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Principal Authors:

Stefan Miska, Principal Investigator

Nicholas Takach, Co-Principal Investigator

Kaveh Ashenayi, Co-Principal Investigator

Mengjiao Yu, Research Associate

Ramadan Ahmed, Research Associate

Mark Pickell

Len Volk

Mike Volk

Lei Zhou

Zhu Chen

Aimee Washington

Crystal Redden

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The University of Tulsa

600 South College Avenue

Tulsa, Oklahoma 74104

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ABSTRACT

The Quarter began with installing the new drill pipe, hooking up the new hydraulic power unit, completing the pipe rotation system (Task 4 has been completed), and making the SWACO choke operational. Detailed design and procurement work is proceeding on a system to elevate the drill-string section. The prototype Foam Generator Cell has been completed by Temco and delivered. Work is currently underway to calibrate the system.

Literature review and preliminary model development for cuttings transportation with polymer foam under EPET conditions are in progress. Preparations for preliminary cuttings transport experiments with polymer foam have been completed.

Two nuclear densitometers were re-calibrated. Drill pipe rotation system was tested up to 250 RPM. Water flow tests were conducted while rotating the drill pipe up to 100 RPM. The accuracy of weight measurements for cuttings in the annulus was evaluated. Additional modifications of the cuttings collection system are being considered in order to obtain the desired accurate measurement of cuttings weight in the annular test section. Cutting transport experiments with aerated fluids are being conducted at EPET, and analyses of the collected data are in progress.

The printed circuit board is functioning with acceptable noise level to measure cuttings concentration at static condition using ultrasonic method. We were able to conduct several tests using a standard low pass filter to eliminate high frequency noise. We tested to verify that we can distinguish between different depths of sand in a static bed of sand. We tested with water, air and a mix of the two mediums.

Major modifications to the DTF have almost been completed. A stop-flow cell is being designed for the DTF, the ACTF and Foam Generator/Viscometer which will allow us to capture bubble images without the need for ultra fast shutter speeds or microsecond flash system.

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1. Executive Summary

Flow Loop Construction (Tasks 4 & 5)

The Quarter began with installing the new drill pipe, hooking up the new hydraulic power unit, completing the pipe rotation system (Task 4 has been completed), and making the SWACO choke operational. Mostly 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.

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. At the writing of this report we have located several "30 ton" mast sections that came off of a Lorain crane. These mast sections have been surplused by a local cartage company. The masts are now being traced back to the manufacturer and their design is being analyzed for use in our loading conditions. The remainder of our time has been taken by managing the remainder of any uncompleted task on order to assure that no items remain after the end of the 5-year program. Additional discussion of these tasks are provided in Section 2.

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

The prototype Foam Generator Cell has been completed by Temco and delivered. The remaining components for the prototype Foam Generator have been obtained and assembled. Work is currently underway to calibrate the system. The reason this unit is called a prototype is primarily because the containment cell has been made of plastic to allow us to observe the foam generation process and refine the propeller and foam flow patterns. Because this prototype is made from plastic, the high temperature part of the Foam Viscometer will not be constructed until after sufficient work has been done with the prototype to be satisfied that no further design changes will be forthcoming.

The couettte-type Thermo-Haake RS300 viscometer: Has not yet been hooked up to the Foam Generator because it is still being used with the Dynamic Test Facility (DTF) flow loop (developed as a part of Task #12) to continue the study "An Experimental Study of the Viscosity of Drilling Foam Using a Foam Generator /Viscometer", also part of Task #9b.

One of the objectives of this research task is to determine the relationship between surface roughness and "slip" of foams at solid boundaries. In a typical Couette-type rheometer, the cup rotates to shear the test fluid. When there is sufficient roughness, wall slip, caused by liquid films, can be eliminated. In order to achieve these objectives, four additional Rheometer cups and cylindrical rotors are being made with different surface roughness. Additional discussion of this task is provided in Section 3.

