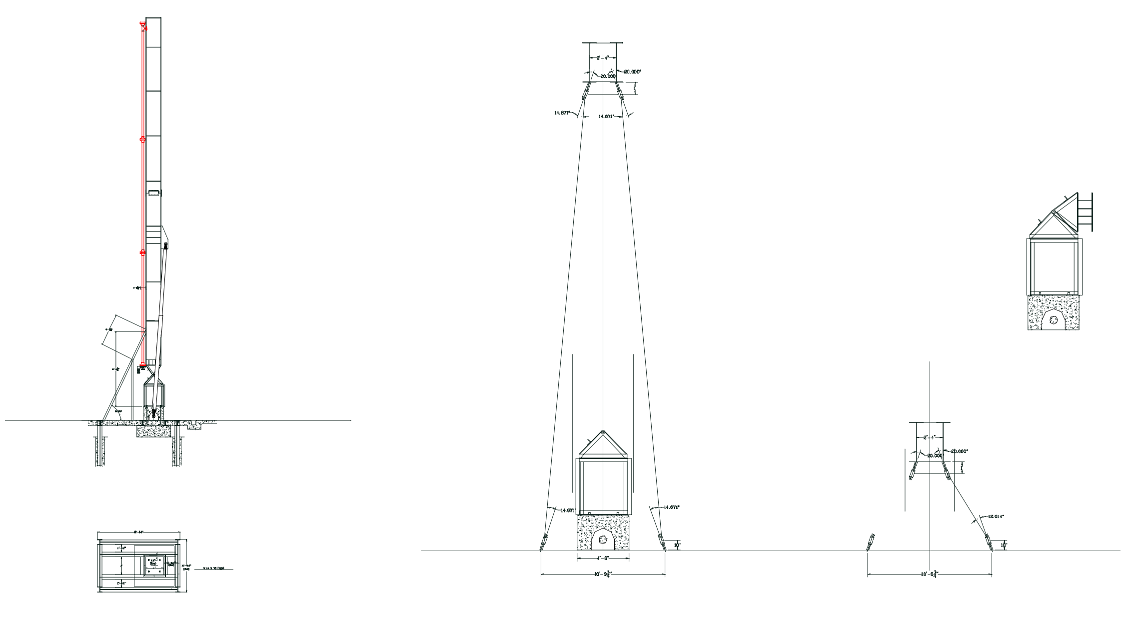


Fig. 2.5 Heim Joints End Points

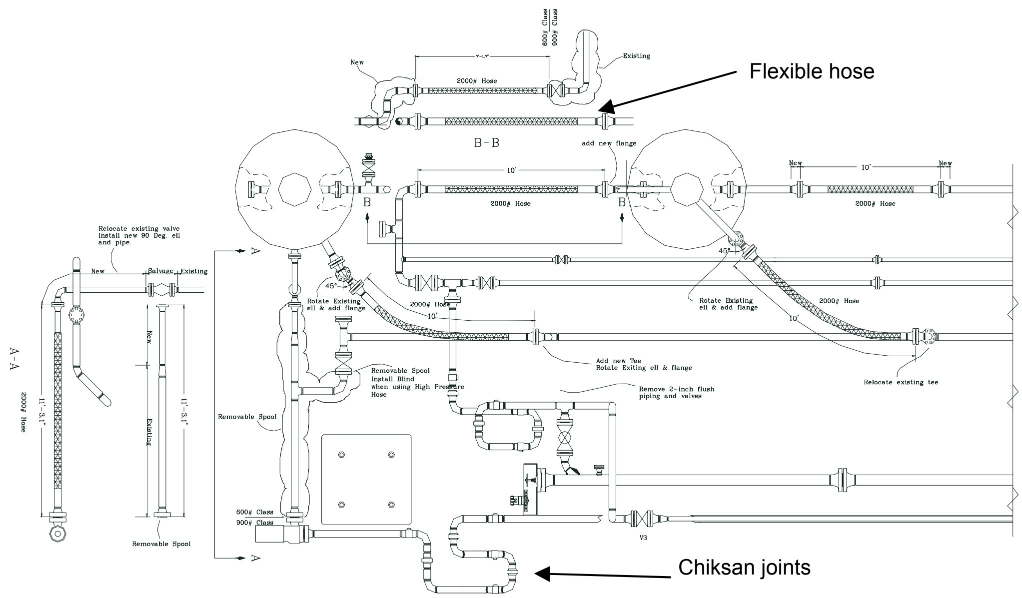


Fig. 2.6 Flexible Connections (Chiksan joints)

Flexible connections shown in Fig. 2.6 are designed to allow the test sections to incline with the mast. During installation, hard piping make-ups using Chiksan joints will connect to the annular section and 4-inch return line. The joints allow for full movement of the mast from horizontal to vertical. Additionally, flexible hoses will be installed to isolate both towers from piping loads which have been blamed for inconsistent readings in the tower load cells.

Also, recirculation piping that is shown in Fig. 2.7 will be installed between the return line and multiphase pump (Moyno pump) suction. This will allow for closed-loop operations. It was decided that the option to be able to recirculate continuously within the test loop would be advantageous.

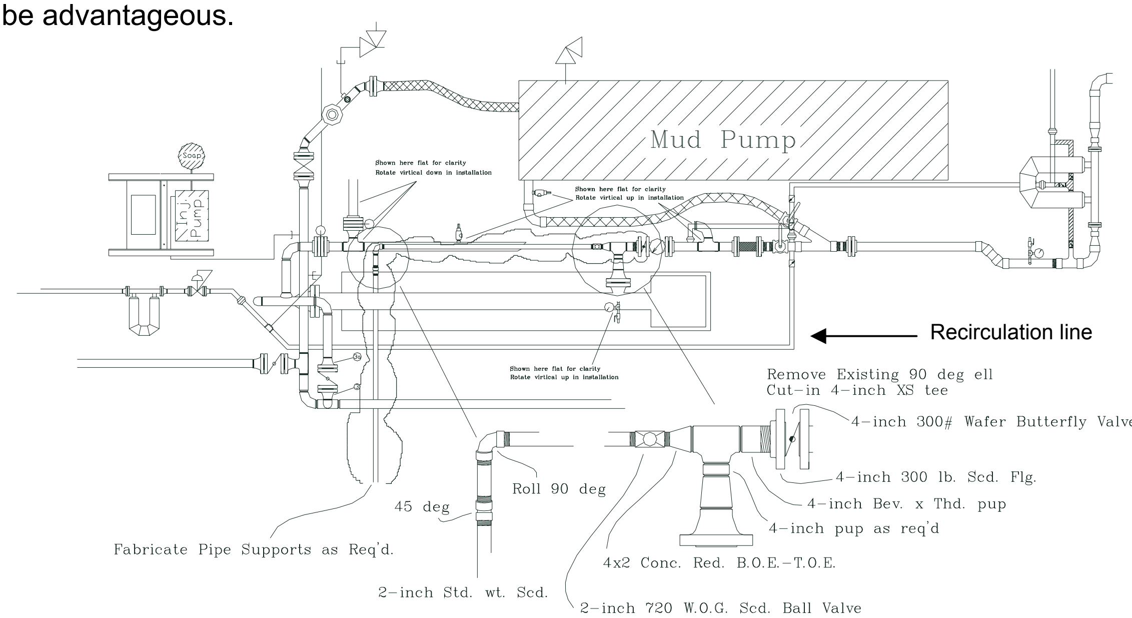


Fig. 2.7 Recirculation Line

2.2 Plans for the Next Quarter

Most of all this past 6 months we have been busy with finishing the experiments for cuttings transport with aerated fluids under elevated temperatures and pressures (Task 10) and planning for year five construction.

Our construction objectives for the next few months are as follows:

- Remove piping that is to be changed
- Fabricate and install the mast pivot support
- Modify the mast for the pivot support and hydraulic cylinders
- Relocate the electrical switch rack
- Install the mast
- Install the hydraulic cylinders
- Install the new piping, flexible hoses, and Chicksan joints
- Modify the cuttings injection auger

The planned schedule for these events is as shown in Table 2.1.

Table 2.1 Construction Schedule

2003/2004 ACTS Flow Loop Schedule

	12/8	12/15	12/22	12/29	1/5	1/12	1/19	1/26	2/2	2/9	2/16	2/23	3/1	3/8	3/15	3/22	3*29	4/5	4/12	4/19	4/26	5/3		
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
																				Ver.		3-Nov-03		
Drill String Elevation																								
Order Hydraulic Cylinders	X	X	X	X	X																			
Order Hydraulic Power Unit	X	X	X	X	X	X	X	X																
Order Pipe, Flanges, & Fittings			X	X	X																			
Purchase Mast	X	X	X	X	X	X	X	X																
Purchase Pivot Steel						X	X	X																
Purchase Bearings & Hardware		X	X	X																				
Order Instrumentation for Angle Measurement			X	X	X	X																		
Fabricate Pivot Mount									X	X	X													
Fabricate Hydraulic Cylinder Mounting Brackets									X	X	X													
Dissasemble Existing Drillstring & Piping								X	X															
Assemble Mast											X	X	X											
Fabricate & Install Mast Tail Rest											X	X	X											
Fabricate Pipe Mounting Brackets								X	X	X														
Fit & Weld New Piping													X	X	X									
Fit & Weld Connections for Flexible Hose													X	X	X									
Install Flexible Hose													X	X	X									
Fit & Re-Weld Liquid Hold-up Piping													X	X	X									
Mount, Wire, & Connect Hydraulic Unit														X	X									
Relocate Existing Electrical Panels									X	X	X													
Connect Power & Instrumentatioin Wiring														X	X	X								
Re-Connect Prior Existing Instrumentation															X	X	X							
Install Drill Pipe & Drill Pipe Rotation																	X	X						
Move Liquid Hold-up Air Accumulator & Re-Connect																		X	X					
Modify Computer Software														X	X	X								
Testing & Calibrations																			X	X	X			

3. DEVELOPMENT OF A FOAM GENERATOR/VISCOMETER FOR ELEVATED PRESSURE AND ELEVATED TEMPERATURE CONDITIONS (Task 9b)

INVESTIGATORS: Mark Pickell, Leonard Volk and Aimee Washington

3.1 Objectives

1. Develop a new instrument that will enable the generation of foams with a controllable bubble size and under elevated pressures and temperatures.

2. Develop a process that will enable measurements of the viscous properties of foams with minimal influences of drainage (syneresis) and bubble coalescence and can quantify the effects of surface roughness on “wall slip”.

3.2 Foam Generator

Calibration of the prototype Foam Generator Cell has been completed and experiments are now being conducted. During initial trials it was determined that the mixing propeller could not supply sufficient thrust to fully involve the foam. Several propellers and propeller combinations were tried to achieve even mixing. A 3-inch propeller modified for additional thrust seems to perform adequately. We were able to generate up to 95% quality foam.

To perform the viscosity measurements, work is currently underway to attach the Thermo-Haake RS300 viscometer (Fig. 3.1) to the foam generator (Fig 3.2). Moreover, a view port with a microscope will be installed on the foam generator assembly in order to measure bubble size and size distribution.

Fig. 3.1 Thermo-Haake RS300 Viscometer

Fig. 3.2 Foam Generator Assembly

The experiments being conducted are intended to demonstrate a potential relationship between applied shear energy, the statistical description of foam, and its rheological performance: 1) that bubble size decreases with added shear energy and becomes asymptotic at some size that is a function of its chemistry, and 2) for a given chemistry, foam viscosity increases with added shear energy and becomes asymptotic at some value that is a function of bubble size.

The efficiency of applying shear energy will hopefully be revealed in the standard distribution of bubble sizes in each foam mixture. If energy were applied evenly throughout the foam mixture, the bubbles would be the same size. The more shear energy applied, the smaller the bubble size. However, shear energy is never applied evenly; there is inefficiency. This wasted energy is spent in heat or in making bubbles smaller than the liquid film can support. The result is a bell shaped curve of quantity of bubbles versus bubble size. The test matrix is given in Table 3.1. Detailed schedule for these tests is presented in Table 3.2

Table 3.1 Test Matrix for Foam Viscometer/Generator

Quality	Mixing Time [Sec]					
	30	45	60	75	85	95
70%	x	x	x	x	x	x
80%	x	x	x	x	x	x
90%	x	x	x	x	x	x

For each data point, viscosity, mean bubble size, and bubble size distribution will be determined.

From this data plots will be made of bubble diameter versus number of bubbles. This plot will be made for each data point. The anticipated bell shaped curve is intended to investigate the change in bubble size and bubble size distribution with increased energy input.

Plots will be made of mean bubble diameter versus shear energy. The anticipated curve is intended to determine the effect of shear energy on bubble size. Theoretically, the average bubble size is expected to decrease with the added shear energy.

Plots will be made of viscosity versus shear energy to show how added shear energy influences foam viscosity for a given foam chemistry. The viscosity is expected to increase as the added shear increases.

Table 3.2 Foam Viscometer/Generator Calibration and Test Schedule

2003/2004 Foam Viscometer Schedule

	11/3	11/10	11/17	11/24	12/1	12/8	12/15	12/22	12/29	1/5	1/12	1/19	1/26	2/2	2/9	2/16	2/23	3/1	3/8	3/15	3/22	3*29	4/5	4/12	4/19	4/26	5/3	5/10	
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Calibration	X	X	X	X	X																								
Evaluate Mixing Procedures				X	X																								
Modification					X	X	X																						
Re-Calibration							X	X	X																				
Hook-up Viscometer										X	X																		
Hook-up Computer										X	X																		
Hook-up Microscope										X	X																		
Hook-up Camera											X	X																	
Conduct Experiments												X	X	X															
Evaluate Test Results													X	X															
Re-testing														X	X														
Meet with Temco to release Evaluation & Recommendations																X													
Construction of Final Foam Generator Cell																X	X	X	X	X	X	X	X						
Order Insulation																X	X	X											
Order Heat Tape																X	X	X											
Order Thermocouple																X	X	X											
Assembly																							X	X	X				
Demonstration for Advisory Board																												X	

3.3 Experimental Study of the Viscosity of Drilling Foams (Foam Viscometer)

In the petroleum industry, foams are used when drilling wells in low pressure oil or gas reservoirs; because in conventional drilling, mud filtrate can cause serious formation damage. As a result, in some drilling applications, foams can be preferable over the conventional drilling. Foam drilling is a relatively new technique and therefore, not much research has been done. The overall purpose of this project is to characterize foam and provide new data that will help drilling engineers achieve better results.

3.3.1 Project Status

Literature Review	Coatings	100%
	Surface Measurement	100%
	Rheometer/Viscometer	100%
	Foams	100%
Coatings	Machining	50%
Calibration	Cannon Standardized Oil – 10, 50 and 100 cP	80%
Foam test on DTF flow loop		80%
Reports	ACTS	100%
	Final	30%

3.3.2 Preliminary Test

Preliminary foam generation test was performed to determine optimum flow rate of foam through the viscometer. Theoretical analysis shows that high flow rate has a tendency to decrease the torque measurement of the viscometer due the helical flow pattern, while at low flow rates the foam may have considerable drainage that affects rheological measurements. In order to determine optimum flow rate, a sensitivity test was carried out while changing the opening of a needle valve that controls the flow through the viscometer. Figures 3.3 and 3.4 present the results of these tests.

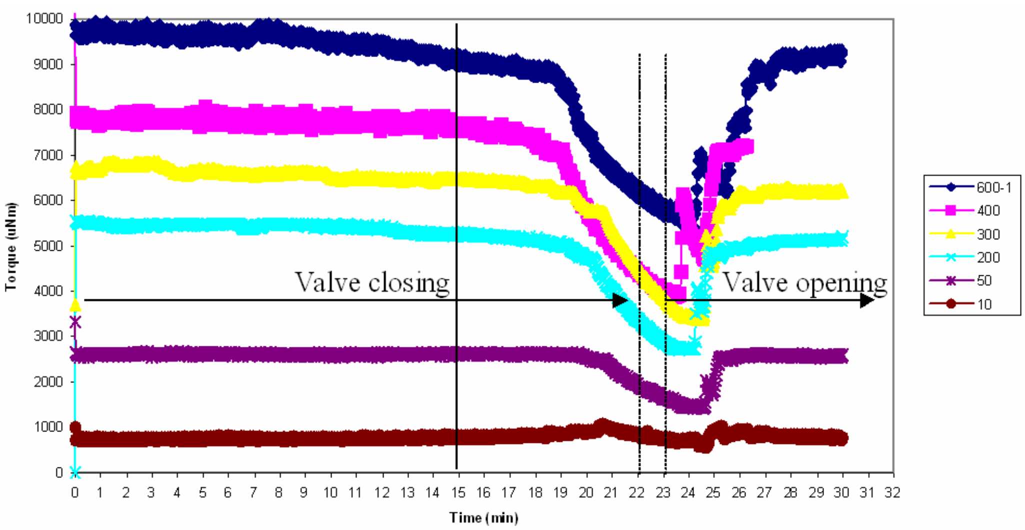


Fig. 3.3 Torque Reading versus Time (number of turn)

During the test, an 80% quality foam was generated in the dynamic testing facility and tested in the RS 300 rheometer. The rpm of the viscometer was set at a certain shear rate for 30 minutes. The test began at 0 minutes with the needle valve that controls the amount of foam flow through the rheometer completely open. It takes 22 turns to completely close this needle valve. While watching a clock, every minute the needle valve was closed one turn until it was closed completely. At this point, the needle valve was left completely closed for another minute to watch the effect it had on the foam. Then the needle valve was opened one turn every minute, until the 30 minute run was complete. This experiment was run for shear rates of 600, 400, 300, 200, 50, and 10 rpm. The experiment was repeated for shear rates of 600, 400, 200, 100, 50, and 10 rpm. As seen in Figs. 3.3 and 3.4, when needle valve reached the completely closed point, the foam could be seen collapsing on the graph, until It made a large drop in the torque readings when it was completely closed. As the needle valve was reopened the foam began to regenerate. From this experiment, it was determined that the needle valve should be set where the foam plateaus, at 15 turns closed, to increase the accuracy of the measurements taken.

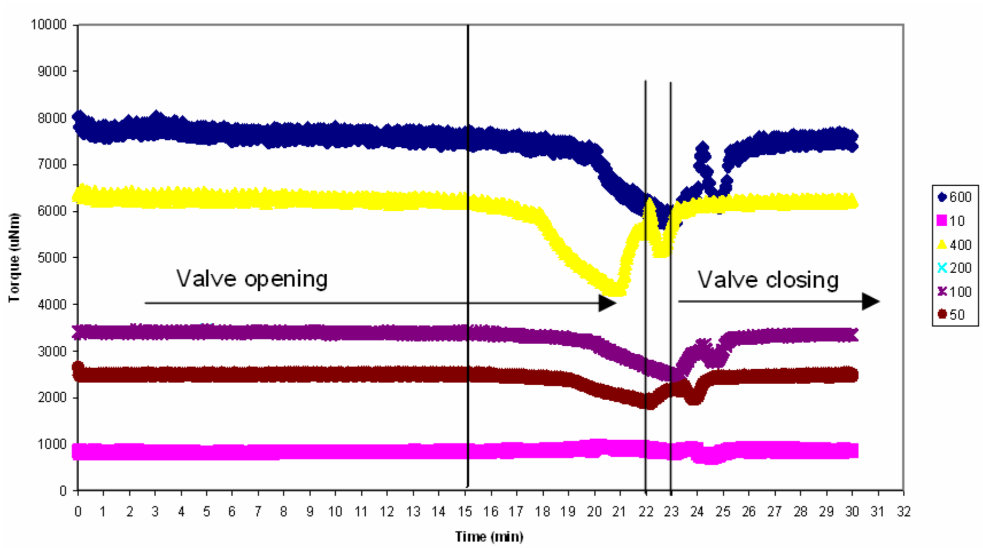


Fig. 3.4 Torque reading versus time (number of turn)

3.3.3 Main Test

3.3.3.1 Test Matrix

A test matrix (Table 3.3) has been devised to provide a flow chart of work that will be performed throughout this study. According to this test matrix, three surfactant concentrations will be used. The basic surfactant will be the Bachman FF-4000 at concentrations of 0.5%, 1.0% and 2.0% by volume. This will provide a variety of foams to test. Secondly, the quality of these foams will vary at 70%, 75%, 80%, and 85%. The bubble size will stay at approximately 50 microns. The wall roughness of the cup and rotor will be varied in order to vary slip and quantify the effects on viscosity readings. It is important to allow enough foam to flow through to eliminate a build up of liquid, but not so fast that a helical flow pattern is formed inside the Rheometer.

Table 3.3 Test matrix

	Test #1	Test #2	Test #3
Foam Formulation	0.5% FF-4000 by volume	1% FF-4000 by volume	2% FF-4000 by volume
Quality	70, 75, 80, 85	70, 75, 80, 85	70, 75, 80, 85
Bubble Size	50 microns	50 microns	50 microns
Wall Roughness	Smooth, 0.025 in & 0.010 in	Smooth, 0.025 in & 0.010 in	Smooth, 0.025 in & 0.010 in

3.3.3.2 Procedure for Making Foam and Using the RS300

The procedure for making foam using the dynamic testing facility was first determined. After the procedure was learned, schematics of the dynamic testing facility were used to write a procedure for this process, including how to hook the RS300 up to the DTF and begin a test. The procedure is as follows:

1. Empty corrosion inhibitor from loop
2. Fill the water tank to the desired level
3. Add surfactant and corrosion inhibitor
4. Turn on air to stir the solution
5. Add surfactant mixture to loop
6. Turn on electricity to pump
7. Begin pump speed at 146 rpm and increase to 500 rpm
8. Inject air to the loop until pressure becomes 40 psi
9. Open the foam generating needle valve (make 2 turns from close position)
10. Close bypass valves to direct the flow through the foam generating needle valve
11. Allow the foam to generate for 5 minutes
12. Throttle foam generating needle valve to 1.5 turns open position
13. Allow to generate for 5 minutes
14. Take foam sample from the loop
15. Drain foam from the loop or inject air if required
16. Allow foam to generate again
17. Wait 10 minutes and test foam quality
18. If too low, take out more liquid and add air
19. Wait 10 minutes and test foam quality
20. When the desired quality is reached turn on computer and temperature control
21. Turn on air and rheometer
22. Set rheometer gap distance to zero, then to appropriate gap distance
23. Make up a program you want to run
24. Attach hoses to rheometer
25. Set differential pressure across the needle value to be between 4 and 6 to regulate the flow through the rheometer
26. Run a constant shear rate program until the value is steady
27. Test foam quality and record pressure drop
28. Allow to generate for 10 more minutes
29. Begin the rheology test
30. Test foam quality and record pressure drop
31. Increase foam quality by taking out more liquid from the loop and injecting air
32. Test foam quality
33. Make sure pressure drop across the needle valve is between 4 & 6 and begin rheometer tests again

3.3.3.3 Rheology Test Result for Dynamic Foam with Smooth Cup and Rotor

The surfactant concentrations of 0.5%, 1%, and 2% were tested with the smooth cup and rotor using the dynamic testing facility. The tests were repeated twice and even three times in order to determine the procedure to obtain optimal results. Rheological measurements are presented in Figs 3.5, 3.6 and 3.7. As seen in Fig. 3.8, for a given rotational speed (shear rate), tests showed an interesting parabola pattern when foam quality was plotted versus torque. This could be evidence of slip, but this cannot be determined until the rough cup and rotor can be tested. If this parabola shape is minimized in the 0.010-inch rough cup and rotor, and eliminated in the 0.025-inch rough cup and rotor, it could be concluded that slip had been the cause of this parabola shape and slip had been eliminated with roughness. Until these tests can be finished, only the present results of the parabola shape can be reported.

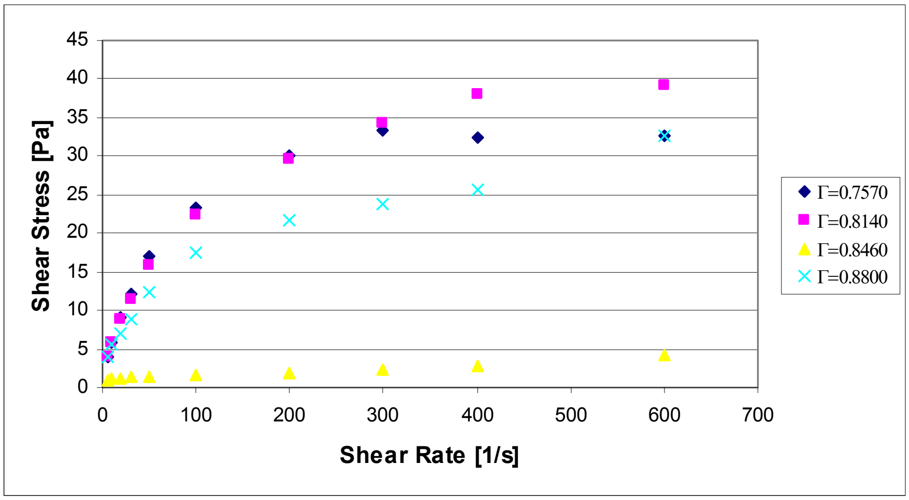


Fig. 3.5 Shear stress versus shear rate for 0.5% surfactant concentration at different foam qualities

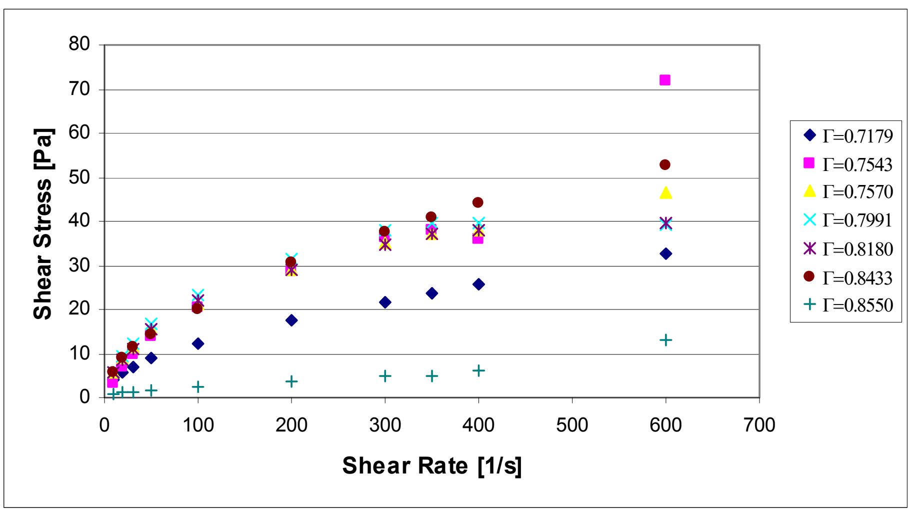


Fig. 3.6 Shear stress versus shear rate for 1% surfactant solution at different foam qualities

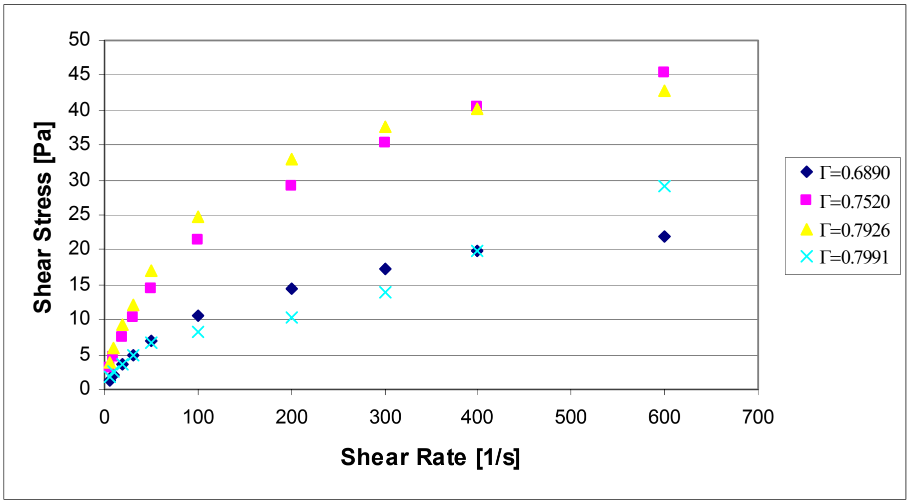


Fig. 3.7 Shear stress versus shear rate for 2% surfactant solution at different foam qualities

3.3.3.4 Discussions

After the RS300 rheometer was set up and calibrated, testing with foams was begun on the DTF flow loop. Foams made with surfactant concentrations 0.5%, 1.0%, and 2.0% were tested on the "smooth set" of rotor & cup (the cup and rotor with roughness only around the magnet and on the bottom of the cup). As seen in Fig. 3.8, the measured torque increases as foam quality increases until a certain point where the torque values begin to decline. This test will also be performed with the roughed cup and rotor. If the torque values decline less and less with increasing roughness, then this may indicate the breakdown of the foam and increased layer of liquid build-up at the surface of the cup and rotor. If the same parabola effect is observed with increased roughness, further consideration will be made in an attempt to describe these observations.