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

This research project is focused on the experimental determination and numerical prediction of volumetric requirements for effective cuttings transport with foam in horizontal wellbores (initially without pipe rotation), a mechanistic cuttings transport computer simulator will be

developed, and predictions of the simulator will be compared with experimental data from the ACTS Flow Loop. Emphasis was given during this period for literature review and preliminary work on cutting transport model development, and preparation for flow loop experiment. Additional discussion of this task is provided in Section 4.

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

Re-calibration of two nuclear densitometers has been finished. Eight-point calibration procedure was used to generate calibration curves of the densitometers. Drill pipe rotation system was installed. The drill pipe was rotated up to 250 RPM. Water flow tests were conducted while rotating the drill pipe up to 100 RPM. The accuracy of weight measurements for cuttings in the annulus was evaluated. Three view ports were installed in the flow loop. Based on the visual observation of cuttings movement in the annulus, test matrix has been modified to meet the research interests. Cutting transport experiments with aerated fluids are being conducted at EPET for the second time. Analysis of the collected data is in progress. Additional modifications of the cuttings collection system are being considered in order to obtain the desired accurate measurement of cuttings weight and transport rate in the annular test section. Additional discussion of this task is provided in Section 5.

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 are using a standard low pass filter to eliminate high frequency noise. We tested to verify that we can distinguish between different depths of sand in a static bed of sand. 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 started again. 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 have identified a potential problem with the sensor impedance. If a sensor needs to be replaced we need to make sure it is replaced with one that has same impedance. We built a new test cell. Additional discussion of this task is given in Section 6.

Research on Instrumentation to Measure Foam Properties while Transporting Cuttings (Task 12)

Major modifications to the DTF have almost been completed. A stop-flow cell is being designed for the DTF, the ACTF and Foam Generator/Viscometer which will allow us to capture bubble images without the need for ultra fast shutter speeds or microsecond flash system.

An agreement with a software vendor for developing a bubble imaging plug-in took place in the summer of 2003. Due to very limited progress made by the vendor, a search for a commercially-available imaging software package was initiated. A package called "Particle Analysis" was found and appeared to be promising. Section 7 discusses extensive

modifications to the Dynamic Testing Facility and a much improved method for generating foam.

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

There has been no activity on task 1S during this quarter.

Reorganization of our Staff

In this quarter we have reorganized our staff. Accordingly, the principal investigator Dr. Troy Reed has been replaced by Dr Stefan Miska. Dr. Mengjiao Yu and Dr. Ramadan Ahmed have been assigned as research associates of ACTS.

SUMMARY OF CURRENT TASKS FOR ACTS PROJECT

This is the first quarterly progress report for Year-5 of the ACTS Project. It includes a review of progress made in: 1) Flow Loop construction and development and 2) research tasks during the period of time between July 1, 2003 and September 30, 2003.

This report presents a review of progress on the following specific tasks:

- a) Design and development of an Advanced Cuttings Transport Facility (Task 4 and 5): Addition of a Pipe Rotation System and Articulated Mast. Task 4 has been completed.
- b) New 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) Foam Texture while Transporting Cuttings. (Task 12)
- f) Viscosity of Foam under EPET (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. Progress 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.

2. ACTF DESIGN AND CONSTRUCTION ACCOMPLISHMENTS (TASKS 4 & 5)

The Quarter began with installing the new drill pipe, hooking up the new hydraulic power unit, completing the pipe rotation system, and making the new SWACO choke operational. Moreover, detailed design work is proceeding on a system that inclines the test section. The inclination system is expected to vary the angle-of-inclination between horizontal and vertical. This capability will enable cuttings-transport tests at different hole-inclination angles and provide simulation of an important drilling parameter. The plan is to place the test section on a mast that will be pivoted on the existing concrete pillar. Two large hydraulic cylinders will be used to incline the mast. Also safety issues are being addressed regarding the mast, mast elevation, and the proximity of the test loop to the property line.