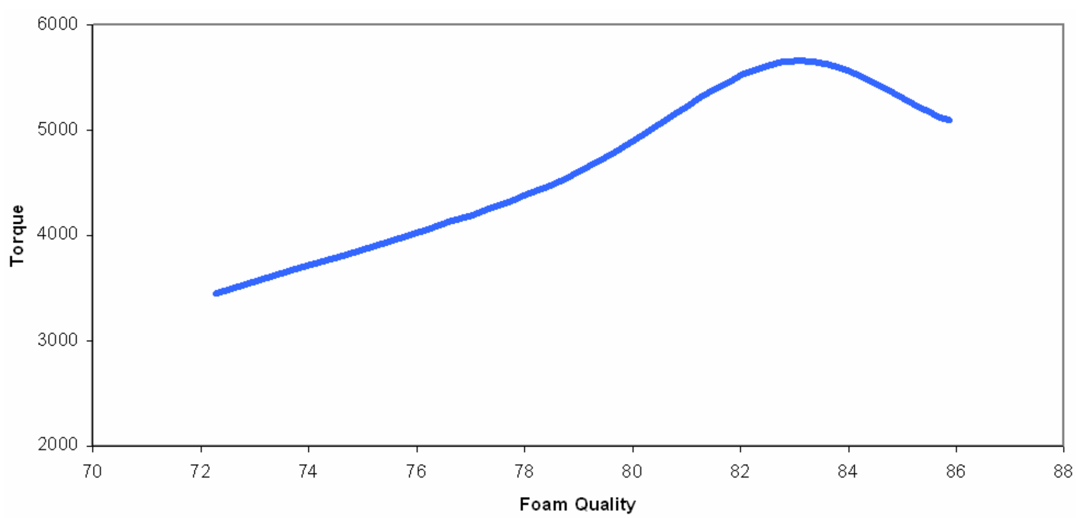


Fig. 3.8 Measured Torque versus Foam Quality with 0.5% surfactant at 200 rpm

4. STUDY OF CUTTINGS TRANSPORT WITH FOAM UNDER EPET CONDITIONS (Task 13)

INVESTIGATOR: Zhu Chen

4.1 Objectives

This research is a continuation of the two recent research projects on foam rheology and cuttings transport. The objectives of this project are:

1. Experimentally investigate foam rheology in pipes and annulus under ETEP conditions
2. Experimentally determine and numerically predict volumetric requirements for effective cuttings transport with foam in horizontal wellbores, with and without pipe rotation
3. Develop a mechanistic cuttings-transport computer simulator
4. Develope computer simulator for cuttings transport with foam and verify the predictions of the simulator with experimental data from the ACTS Flow Loop

4.2 Laboratory Tests of the Proposed Foam System

In the last DOE quarterly report, we proposed to use the Weatherford foam system, by the end of November, all of the chemicals needed for flow loop experiment were received, which include 160 gallons of Weatherford liquid polymer KLEAN-VISH™, 640 gallons of Weatherford surfactant WFT-FOAM™, and 640 gallons of Weatherford foam breaker WFT-DF-250. Even though the sodium hydroxide is commonly used for field application purpose, it is not included in this foam formulation.

After receiving the chemicals, indoor laboratory tests were carried out. Although the foam system is being widely used in UBD, it is new for ACTS and TUDRP group. Therefore, laboratory tests were performed before flow loop test to characterize and evaluate the surfactant. The main objectives for the lab test were:

1) To evaluate the properties of liquid phase, which is of great importance because polymers were used in this system. The effect of polymer concentration on foam properties will be evaluated
2) To evaluate the surface tension of the surfactant with respect to surfactant concentration
3) To evaluate the feasibility of the original proposal, i.e., pre-mixing the surfactant and liquid polymer and inject them after the multiphase pump (Moyno pump)

The viscosity of the Weatherford base liquid and foam stability of this foam system were evaluated. Table 1 shows a sample of rotational viscometer readings of the Weatherford base liquid

Table 4.1 Rheological Data for the Weatherford Base Liquid

Formulation	Reading						Rheological model (PL)
	θ (3)	θ (6)	θ (100)	θ (200)	θ (300)	θ (600)	
Weatherford Formulation*	0.2	0.3	2.0	3.5	5.0	9.0	$\tau = 0.0128\ \gamma^{0.85}$

* Base liquid: Water + 0.3% liquid polymer (Klean-VISH) (pH 9.2)

Figures 4.1 and 4.2 show the half-life time and foam volume as a function of polymer concentration. Two test samples, each with 100-ml polymeric surfactant solution (water + 0.5% surfactant + liquid polymer) were prepared. Foam was generated by 1 minute stirring this solution by using the "MultiMixer®" and "Warring® blender". After 1 minute stirring, the volume of foam and half-life time was measured with different liquid polymer concentration. It can be seen that, with the increase of liquid polymer concentration, the half-life time increases while the volume of foam decreases. The decrease of foam volume is probably because, for a given energy of mixing, there is a maximum polymer concentration that can be used, above which the volume of foam created becomes smaller because of high viscosity. Also we found that there was a pronounced property difference between the foam generated with MultiMixer® and Warring® blender, this indicates again that shear and energy are important factors in foam generation.

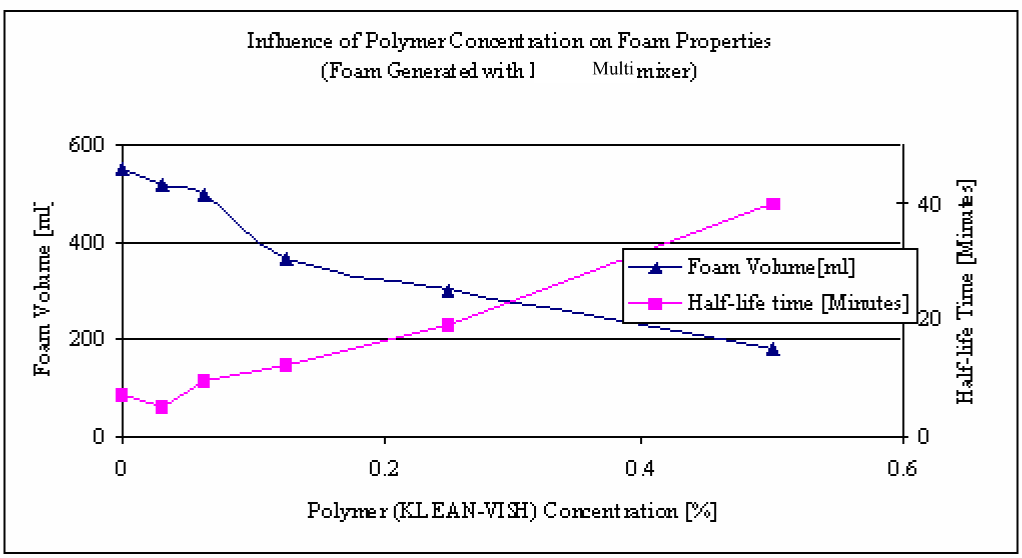


Fig. 4.1 Influence of Polymer Concentration on Foam Properties (Foam Generated with MultiMixer)

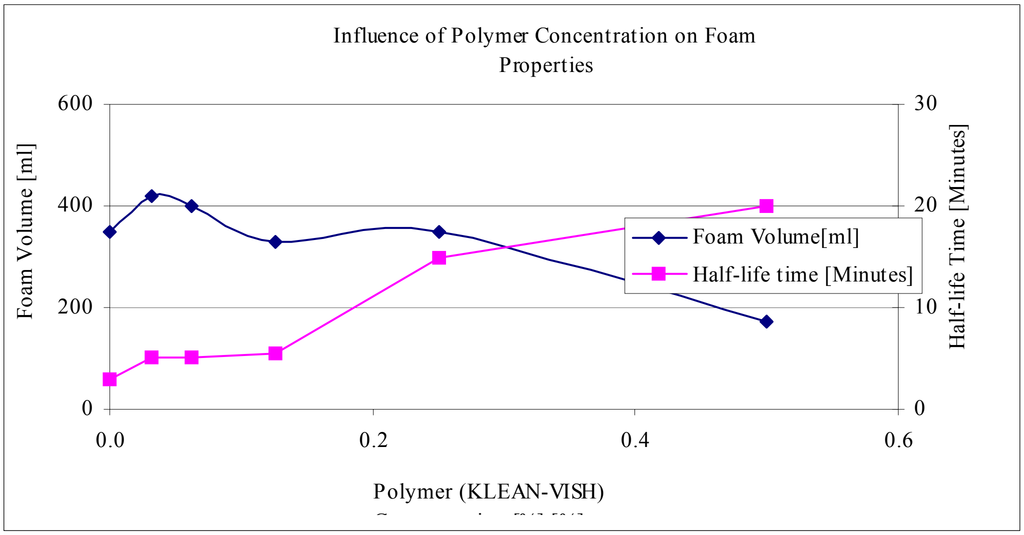


Fig 4.2 Influence of Polymer Concentration on Foam Properties (Foam Generated with Blender)

Figure 4.3 shows the surface tension of the Weatherford surfactant at room temperature. The surface tension was measured with the capillary method, pure water surface tension at standard condition is 0.072 N/m, and we found that the surface tension decreases significantly until the surfactant concentration is about 0.5%. There is little change of surface tension beyond this concentration. This experiment, together with foam properties versus polymer concentration test, reveals that for this foam system, a minimum of 0.5% surfactant concentration will be needed for the flow loop experiments.

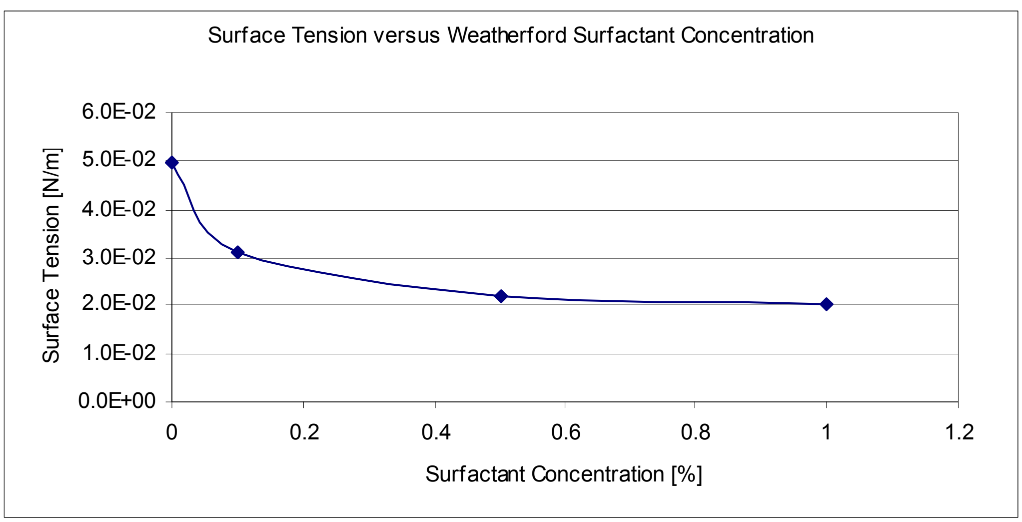


Fig 4.3 Surface Tension versus Weatherford Surfactant Concentration

Another objective for laboratory test is to check whether it is feasible to pre-mix surfactant and liquid polymer, and then inject them downstream of the multiphase pump (Moyno pump). It was found that when surfactant solution is mixed with full-concentration of liquid polymers (i.e. 50% polymer concentration) a very thick gel was formed. It was impossible to inject this mixture with the surfactant injection pump. Therefore, it was decided to add liquid polymer into the 100-bbl water tank.

4.3 Flow Loop Setup for Foam Experiment

Previously we reported the preparation work for flow loop experiment such as test input data calculation, test procedure planning, etc. The test preparation during this quarter was mainly on flow loop hardware installation and modification. Before this foam experiment, the ACTF was busy with cuttings transport test with aerated mud. To conduct the foam experiment, some new components had to be re-installed; Figure 4.4 shows the schematic representation of the ACTF for foam experiment. New components are shown in Fig 4.5, 4.6, 4.7, 4.8.