2.1 Installing Equipment for Drill Pipe Rotation Capability (Task 4)

Installations of the new drill pipe and rotating facility were completed and a series of shake-down tests were run to commission this new system and make it fully operational. Incoming piping to the test section was re-routed to make room for the pipe-rotation equipment. As seen in Figure 2.1, a hydraulic motor was installed to rotate the drill pipe. This arrangement gives the system flexibility and compactness, which are required for inclining the test section. A 40 HP electric driven pump was installed to supply the hydraulic power to the motor. This pump will also power hydraulic cylinders for the articulated mast.

Figure 2.1 Hydraulic Power Unit with the Pipe Rotation System

The drill pipe is equipped with centralizers in order to get more or less a concentric geometry in the test section. In total 6 centralizers were placed in the 73 ft long drill pipe. A centralizer and drill pipe assembly is presented in Figure 2.2.

Figure 2.2 Drill Pipe and Centralizer Assembly

2.2 Construction of Inclination Facility (Task 5)

The feature item for this year's additions is inclination of the test section. As has been planned since the inception of this 5-year program, the flow loop will include a mast section which pivots on the existing concrete pillar and is elevated by two large hydraulic cylinders as shown in Figure 2.3.

Figure 2.3 Articulated Mast

At the writing of this report we have located several "30-ton" mast sections that came off of a Lorain crane. The mast sections, which are shown in Figure 2.4, have been surplused by a local cartage company. The masts are now being traced back to the manufacturer and their design is being analyzed for use in our loading conditions.

Figure 2.4 Mast Sections Surplused by a Local Cartage Company

2.3 Flow-loop Modifications

The remainder of our time has been taken by managing the remainder of any uncompleted tasks to assure the functionality of the flow-loop. Accordingly, the installed SWACO choke, which is shown in Figure 2.5, was commissioned and made operational. The choke will be mainly used to regulate the pressure in the test section during the high pressure test.

Figure 2.5 SWACO Choke

2.4 Construction of Canopy

We are adding an extension to our existing canopy. The new canopy, which is shown in Figure 2.6, is going to cover parts of the facility. It does not cover the injection and removal towers, and area reserved for the articulated mast. After the construction of the canopy, we will be able to run some experiments in the winter time.

Figure 2.6 Extension to the Existing Canopy

2.5 Plans for the Next Quarter

1. Obtain bids to build the inclination facility of the flow loop.
2. Finalize modifications to flow-loop piping around the Injection and Separation Towers in order to minimize the effects of connections on measurements of changes in weights of both towers during cuttings-transport tests.
3. Finalize the modification of cuttings injection system.

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

INVESTIGATORS: Mark Pickell and Leonard Volk

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 The Need for New Instrumentation and a Process

Important findings from flow-loop tests with foam (Task #9) have identified the need to have an instrument that can generate foam with a controlled bubble size and rheological properties. This has led to the development of a new concept for achieving these objectives. In particular, there is currently a need for an instrument that can generate a foam and measure its viscous properties. The instrument should be capable of controlling: i) foam quality ii) pressure and temperature iii) concentration of surfactants and other additives, and iv) bubble size. A survey of different manufacturers of viscometers and rheometers revealed that there is currently no commercially available instrument of this type.

3.3 Progress

3.3.1 Foam Generator

According to the plan, the manufacturing of prototype Foam Generator Cell has been completed and delivered by Temco. The remaining components for the prototype Foam Generator have been obtained and assembled. The Foam Generator Cell assembly is presented in Figure 2.7.

Figure 2.7 Prototype Foam Generator Cell

Work is currently underway to calibrate the system. The reason this unit is called a prototype is primarily because the containment cell has been made of plastic to allow us to observe the foam generation process and refine the propeller and foam flow patterns. Because this prototype is made from plastic, the high temperature part of the Foam Viscometer will not be constructed until after sufficient work has been done with the prototype to be satisfied that no further design changes will be forthcoming.