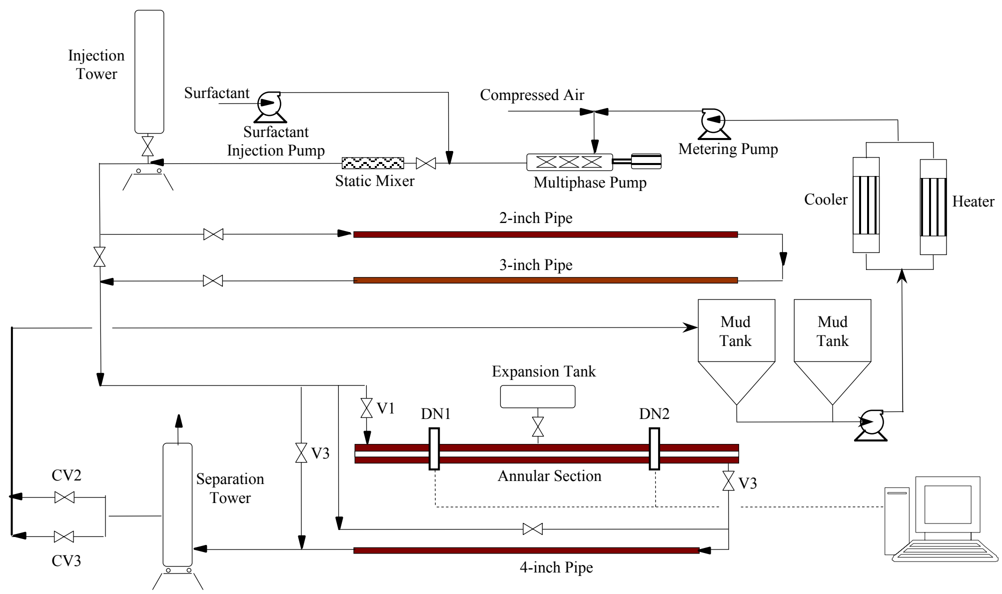


Fig 4.4 Simplified Schematics of the ACTF Flow Loop

For foam tests, liquid polymer was mixed in one of the 100-BBL water tanks. Water was pumped with a centrifugal pump and then with a metering pump. Liquid and air were mixed at the suction side of multiphase pump (Moyno pump) and compressed by the pump to the desired pressure. At the discharge of the multiphase pump, surfactant was injected with a surfactant metering pump (Fig 4.5). The ball valve and/or Fisher valve and static mixer are used as foam generators. Foam passes by the injection tower, and flows through the 2", 3" pipes, 5.76"x3.5" annulus. In each of these sections, a view port (Fig. 6) is installed to offer realtime visual observation of flow behavior. Foam then flows through the 4" pipes. Between the outlet of 4" pipe and injection tower, foam breaker is injected with a defoamer injection pump (Fig 7) through three defoamer injection quills (Fig 8). Foam is broken in the separation tower and along the return line back to another waste liquid tank. The loop is not a closed system because the foam flows through the flow loop only once and is then discarded.

To conduct cuttings transport test with foam, cuttings will be injected from the injection tower, then foam-cutting mixture will bypass the 2” and 3” pipes, and flow directly to the 5.76”x3.5” annular test section. When the steady state condition is achieved, the quick closing valves V1 and V3 will be closed to trap the foam-cutting mixture. With densitometer reading and foam expansion data, it is possible to calculate the in-situ cuttings concentration. Also, if more accurate data is desired, the cuttings in the test section can be flushed out and weighed with a scale.

Fig 4.5 Surfactant Injection Metering Pump

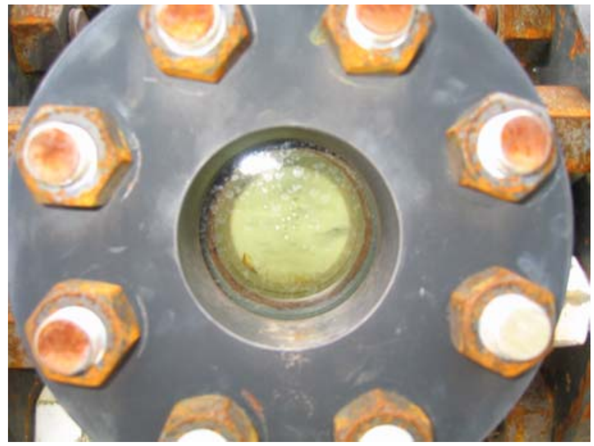


Fig 4.6 View Port

Fig 4.7 Foam Breaker Pump

Fig 4.8 Breaker Injection Nozzles

4.4 Experiment on Foam Rheology

Foam rheology tests were carried out to evaluate the rheological properties of the proposed foam formulation. Since foam rheology study is not the main objective of this research project, we will try to minimize the amount of experiments needed for foam characterization.

Theoretically, we can obtain the volume equalized K and n with one set of experiments (i.e. 3 different foam flow rates). After successful completion of the first foam test, two sets of rheological tests were conducted at different foam flow rates while keeping other parameters constant (100 psig, 70 °F, 80% quality). Figures 4.9 and 4.10 present wall shear stresses as a function of Newtonian shear rates for polymeric foams; polymer concentrations during the test were 0.025% and 0.075% respectively. These flow curves are generally in agreement with the previous foam tests done during task 9. However, an interesting observation during these tests was that in both cases, the frictional pressure drop in 2” pipe was lower than that in the 3” and 4” pipes. With the present foam tests results shown in Fig 4.9 and Fig 4.10, foam rheological parameters K and n can not be obtained due to the deviation of the 2” pipe differential pressure data.

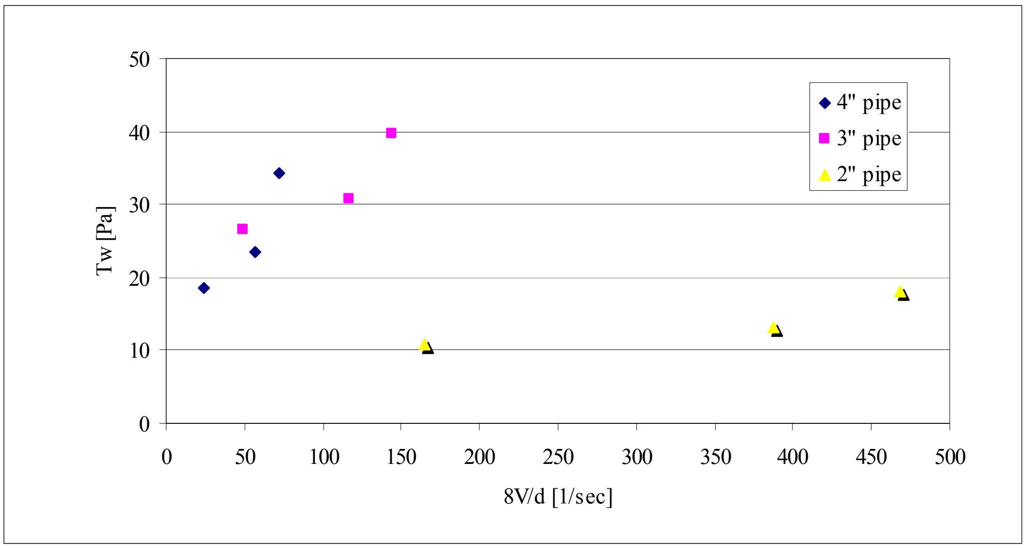


Fig 4.9 Wall Shear Stress vs Newtonian Shear Rate for Polymeric Foam (0.025% polymer, 0.83 % surfactant, 70 °F, 100 psig, 80% quality)

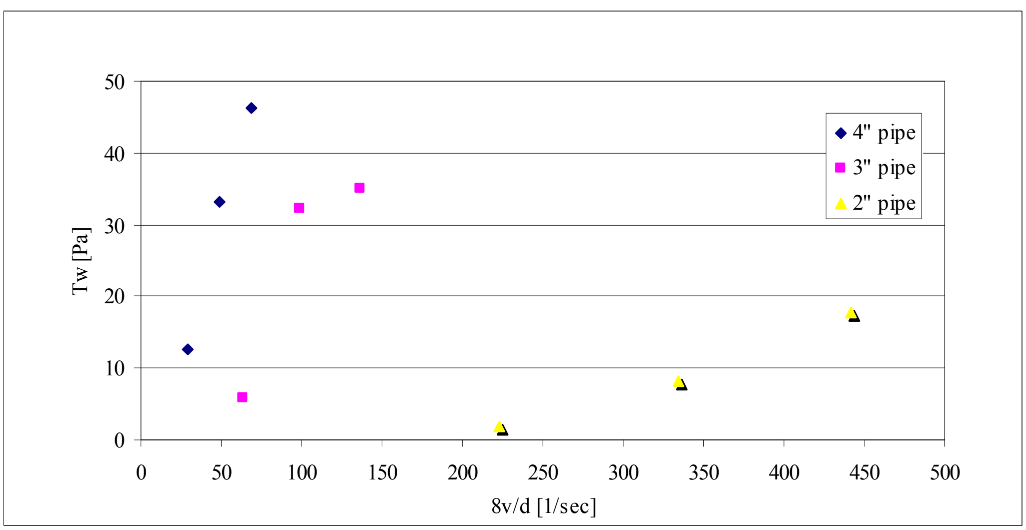


Fig 4.10 Wall Shear Stress vs Newtonian Shear Rate for Polymeric Foam (0.075% polymer, 0.83 % surfactant, 70 °F, 100 psig, 80% quality)

In order to find out what contributed to this unexpected phenomenon, another 10 extended preliminary tests were performed, which included:

1. Comparison of three foams with different surfactant concentrations
2. Foam test with and without polymers
3. Comparison of foams generation using ball valve and Fisher valve
4. Differential pressure transmitter evaluation tests with water

The extended preliminary tests showed that differential pressure measurements were acceptably accurate. However, all the foam test results showed the same trend. (i.e. the lowest pressure drop across the 2" pipe). Our next plan will be to test if this unexpected low pressure drop phenomenon is attributed to the type of surfactant used, since the surfactant we are using now is different from that used during Task 9. A drum of Bachman surfactant F450 was obtained, which was used previously during task 9.

4.5 Preliminary Experiment on Cuttings Transport with Foam

This experiment was performed to answer the following key questions:

1. Can we inject cuttings in a controlled way?
2. What is the response of densitometers during foam flow and foam-cuttings flow?
3. Will foam have the desired carrying capacity to transport the injected cuttings without blocking the pipes?

The results of the cuttings transport experiments are shown in Figs. 4.11 and 4.12. Figure 4.11 shows the densitometer reading response during the test; 4-stages of flow can be distinctly observed from this figure:

- Stage one is the water flow, with densitometer reading approximately 1.0
- Stage two is air-water flow, the densitometer reading approximately 0.2-0.5
- Stage three is foam flow. During this period, the densitometer reading is nearly zero, which was also observed for all the other foam rheology tests
- Stage four is when cuttings were introduced; the densitometer reading was positive

The reason why the densitometer readings are nearly zero during foam flow is still not clear at this point, and more detailed study of densitometer reading with respect to cuttings concentration will be done in the future.

Figure 4.12 shows the injection and collection of cuttings rate for the same experiment. Cuttings injection began at about 15000x0.5 seconds. It can be seen that a nearly-constant injection rate (the slope of the curve) is obtained, which means cuttings can be injected in a controlled way. During this experiment, we were able to transport cuttings with foam without any blockage. In addition, cuttings were observed through the view port installed in the annulus section.

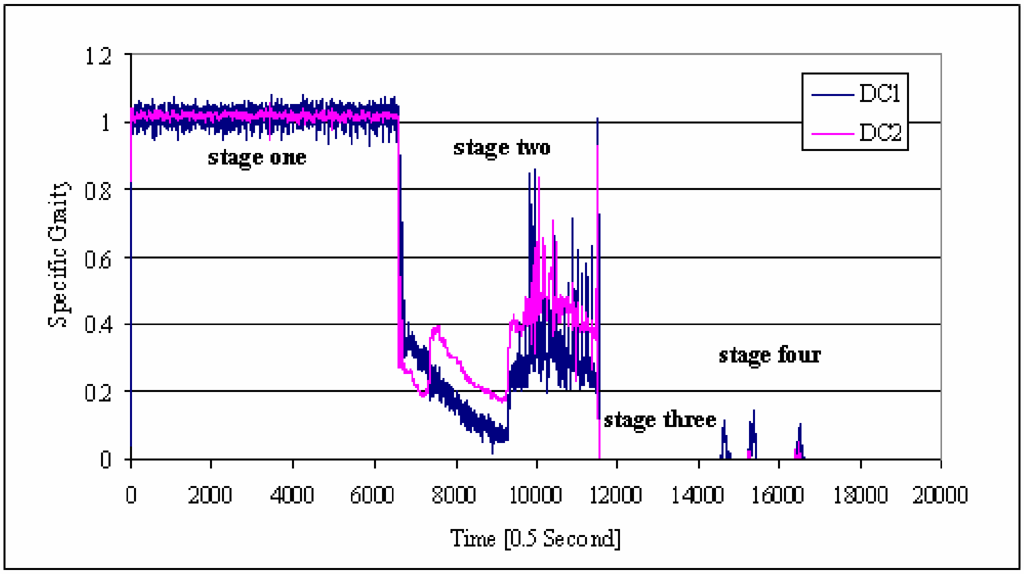


Fig 4.11 Densitometer Reading for Foam Cutting Transport Test

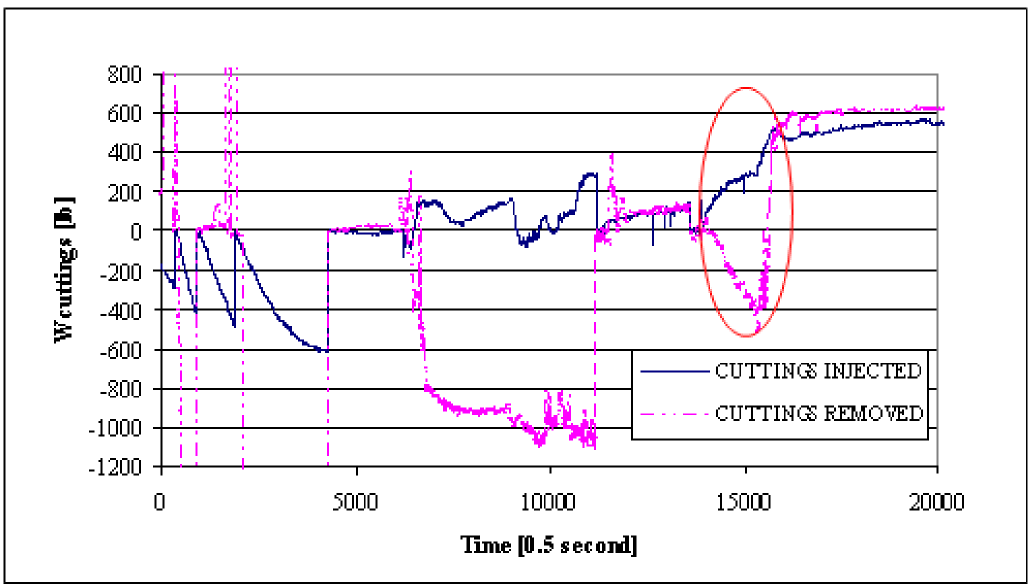


Fig 4.12 Cutting Injections and Collection

4.6 Future Work

1. Conduct foam rheology tests with Bachman surfactant and compare the results with Weatherford foam result
2. Investigate the unexpected 2" differential pressure phenomenon
3. Conduct foam rheology test with the Weatherford foam system
4. Conduct cuttings transport tests with foam flow when the rheology test is done

5. STUDY OF CUTTINGS TRANSPORT WITH AERATED MUD UNDER ELEVATED PRESSURE AND TEMPERATURE CONDITIONS (TASK 10)

INVESTIGATOR: Lei Zhou (Ph.D. Candidate)

5.1 Objectives

1. Develop two-phase flow model for aerated fluids under elevated pressure and temperature conditions inside an annulus in a horizontal position without pipe rotation
2. Determine experimentally the cuttings transport ability of aerated fluids under elevated pressure and temperature conditions
3. Determine the gas/liquid flow rates for effective cuttings transport
4. Develop a computational tool to calculate pressure loss in aerated fluids flowing under elevated pressure and temperature conditions

5.2 Experiments on Aerated Fluids under Elevated Temperature and Pressure

Experiments on aerated fluids without cuttings have been completed in ACTF. Gas and liquid were injected at different flow rates. Two different sets of experiments (Test #1 and Test #2) were carried out, where the only difference was the temperature (See Table 5.1 and Table 5.2). Another set of tests (Test #3) was conducted which covered a wide range of pressures and temperatures: pressures from 100 psig up to 400 psig; temperature from 80 °F up to 175 °F. Several parameters were measured during these tests, including: differential pressure and mixture density in the annulus.

Table 5.1 Test Set # 1: T=80 ºF and 200 psig

Q_L=50 GPM	Q_L=100 GPM	Q_L=150 GPM	Q_L=200 GPM	Q_L=250 GPM
Q_g=50 Scfm	Q_g=50 Scfm	Q_g=50 Scfm	Q_g=50 Scfm	Q_g=50 Scfm
Q_g=75 Scfm	Q_g=75 Scfm	Q_g=75 Scfm	Q_g=75 Scfm	Q_g=75 Scfm
Q_g=100 Scfm	Q_g=100 Scfm	Q_g=100 Scfm	Q_g=100 Scfm	Q_g=100 Scfm
Q_g=125 Scfm	Q_g=125 Scfm	Q_g=125 Scfm	Q_g=125 Scfm	Q_g=125 Scfm

Table 5.2 Test Set #2: T=140 ºF and 200 psig

Q_L=50 GPM	Q_L=100 GPM	Q_L=150 GPM	Q_L=200 GPM	Q_L=250 GPM
Q_g=50 Scfm	Q_g=50 Scfm	Q_g=50 Scfm	Q_g=50 Scfm	Q_g=50 Scfm
Q_g=75 Scfm	Q_g=75 Scfm	Q_g=75 Scfm	Q_g=75 Scfm	Q_g=75 Scfm
Q_g=100 Scfm	Q_g=100 Scfm	Q_g=100 Scfm	Q_g=100 Scfm	Q_g=100 Scfm
Q_g=125 Scfm	Q_g=125 Scfm	Q_g=125 Scfm	Q_g=125 Scfm	Q_g=125 Scfm

Flow patterns during the aerated fluids test have been observed through the view port in the annulus and recorded by a digital video camera. Most of the flow patterns were slug flow. Only at very low gas and liquid flow rates, the stratified flow was observed. As the gas flow rate increases unstable wavy surface was observed at the interface. Further increase in gas flow rate changed the wavy flow pattern to slug flow. Slug flow commonly occurs when the suction force is greater than the gravity force. Figure 5.1 shows the flow patterns for Test set #1. Stratified flow was observed at low air and water flow rates (50 SCFM and 50 GPM). A stratified wavy flow was also observed at a higher gas flow rate (75 SCFM and 50 GPM).

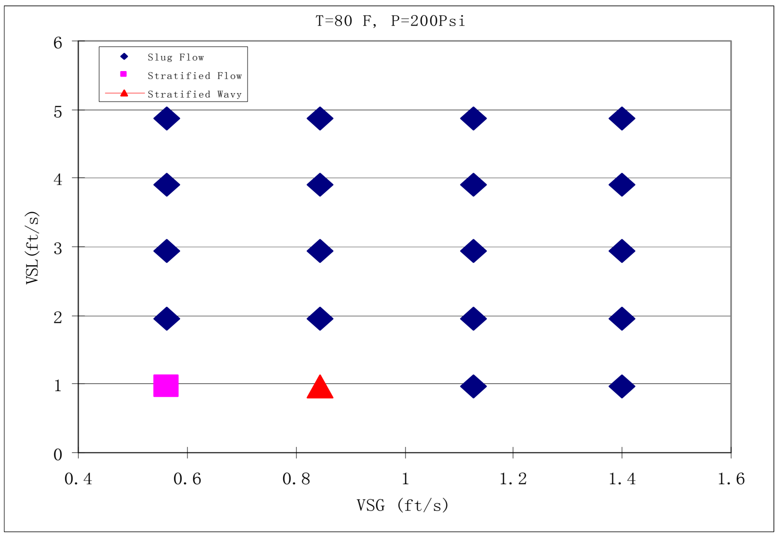


Fig. 5.1 Flow Patterns of Air Water Flow at 80 °F 200 Psig

Figure 5.2 shows the flow patterns for Test set #2. Stratified smooth flow was not observed at this time. Stratified wavy flows were observed at Q_g=50 SCFM and Q_L=50 GPM and Q_g=75 SCFM- and Q_L=50 GPM. A further increase of gas or liquid flow rate resulted in slug flow.

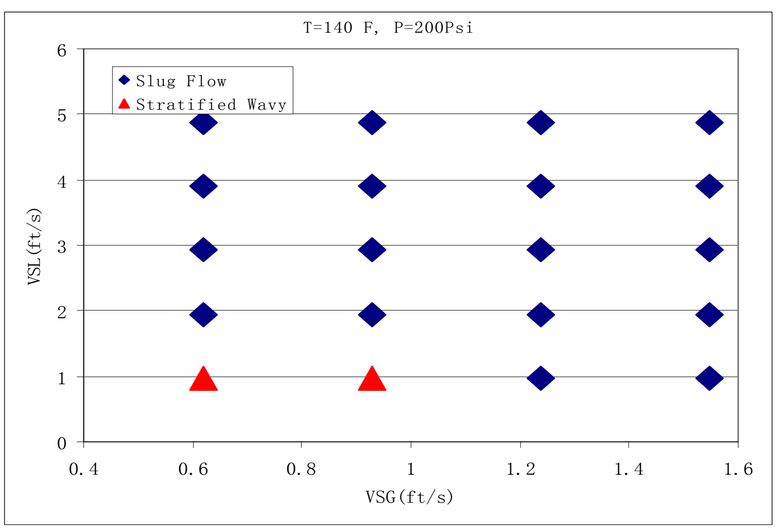


Fig. 5.2 Flow Patterns Of Air Water Flow at 140 °F 200 Psig

Pressure losses of air/water flow have been measured along the annular section. Figure 5.3 and Figure 5.4 show the differential pressure changes with respect to liquid flow rates for Test set #1 and Test set #2, respectively. Apparently, the two-phase flow differential pressure is a strong function of liquid flow rate. The curve indicates the pressure loses are not very sensitive to the increase of air injection rate. There was a slight increase when the air flow rate increases.

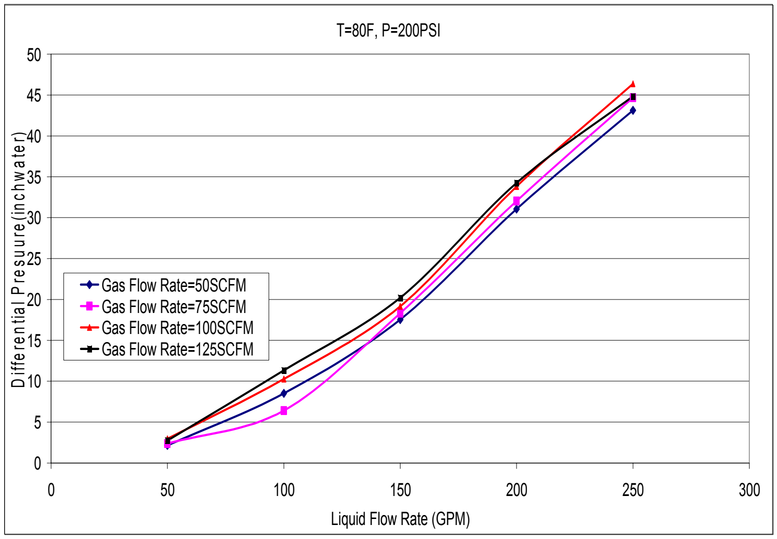


Fig. 5.3 Differential Pressure Vs Liquid Flow Rate for Test set #1

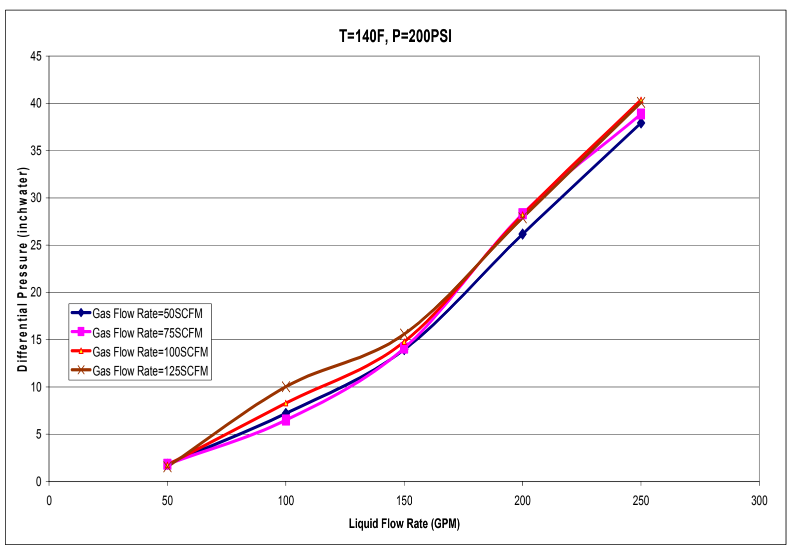
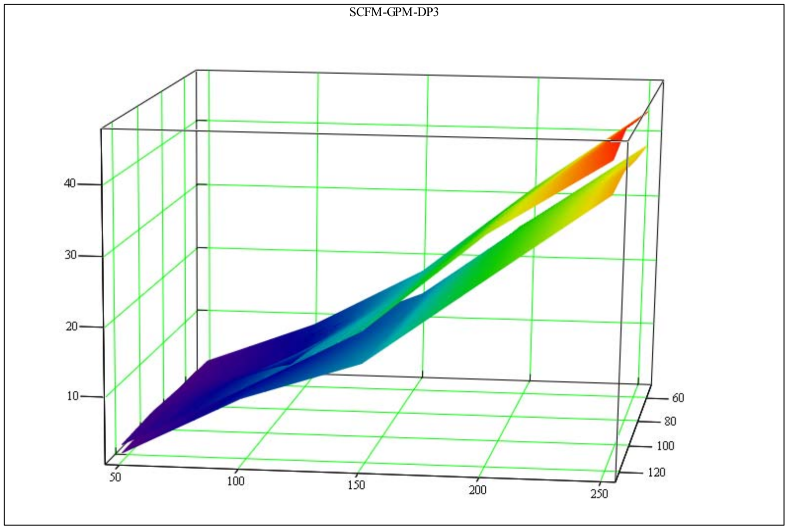


Fig. 5.4 Differential Pressure vs. Liquid Flow Rate for Test set #2

Figure 5.5 is a 3-D plot of the frictional pressure losses data for both Test set #1 and Test set #2. It shows the temperature effect on the frictional pressure losses. As seen from the curves, the frictional pressure losses in the annulus decreases as temperature increases.



(SCFM2, GPM2, DP32), (SCFM1, GPM1, DP31)

Fig. 5.5 Comparison of DP for Test set #1 and Test set #2

A mechanistic model was developed to predict the aerated mud flowing pressure loses and mixture density (liquid holdup). It is based on existing two-phase pipe flow model and extended to concentric annular geometry. Figure 5.6 shows the model predictions and compares the predictions with experimental measurements from Test set #1. The model showed good performance for the pressure drop prediction, with 4.2% average error.

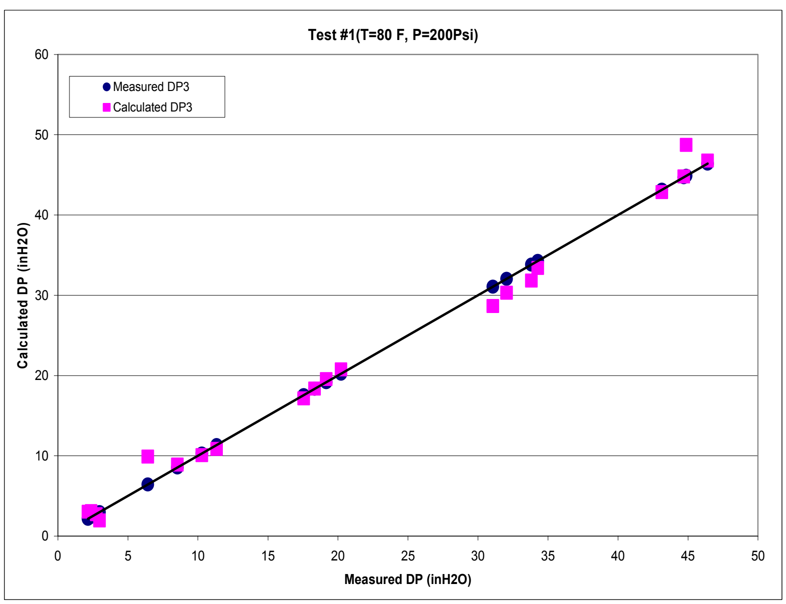


Fig. 5.6 Measured DP Vs Predicted DP for Test set #1

Figure 5.7 shows the model predictions compared with experimental measurements for Test set #2. In this case, the model prediction has about 2% average error.