The Foam Generator Cell is designed to work with couette-type rotational viscometer (Thermo-Haake RS300), which is shown in Figure 6.8. Currently the foam generator has not yet been hooked up to the Foam Generator because it is still being used with the Dynamic Test Facility (DTF) flow loop. The DTF was developed as a part of Task #12 to investigate the texture of drilling foams.

Figure 2.8 Rotational Viscometer (Thermo-Haake RS300)

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

INVESTIGATOR: Aimee Washington (MS Student)

3.3.2.1 Introduction

In the petroleum industry, foams are used when drilling wells in low pressure oil or gas reservoirs. In such cases, the higher weight of conventional drilling fluids can force solids and other debris into the producing formations and reduce production from a well. Foams are used in this situation because their densities are much lower, and well pressures can be maintained below formation pressures, i.e., underbalanced. This is a relatively new drilling technique and therefore, not much research has been done on foams. The overall purpose of this project is to characterize foam and provide new data that will help drilling engineers achieve better results.

A major factor that must be considered when studying the behavior of foam is the phenomenon of “wall slip”. In order to quantify this phenomenon, a variety of roughnesses must be applied to the surfaces that the foam is in contact with, while torque measurements are being made. Roughnesses that are uniform and easily quantified will be used in this study. The RS300 Rheometer first needs to be calibrated, and then preliminary tests should be run using commercially available foams. Finally, the dynamic testing facility will be connected to the RS300 Rheometer, and the behavior of dynamic foam, one that is moving through the Rheometer, will be tested over a range of surface roughnesses on the cups and rotors in order to define the effects on torque measurements of foam. It is expected that “wall slip” will decrease as roughness increases. The required minimum surface roughness to eliminate “wall slip” is also expected to be a function of foam quality (ratio of gas to total foam volume), bubble size, and the viscous properties of the liquid phase.

3.3.2.2 Objective

The purpose of this project is to investigate the phenomenon of foam wall slip and how this affects the measured torque of foams. In the RS300 Rheometer, an inner cylinder rotates inside a cup. Typically, foams form a liquid film at solid surfaces. This layer inhibits the shearing of the foam, which causes the torque reading to be lower than the true value. This project investigates the addition of wall roughness over all surfaces that contact the foam. This allows the liquid layer to sit inside the roughness elements, while the protrusions from the roughness contact the foam causing it to be sheared. This should allow the viscometer to give more accurate reading for shear stress and shear rate.

3.3.2.3 Experimental Section

Rough Surface Application

The project began by researching different ways to apply a uniform, reproducible coating to the outside surface of the rotor and the inside surface of the cup without significantly changing the 2mm gap that was originally between them. Many possibilities were explored. First, alumina was considered. It had the advantage of producing a very thin layer coating, which would only slightly change the gap space inside the rheometer. In order to add different roughnesses, a variety of sands with differing grit sizes or different size clusters of alumina were to be added to the alumina before application. Problems arose with the application of the alumina because it did not adhere well to the stainless steel. Different techniques were researched including plasma spray, thermal spray, and “dip, spin and bake”. The plasma spray and thermal spray were unfeasible due to the expense, and the “dip, spin, and bake” method produced a flaky coating, which would not meet the needs of this project. Questions of durability and reproducibility also discouraged the use of alumina as our coating.

Secondly, using an epoxy as an adhesive to fix sandpaper onto the cup and rotor was considered. The uniformity of the sandpaper and the change in gap width also made this an unacceptable technique. Thirdly, adhering sand to a flat surface such as foil, and then applying it to the cup and rotor was considered. This also conflicted with gap width and adhering it to the stainless steel surface that would be submerged in a liquid for long periods of time was a concern. Finally, the decision was made to apply a rough surface by

machining grooves into the surface with a designated depth and design to provide a reproducible roughness. By varying the depth and width of the design, different surface roughnesses are produced.