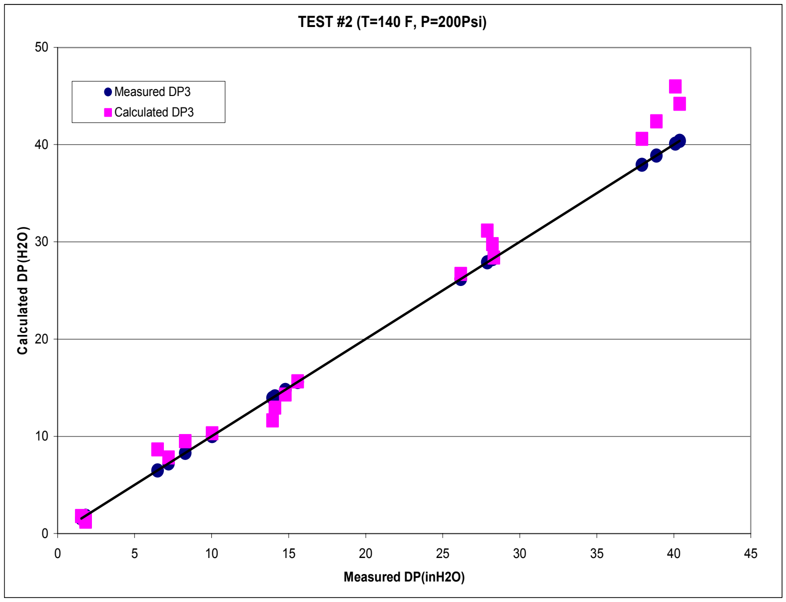


Fig. 5.7 Measured DP Vs Predicted DP for Test #2

The liquid holdup was measured by using gamma-ray densitometers. The mixture density was recorded during the entire test running time. Data collected at steady state were used to calculate time-averaged density values. Figure 4.8 is a typical data plot of the densitometer readings with respect to time.

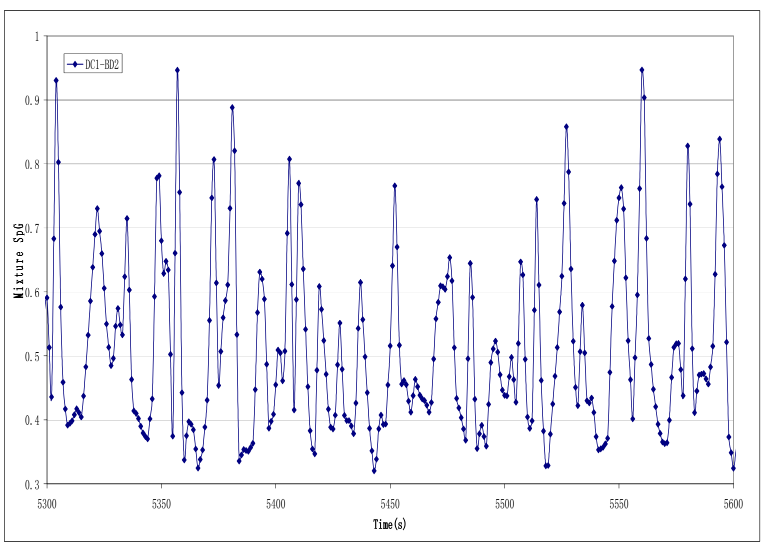


Fig. 5.8 Sample Data of Gamma-Ray Densitometer Readings

The plot shows the maximum densitometer reading was close to 1.0, which indicates the annular space was almost all occupied by liquid phase, with only a small amount of gas dispersed in the liquid slug. The minimum reading was as low as 0.3, which indicates a gas pocket with a liquid film was passing through the densitometer. This verified the slug flow pattern, which is characterized a slug body pushed by a gas pocket. Figure 4.9 shows the measured liquid holdup results from Test set #1. The data show apparently that liquid holdup is decreasing while the air flow rate is increasing.

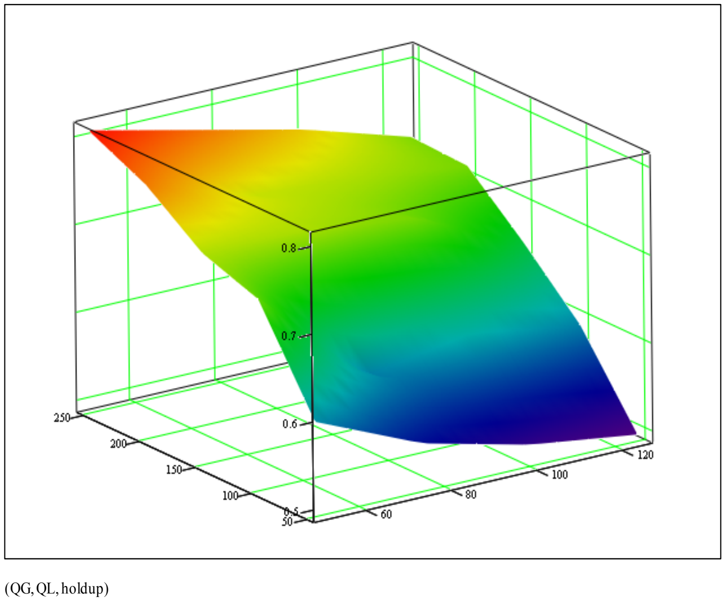


Fig. 5.9 Liquid Holdup for Test set #1

Figure 5.10 shows the model predictions of liquid holdup comparing to experimental measurements for Test set #3. The performance of the model showed an average error of 2.6%.

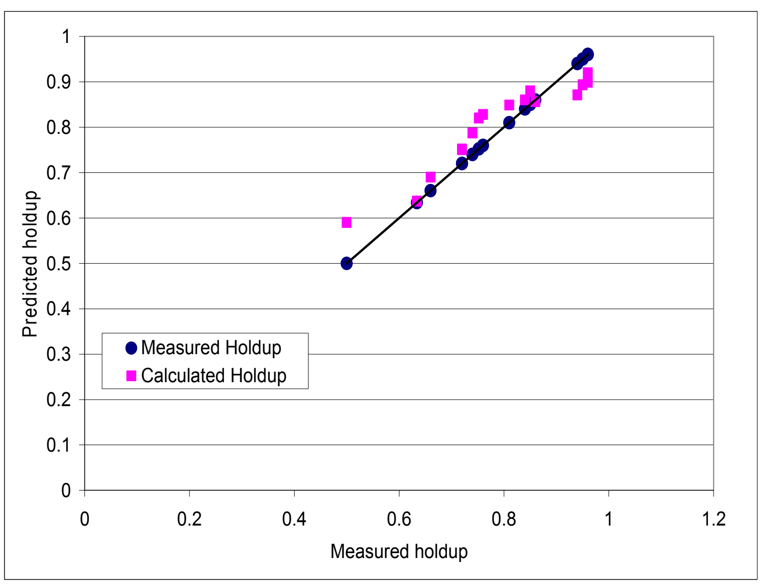


Fig. 5.10 Measured Holdups versus Predicted Holdups

5.3 Experiments on Cuttings Transport with Aerated Fluids

At this stage, all of the planned cuttings transport tests have been completed. The following data were collected: i) cuttings weight in the annulus (the volumetric cuttings concentration or cuttings bed height); ii) liquid holdup; and iii) pressure losses. The results clearly show that temperature significantly affects the cuttings transport efficiency of aerated muds in addition to the liquid flow rate and gas liquid ratio (GLR). The effects of liquid flow rate and GLR on cuttings transport were described in the last DOE quarterly report. Figures 5.11 and 5.12 show the measured cuttings weight and cuttings volumetric concentration in the annulus versus temperature; the liquid flow rate was 100 GPM and GLR=0. When temperature was increased from 80 °F to 170 °F, the measured cuttings weight in the annulus changed from 352 Lbm to 476 Lbm. The corresponding volumetric concentrations changed from 27% to 36%.

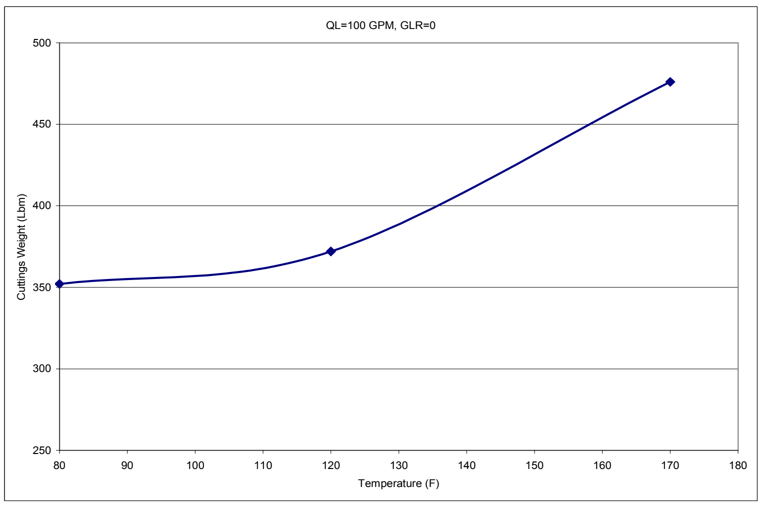


Fig. 5.11 Cuttings weight versus Temperature

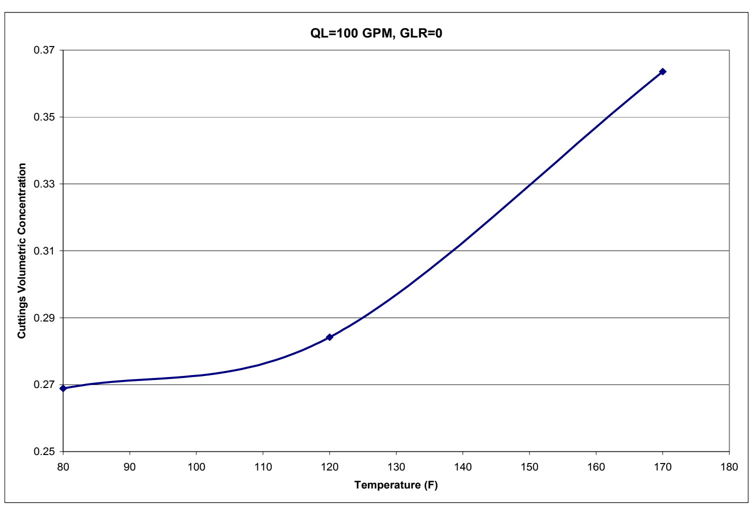


Fig. 5.12 Cuttings Volumetric Concentration versus Temperature

Figures 5.13 and 5.14 show the measured cuttings weight and cuttings volumetric concentration in the annulus versus temperature; the liquid flow rate in this case was 100 GPM and GLR=0.38. When temperature was increased from 80 °F to 170 °F, the measured cuttings weight in the annulus changed from 294 Lbm to 439 Lbm. The corresponding volumetric concentrations changed from 22% to 33%.

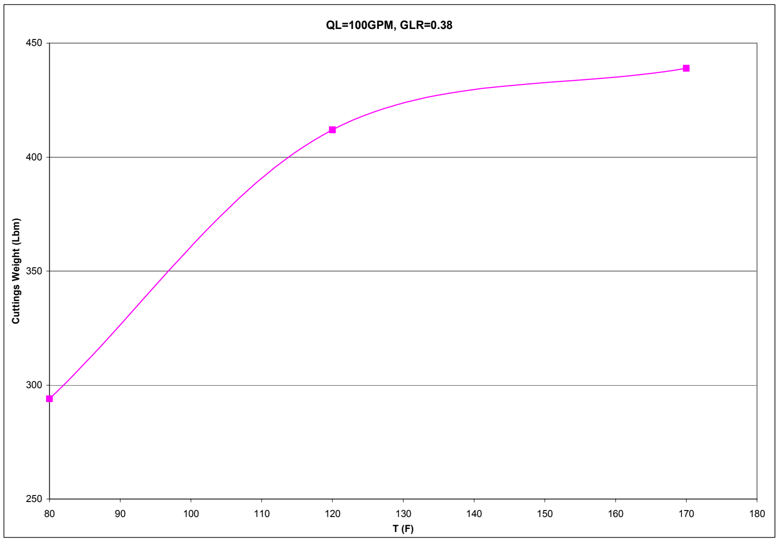


Fig 5.13 Cuttings weight Vs Temperature

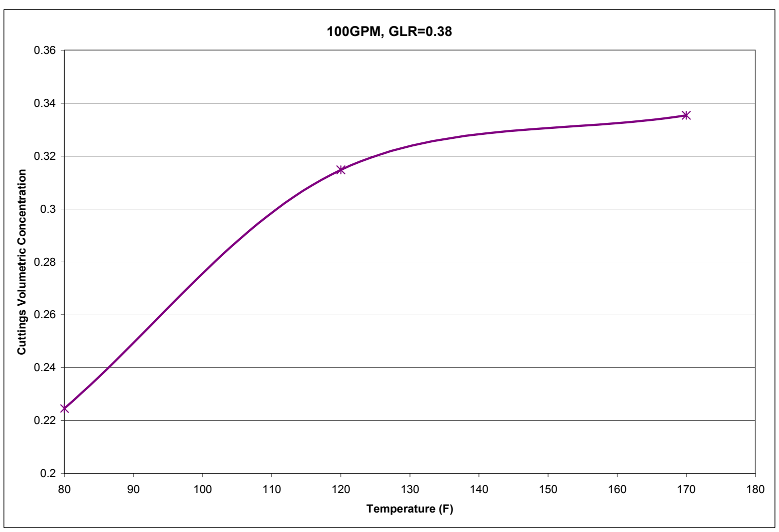


Fig. 5.14 Cuttings Volumetric Concentration versus Temperature

Further data analysis for aerated muds cuttings transport tests is in progress. We are developing a hydraulic model for aerated muds under EPET conditions.

5.4 ACTS Flow Loop Maintenance

Routine maintenance was conducted on a daily basis to keep the flow loop operational. A canopy was built to keep most of the pumps and electronic devices protected from rain and snow. But the high pressure and high temperature test requires more maintenance. Especially when three-phase (air-water-cuttings) tests are conducted at under EPET conditions. The presence of solids in a flow system can cause many problems. Fine cuttings can set in the valves and cause seal problems. Effort has been made to prevent cuttings getting into the water storage tank by putting two sand strainers on the return line. Unfortunately, screens of the strainers were too fine and did not work for long. As a result, they were temporarily removed from the system until coarser screens were obtained. Effective solid particle separation is necessary to remove the cuttings from the return line. Otherwise, cuttings get into the mud pump (Halliburton HT400) and imbed into the valve inserts. It does not take very long time to damage the valve inserts under EPET conditions and cause operation problems. Six valve inserts of the mud pump (Halliburton HT400) have already been replaced. A repair/maintain list has been set up. It will be carried out during the next quarter.

5.5 Future Work

1. Data analysis.
2. Any necessary loop modification.
3. Continue development of the hydraulics model for cuttings transport.
4. Prepare final report.

5.6 Deliverables

1. Semi-annual Advisory Board Meeting (ABM) reports.
2. Two-phase flow model for aerated fluids under elevated pressure and temperature conditions.
3. Practical guidelines and/or graphs to determine the gas/liquid rate for effective cuttings transport capacity under elevated pressure and temperature conditions.
4. A computational tool to calculate frictional pressure drops inside an annulus for aerated fluids flowing over the range of experimental conditions.

6. DEVELOPMENT OF CUTTINGS MONITORING METHODOLOGY (Task 11)

INVESTIGATORS: Kaveh Ashenayi and Gerald Kane (Profs Electrical Engr.)

6.1 Objective:

The ultimate objective of this task (Task 11) is to develop a non-invasive technique for quantitatively determining the location of cuttings in the drill pipe. There are four different techniques that could be examined. However, as it was pointed out in the previous reports only three have good potential for success. These are Ultrasound, X-Ray/γ-Ray and Optical.

We have concentrated our efforts on the ultrasound technique. If this technique is not successful then we will switch to the other techniques or use a hybrid system that will utilize a combination of these techniques.

6.2 Team Composition:

The instrumentation team charged with completing Task 11 consisted of Dr. Gerald R. Kane and Dr. Kaveh Ashenayi both registered professional engineers and professors of Electrical Engineering at the University of Tulsa. MS level graduate students are assisting them. These students have BS degrees in EE and Computer Science. This particular combination works well because successful completion of this project requires skills needed in both disciplines. To achieve objectives of this task we will need to develop a very complicated electronic hardware/sensor and a software package that correctly interprets the data received.

In addition, Dr. Len Volk is a member of this team working on task 12.

6.3 Progress to Date:

The new control board is functioning well. We have used it to test our new pipe section. We conducted tests to see if the basic system is functioning correctly. We used the new test cell and added sand and water to see the system's response. The system did classify different sand levels differently. As sand was added the system response changed.

The data collection software revision is proceeding. The software will start by allowing the user to setup the communication characteristics of the system. Then it will proceed to identify the number of boards connected. The data received from the sensor board is in the form of ASCII characters as shown in Table 6.1. We developed and tested the conversion algorithm that allows us to calculate the numerical voltage value corresponding to the character combinations that are received.

The software will then export the data as a text file to be used as input for the neural network development package we purchased.

We are still working on developing a solution for a potential problem with the sensors' impedance identified before. It seems that all units are not a close match from impedance point of view. This could be a problem if we need to replace a sensor after the system has been calibrated. We are further investigating.

6.4 Approach:

In subtask one of Task 11 we are to develop a static (followed by a dynamic) radial test cell and to develop a preliminary set of instruments to detect presence of cuttings in this cell.

The main approach to be investigated is the ultrasound transmission. We will further investigate the need for an inner ring by comparing the results of two experiments. First we will use a set of rings in the outer pipe. We will rotate the angle at which sound is being transmitted relative to the sand collection. We will measure the sound received and compare it against sound transmitted. After suitable data processing we believe it is possible to get an acceptable picture of what is inside the pipe. This is very similar to the MRI technique used by physicians.

In the second experiment we will repeat the same experiment except we will use an inner ring of sensors on the inner pipe. The inner ring will act as source and the outer ring will act as receivers. Then we will repeat the experiment above.

Table 6.1 Data received from the sensor board in the form of ASCII characters

Readings taken with the cell entirely filled with water				Readings taken with 1 " sand in the cell filled with water				Readings taken with 2 " sand in the cell filled with water				Readings taken with 3 " sand in the cell filled with water				Readings taken with 4 " sand in the cell filled with water			
ASCII		**Hex**	**Dec**	**ASCII**		**Hex**	**Dec**	**ASCII**		**Hex**	**Dec**	**ASCII**		**Hex**	**Dec**	**ASCII**		**Hex**	**Dec**
□	□	3FF	5	s	}	27E	3.1	p	}	21E	2.65	j	p	150	1.64	g	o	EF	1.2
□	□	3FF	5	t	a	281	3.1	p	y	219	2.63	j	m	14D	1.63	g	l	E9	1.1
□	□	3FF	5	t	j	28A	3.2	p	~	21D	2.64	j	t	154	1.66	g	d	E4	1.1
□	□	3FF	5	t	z	29A	3.3	p	h	208	2.54	j	y	159	1.69	g	b	E2	1.1
□	□	3FF	5	t	w	297	3.2	q	e	225	2.68	j	}	15E	1.71	f	|	DB	1.1
□	□	3FF	5	t	v	296	3.2	p	}	21E	2.65	j	□	15F	1.72	f	t	D4	1
□	□	3FF	5	t	l	28C	3.2	p	u	215	2.58	k	e	165	1.74	f	q	D1	1
□	□	3FF	5	s	w	277	3.1	p	o	20F	2.61	j	}	15E	1.71	f	l	CC	1
□	□	3FF	5	s	}	273	3.1	p	t	214	2.6	j	q	151	1.65	f	l	CC	1
□	□	3FF	5	s	r	272	3.1	p	n	2OE	2.57	j	u	155	1.67	f	k	CB	1
□	□	3FF	5	s	q	271	3.1	p	k	20B	2.56	j	|	15B	1.7	f	k	CB	1
□	□	3FF	5	s	q	271	3.1	p	l	209	2.55	k	l	169	1.76	f	n	CE	1
Average			**5**	**Average**			**3.1**	**Average**			**2.6**	**Average**			**1.69**	**Average**			**1.05**

6.5 Future Work:

Using a test cell we will conduct a set of experiments, as outlined in Table 6.2.

We will use neural networks to model impact of fluid flow on the signal received as well as the shape of the sand collection. This is needed due to highly nonlinear nature of the flow. It has been shown that neural networks can successfully model nonlinear systems.

Table 6.2 Testing Plan

No.	Planned Test	Start Date	Time req. for prep. & testing
1	Static test with clear plastic on one end of the test cell.	01/20	2 days
2	Heat Test	01/22	3 days
3	Testing with flowing water.	01/27	2 days
4	Static test by integrating the test section in the low-pressure test flow loop.	01/29	2 weeks
5	Dynamic tests on the same low-pressure loop.	02/13	1 week
6	Static and Dynamic test at elevated temperatures.	02/20	2 weeks
7	Static and Dynamic tests at elevated temperatures and pressures.	03/05	2 weeks

Test details:

1. Static Tests with one clear see-through end of the test cell:
    - First static test with two sensors to check for repeatability by performing number of tests without changing the sensors positions.
    - The methodology of positioning the sensors should be formulated to achieve non-changing positions for the sensors.
    - Static test with all four sensors in a ring and again check for repeatability.
2. Heat Test
    - Re-verification of sensor performance at elevated temperatures.
3. Testing with flowing water
    - Use taps to generate flow of water. Repeated tests to be performed with a ring of sensors.
4. Static test by integrating the test section in the low-pressure test flow loop.
5. Dynamic tests on the same low-pressure loop.
6. Static and Dynamic test at elevated temperatures.
7. Static and Dynamic tests at elevated temperatures and pressures.

7. FOAM BUBBLE CHARACTERIZATION METHOD (TASK 12)

INVESTIGATOR: Leonard Volk

7.1 Introduction

Bubbles (as foam or aerated fluid) will be moving at a high rate (up to 6 ft/sec) in the drilling section of the ACTF, and may be very small (down to 0.01 mm). The bubble size and size distribution influence the fluid rheology and the ability of the fluid to transport cuttings. Bubbles in a shear field (flowing) may tend to be ellipsoidal, which might alter both the rheology and transport characteristics.

This project is Task 12 (Develop a Method for Characterizing Bubbles in Energized Fluids in the ACTF During Flow) in the Statement of Work, and is divided into four subtasks:

- Subtask 12.1. Develop/test a microphotographic method for static conditions
- Subtask 12.2. Develop/test a method for dynamic conditions
- Subtask 12.3. Develop simple, noninvasive methods for bubble characterization
- Subtask 12.4. Provide technical assistance for installation on ACTF

Subtask 12.1 includes (1) magnifying and capturing bubble images, (2) measuring bubble sizes and shapes, and (3) calculating the size distribution and various statistical parameters. Subtask 12.2 develops the methods needed to apply the results of Subtask 12.1 to rapidly moving fluids, especially the method of "freezing" the motion of the bubbles. A dynamic testing facility will be developed in conjunction with Task 11 for development and verification.

Subtask 12.3, added in Year 3, develops simple, inexpensive and small-in-size methods for characterizing bubbles. This task was previously referred to as "New Techniques". Techniques and methods developed under Subtask 12.2 and 12.3 will be applied to the drilling section of the ACTF in Subtask 12.4.

7.2 Objective

The objective of this task is to develop the methodology and apparatus needed to measure the bubble size, size distribution and shape during cuttings transport experiments.

7.3 Project Status

7.3.1 Dynamic Bubble Characterization

7.3.1.1 Dynamic Imaging

The Hatachi KP-F120 progressive scan digital camera has been installed on the Nikon microscope associated with the DTF, however we are attempting to resolve a few programming difficulties that occur during image capturing. In-house attempt continue in the application of existing software to recognize and measure bubble sizes and distributions.

7.3.1.2 Dynamic Testing Facility

Major modifications to the dynamic bubble characterization facility (DTF) were completed. The schematic was presented last quarter. Figure 7.1 is a much-simplified schematic of the DTF showing the essential features for foam generation to be described below.

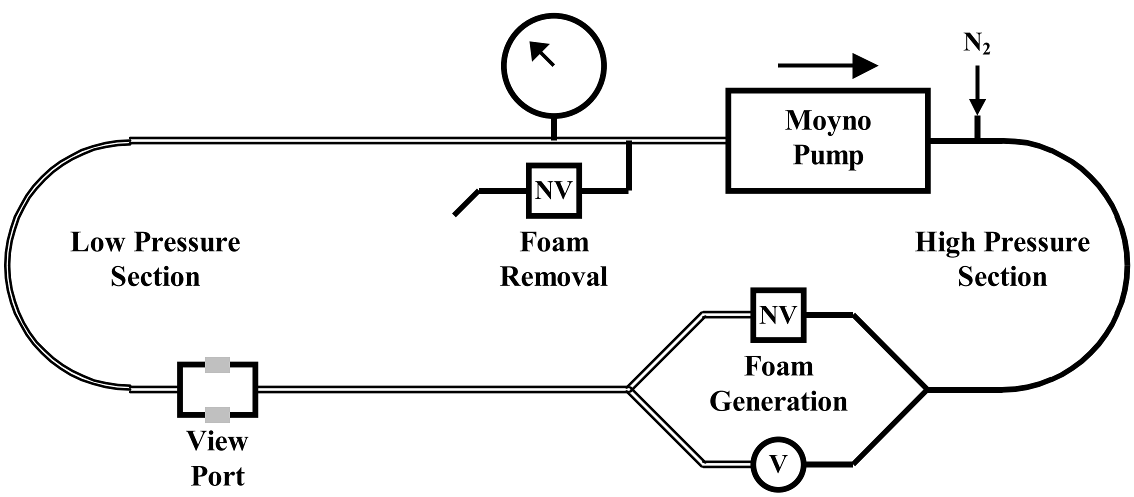


Fig. 7.1 Simplified schematic of DTF illustrating foam generation and removal

Figure 7.2 illustrates an Excel program that allows the volume of the empty DTF to be calculated by recording the time it takes to pressurize the loop with nitrogen from a calibrated needle valve. The first stage in forming foam is to introduce sufficient surfactant-containing fluid into the DTF so that it can be circulated by the Moyno pump. The next step is to pressurize the loop with nitrogen and record the time required. This data, entered into the right portion of the Excel spreadsheet shown in Fig. 7.2, allows us to calculate the initial "foam" quality in the DTF. Typically the initial foam quality ranges between 25 and 35%. The next step is to turn on the Moyno pump and close the foam generation needle valve to the desired opening. Next, the objective is to meter nitrogen into the DTF and removed foam at a sufficient rate so as to maintain a constant pressure (refer to Fig. 7.1). This process was generally described last quarter.