Quantification of Rough Surface

The next step was to quantify these roughnesses in a standardized manner. This required researching the instruments used by the surface coatings industry. Many instruments were explored before deciding on the SurfTest 401. This instrument will provide a precise and acceptably accurate surface roughness measurement, not only for our rotors and cups, but also for the inside of the ACTS Flow Loop, in which hydraulic tests with foams are planned.

3.3.2.4 Viscometer Calibration

Available information concerning viscometers and rheometers was studied in order to better understand how the Thermo Haake RS300 works. The manuals for the rheometer were read, and the technician that was setting up the instrument was asked numerous questions. Then calibration of the RS300 Rheometer began.

The rheometer readings are based on the measured torque acting on a given rotor. In addition to the size and geometry of a rotor, the fluid being sheared, the end effects, and the bearing drag affect the torque measured by the electronic instrumentation. The basic purpose of a calibration is to quantify the magnitude of the end effects and bearing drag so that they can be subtracted from the reading in order to obtain only the torque caused by shearing the test fluid in the gap.

Cannon standardized oils of 9.493 cP, 51.92 cP, and 108.3 cP (all at 20.0 °C) were used to calibrate over a range of rotor speeds: 500, 300, 200, 100, 50, and 10 rpm. An example of the calibration spreadsheet and equations used to calibrate is provided in the Appendix. Rotational speeds greater than 300 RPM were not used for the 9.493 cP calibration oil because Taylor vortices began to form at 356 rpm. The Taylor number and its calculations are presented in the Appendix. For the purpose of this experimentation, the behavior and trends of the foam torque readings are used to draw conclusions concerning the effects of surface roughness on foam viscosity measurements.

3.3.2.5 Test Matrix

A test matrix (Table 3.1) has been devised to provide a flow chart of work that will be performed throughout this study. According to this test matrix, three types of foam formulations 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 3.1 Preliminary test matrix

	Test #1	Test #2	Test #3
Foam Formulation	0.5% F4000 by volume	1% F4000 by volume	2% F4000 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

3.3.2.6 Height of Foam Travel

It was necessary to determine how high the foam was reaching inside the cup during viscosity measurements. A moderately thick starch-water mixture was made and colored with blue dye. Stainless steel spoons were coated with this mixture and allowed various drying times. Afterwards, each spoon was gently swirled in water to see how easily the starch-dye was to remove. The starch-dye needed to be washed off but not too easily. About 25 minutes seemed to be an appropriate drying time.

The upper bearing end of the rotor and cup were painted with the starch-dye mixture and allowed to dry for about 25 minutes. Approximately 75 quality foam was then circulated through the cup and rotor at 300 rpm for about 10 minutes.

After depressurization and disassembly, the starch-dye was completely removed from the lid around the circumference of the rotor, which indicated that fluid had entered this narrow space. All of the starch-dye was washed from the cup below the fluid entrance port indicating that rapidly-moving foam was present there. The starch-dye in the lid above the rotor magnet was intact indicating that foam didn't enter here or at least that fluid circulation was very slow. Starch was mostly, but not completely, removed from the remainder of the lid and the rotor above the point of fluid entrance. This indicates that foam had entered this region but was not being readily washed with the bulk of the foam. Most likely collapsing foam was responsible for this incomplete starch-dye removal.

3.3.2.7 Results and Discussions

The decision was made to machine the cup and rotor in order to produce a uniform, reproducible roughness to the outside of the rotor and the inside of the cup. This also allows the original gap inside the Rheometer to remain unchanged. Samples of surface roughness were made in order to decide the best roughnesses to begin with compared to the bubble sizes in the foam that will be used. The Surftest 401 has been purchased to quantify these surface roughnesses. Also, the RS300 Rheometer is set up and calibrated. The preliminary testing has begun in order to determine the final procedure, while four new cup and rotor sleeves are being machined with rough surfaces. A surface roughness of 0.025 in has been applied to the rotor magnet and the bottom of the cup. Drainage grooves have also been applied to the bottom of the cup to promote drainage of liquid that occurs as a result of foam breakdown. Surface roughness of 0.025 in and 0.010 in have been decided upon for the first two rotor and cup sleeves. The remaining two rotors and cup sleeves will remain smooth for the time being until experimentation indicates whether smoother or rougher surfaces are necessary, and another project will take on this task. Testing with foams has begun on the DTF flow loop. The 0.5%, 1.0%, and 2.0% concentrations of foam

were tested on the “smooth” (the cup and rotor with roughness only around the magnet and on the bottom of the cup) set of the cup and rotor