SS-SS4-MH Needle Valve Calibration with P=200psi n=PV/RT

Needle Valve Opening	Time (s)	Flow Rate (mL/s)	Flow Rate (mL / min)	V/t Flow Rate (L/min)	n/t (Moles/min)
0.0	202.9	22.64	1358	1.36	**0.056**
1.0	115.6	39.74	2385	2.38	**0.098**
2.0	72.1	63.74	3824	3.82	**0.158**
3.0	55.3	83.00	4980	4.98	**0.206**
4.0	42.4	108.30	6498	6.50	**0.268**
5.0	35.1	130.71	7842	7.84	**0.324**
6.0	29.4	156.44	9386	9.39	**0.388**
7.0	25.2	182.12	10927	10.93	**0.451**
8.0	22.4	205.50	12330	12.33	**0.509**
9.0	19.9	230.92	13855	13.86	**0.572**
10.0	17.7	259.05	15543	15.54	**0.642**

10-16-03

Values in blue are input parameters

V = t*(n/t)*R*T/[P(f)-P(i)]

Volume of Empty Loop (NV 10 Turns Recommended)

P(Bar)	**14.74**	psi		
P(i,gauge)	**0**	psi		
P(i)	**14.74**	psi	**1.003**	atm
P(f,gauge)	**60**	psi		
P(f)	**74.74**	psi	**5.084**	atm
T(F)	**76.8**	F		
T(K)	**297.9**	K		
R	0.08206	atm lt/mole K		
Clock Time	**6**	min	**58**	sec
t	**6.97**	min		
n/t	**0.642**	moles/min for NV=10 turns		
n	**4.47**	moles		
V	**26.79**	liters		

Volume of Partially Full Loop

NV Opening	**5.0**	turns	**7.88**	**V/t**	**0.325**	**n/t**
P(Bar)	**14.74**	psi				
P(i,gauge)	**0.3**	psi				
P(i)	**15.04**	psi	**1.023**	atm		
P(gauge)	**60**	psi				
P(f)	**74.74**	psi	**5.084**	atm		
T(F)	**77**	F				
T(K)	**298.0**	K				
R	0.08206	atm lt/mole K				
Clock Time	**3**	min	**28**	sec		
t	**3.47**	min				
n/t	**0.325**	moles/min				
n	**1.13**	moles				
V	**6.79**	liters				

"Foam" Quality: 25.3

Fig. 7.2 Determination of empty and partially liquid filled volume of the DTF

Foam Generation

Input data in blue

0.06	Fraction of flow to replace with gas at P				
65	System pressure, P, psi	**14.97**	Barometric pressure		
	Flow Rate (Moyno), GPM	**800**	Moyno "RPM"		
25.3	Initial foam quality				
26.79	System volume (empty), liters				
	Gas vol with foam in line, liters				
	Nitrogen injection rate at P, liters/min		Nitrogen injection rate at P, liters/s		
	Number of NV turns to get desired flow(Max 10)		NV Turns:	NV Fraction:	
	Nitrogen injection rate at STP, liters/min				
80	Desired final foam quality, Q				
	Time to achieve Q, min				

Elapsed Time (Min)	Foam Quality (%)
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	

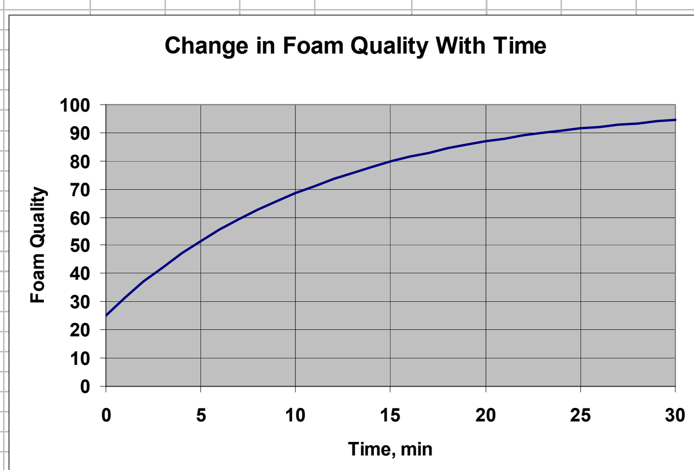


Fig. 7.3 Development of foam in the DTF

Figure 7.3 shows a second Excel spreadsheet to assist us in this task. Listed below are the input parameters and a brief description of each.

Fraction of flow to replace with gas at P: This technique replaces foam being withdrawn with nitrogen. To prevent starving the Moyno pump and to reduce the chance of foam collapse at high foam qualities, the fraction of foam being replaced with gas should not be too great. Limiting the amount of gas being input at higher foam qualities also helps the integration of the new gas into the foam (reduces the change of gas slugging). Probably 0.1 or less is acceptable.

System pressure: Normally, one would like to operate a predetermined pressure, such as 60 psi. If one pressurizes the DTF to 60 psi and then closes the bypass valve (labeled "V" in Fig. 7.1), a pressure drop will develop across the foam generation needle valve so that there will now be a high pressure section and a low pressure section. What was once 60 psi may now be 55 psi in the low pressure section and 65 psi in the high pressure section. So if one wants to perform experiments in the low pressure section at 60 psi, additional nitrogen must be added to increase the pressure from 55 to 60 psi. The high-pressure section pressure will also increase to say 70 psi. We have therefore increased the average system pressure from 60 psi to 65 psi and this increased pressure is entered into the spreadsheet, Fig. 7.3. The average pressure is actually measured by temporarily opening the bypass valve since the high-pressure and low-pressure sections of the DTF do not have identical volumes.

Initial foam quality: This value comes from the spreadsheet in Figure 2 and represents the initial gas/liquid ratio in the DTF as foam generation begins.

Moyno "RPM": This is a number that is proportional to the pump RPM and comes from the variable frequency drive. Although the approximate volumetric flow rate is known, it is more convenient to use the Moyno "RPM".

Barometric pressure: Although changes in the barometric pressure can be included, these changes do not have much effect.

Desired final foam quality Enter the final foam quality you would like to achieve. Depending on the desired foam quality, this program will under predict the foam quality by as much as 5%. We are working on corrections that should reduce this error considerably.

Data and the plot in Fig. 7.3 help one understand the change in foam quality with time. As mentioned above, the system pressure should be the average pressure. Unfortunately, the system pressure changes as the foam quality increases. Figure 7.4 shows how the pressure drop across the foam generation needle valve varies as the foam quality increases for a particular needle valve setting. Since the pressure in the low pressure section is held constant, the system pressure must change somewhat. Although one could automate this technique to account for changes in the average system pressure, a simple first-order correction should provide sufficient accuracy without added expense or complexity.

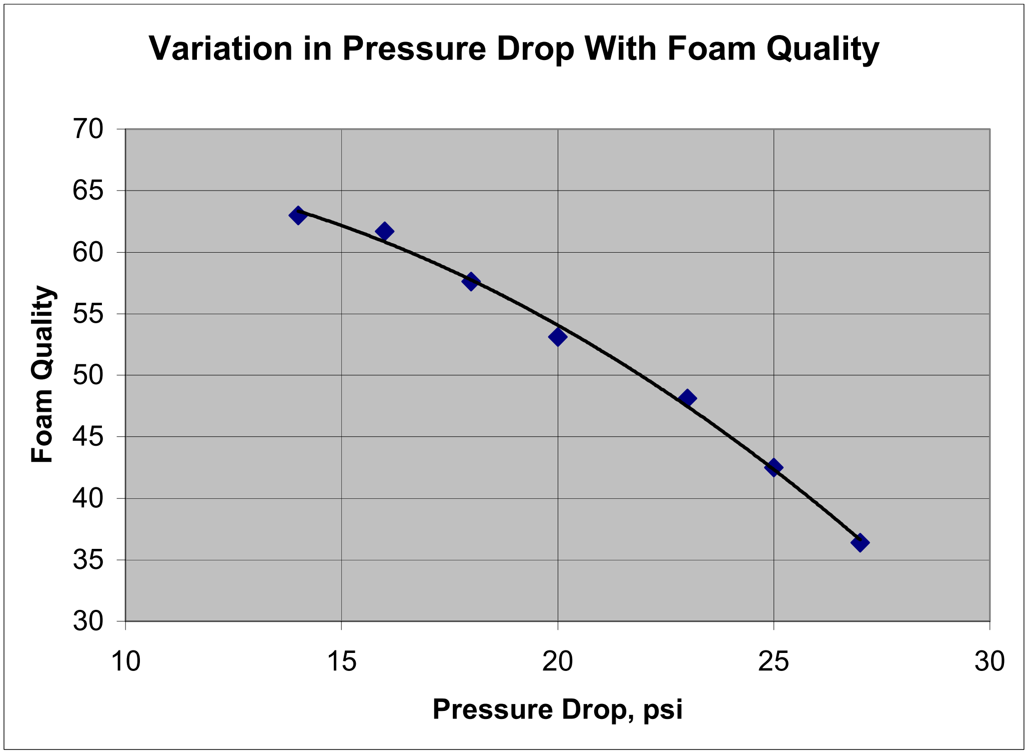


Fig. 7.4 Change in pressure drop through an orifice as foam quality changes

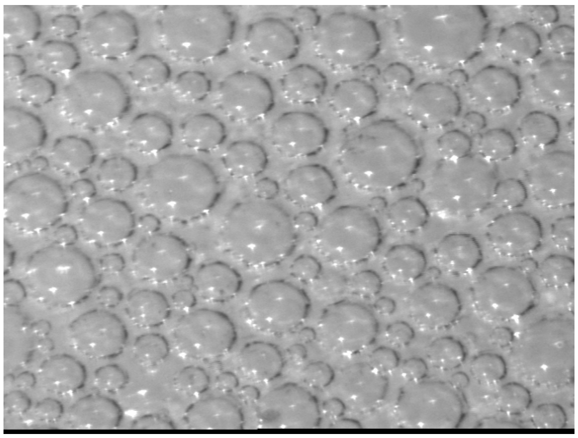
7.3.2 Novel Techniques for Bubble Characterization

In order to incorporate foam as a drilling fluid in a cuttings transport model, the average bubble size and bubble size distribution of the foam must be measured under various conditions. This is accomplished by imaging the foam through a glass cell and subsequently analyzing the image with software. Back illumination is not possible as the foam absorbs the light entirely, allowing no light to reach the front surface. This results in inherent features of the images that make them difficult to be analyzed by standard means.

As we mentioned in the last report, there were complications we had encountered as a result of our illumination technique. The previous online camera used for bubble imaging was an analog camera. The image capturing board used to obtain images from this analog camera was taking very poor quality pictures. A sample picture taken by this camera is shown in Fig. 7.5. Beside this, the previous system cannot obtain the complete shape of the bubbles. Only part of the circle indicative of the boundary of the bubble was evident. Much progress has been made towards an automated procedure for bubble analysis; however, many obstacles still remain.

In order to ascertain enhanced image quality a new CCD digital camera with higher resolution (1.45M) was purchased and installed. This will allow us to image the foam with less intense light, which could minimize the reflections. Moreover, a new data acquisition board and software packages were installed to capture digital images from the new camera. With this new imaging system sharper images were captured and the complete shape of bubbles was obtained. Figure 7.6 shows a sample picture taken by the new digital camera. A visual basic program has been developed to remove the “bright dots (noise)” from the images. An imaging software package, “particles”, was used to obtain preliminary data (bubble sizes and distribution).

A new cell (view port) is also being designed, which will allow more freedom in illumination techniques. Also, alternative illumination is being considered, including multi-directional illumination and polarization. Polarization has the possibility of reducing the reflections and multi-directional illumination may lead to a more defined arc, or possibly a complete boundary on the bubbles.



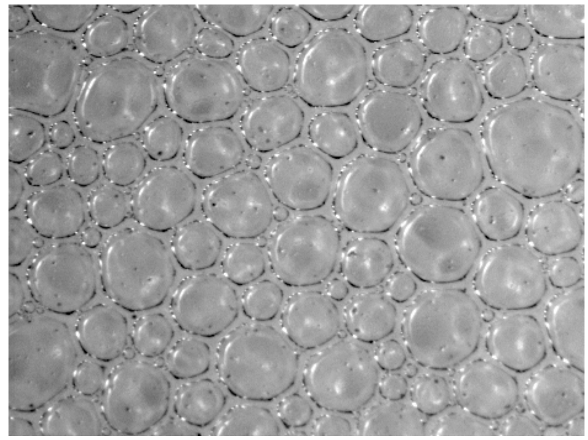


Fig. 7.5 Picture taken by the analog Camera

Fig. 7.6 Picture taken by the digital Camera

7.3.3 Installation of Bubble Characterization Methodology on ACTF

Design has begun on a cart that will house the stop-flow cell, microscope with digital camera and the valving needed to automatically capture and record bubble images of foam flowing in the ACTF.

7.4 Planned Activities

7.4.1 Dynamic Bubble Characterization

- Complete design and construction of the stop-flow cell
- Verify operation of the stop-flow technique

7.4.2 Installation of Bubble Characterization Methodology on ACTF

- Design and construct bubble characterization cart

8. SAFETY PROGRAM (TASK 1S)

Chairman, Process Hazards Review Team: Leonard Volk

8.1 Introduction

This project was initiated during the fourth quarter of 2000 to assess the hazards associated with the Advanced Cuttings Transport Facility (ACTF) and develop an Action Plan to address problems discovered during this Hazards Review.

8.2 Objective

The objective of this task is to identify problems (findings) that might result in injury, property damage or the release of environmentally damaging materials and provide recommendations to minimize them, and to develop an action plan based on these recommendations.

8.3 Project Status

There has been limited activity on Task 1S during this quarter. A hazard review will be conducted on the ACTF once it attains a “steady state” configuration and schematics can be drawn. In the meantime, progress on the ACTF construction is being monitored with respect to safety.

8.4 Planned Activities

- Complete addressing the Findings listed in Action Plan #1
- Begin Hazards Review of new modifications to the ACTF

9. TECHNOLOGY TRANSFER

Meetings with Petroleum and Service Companies

Representatives from the following JIP members attended the November 18, 2003 Advisory Board Meeting (ABM): the U.S. DOE, Baker-Hughes, ChevronTexaco, Schlumberger, Halliburton, Statoil, Totalm, Petrobras and Weatherford International. There were also visitors from the following companies: ConocoPhillips, Oil and Gas Institute of Poland, ExxonMobil, Anadarko Petroleum, M-I Drilling, Precision Drilling and ASCOMETAL.

A representative from PDVSA and BP did not attend the November ABM. However, we had a teleconference with a BP representative later during the month of December. The meeting was constructive.

ACTS-JIP Advisory Board Meeting

The next Advisory Board Meeting will be held on May 11, 2004. In addition to the DOE, there are currently 10 member companies participating in the ACTS-JIP Project. They are: 1) British Petroleum, 2) Baker-Hughes, 3) ChevronTexaco, 4) Schlumberger Dowell, 5) Halliburton, 6) Intevep, 7) Petrobras, 8) Statoil, 9) Total, and 10) Weatherford

Other Activities

We participated in the Annual SPE meeting in Denver, which was held from October 5 to 8, 2003. In particular we would like to mention that the SPE paper 84175 was presented at the meeting. This article presents some of results obtained in Task 9, which was completed in 2002. An abstract submitted to SPE/ICoTA Coiled Tubing Conference has been accepted; we are preparing the article for submission. An abstract for the next Annual SPE meeting has been also submitted.