3.3.2.8 Project Status and Future Work

Table 3.2 Project status

Literature Review	Coatings	100%
	Surface Measurement	100%
	Rheometer/Viscometer	100%
	Foams	80%
Surface roughening	Machining	10%
Surface Measurement Instrument		100%
Calibration	#1 Canon Standardized Oil – 9.493 cP	100%
	#2 Canon Standardized Oil – 51.92 cP	100%
	#3 Cannon Standardized Oil – 108.3 cP	100%
Foam test on DTF flow loop		80%
Reports	DOE	80%
	Final	40%

Future Work

1. Two cups and rotors with 0.025 inches and 0.010 inches respectively surface roughnesses are being machined.
2. In a future research project, the two remaining cup and rotor sleeves will have rough surfaces applied in the amount indicated by previous experimentation.
3. Finally, in a future research project, the foam generator will be connected to the RS 300 Rheometer, and the viscosity of dynamic foam will be tested against varying degrees of rough surfaces on the cup and rotors in order to obtain an accurate viscosity for particular foam over a range of elevated temperatures and pressures.

References

1. Haake, Thermo. “Instruction Manual RheoStress RS300”.
2. Herzhaft, Benjamin. “Correlation between Transient Shear Experiments and Structure Evolution of Aqueous Foams” 247, Journal of Colloid and interface Science, 2002.
3. Khan, Saad A. “Foams” Marcel Dekker, Inc, 1996.
4. Schramm, Laurier L. “Foams: Fundamentals and Applications in the Petroleum Industry” American Chemical Society, 1994.

Appendix

Calibration spreadsheet for first ten data points of 9.493 cP

Calibration oil filling the cup completely at 20 °C and 600 rpm

Mm [μ Nm]	f [cP]	$\dot{\gamma}$ [1/s]	τ [Pa]	T [°C]	t [min]	Shear Rate	Me(Nm)	Mm-Me (Nm)	Me/Mm	Shear stress	Cal. viscosity
0	0	609.1	0	20	0.005365	607.63417	-0.00094	0.0009394	#DIV/0!	5.7682712	9.493
2500	25.602	600	15.36	19.9	0.03574	598.55607	0.001575	0.0009253	6.3E-07	5.6820928	9.493
2570	26.343	600	15.81	19.9	0.06608	598.55607	0.001645	0.0009253	6.4E-07	5.6820928	9.493
2510	25.697	600	15.42	19.9	0.0965	598.55607	0.001585	0.0009253	6.31E-07	5.6820928	9.493
2450	25.042	600.1	15.03	19.9	0.127	598.65583	0.001524	0.0009255	6.22E-07	5.6830398	9.493
2470	25.256	600	15.15	19.9	0.157	598.55607	0.001545	0.0009253	6.25E-07	5.6820928	9.493
2570	26.33	600	15.8	19.9	0.187	598.55607	0.001645	0.0009253	6.4E-07	5.6820928	9.493
2410	24.623	600	14.77	19.9	0.218	598.55607	0.001485	0.0009253	6.16E-07	5.6820928	9.493
2590	26.544	600	15.93	19.9	0.248	598.55607	0.001665	0.0009253	6.43E-07	5.6820928	9.493
2470	25.267	600	15.16	19.9	0.278	598.55607	0.001545	0.0009253	6.25E-07	5.6820928	9.493
2480	25.343	600.1	15.21	19.9	0.309	598.65583	0.001554	0.0009255	6.27E-07	5.6830398	9.493
2460	25.187	600	15.11	19.9	0.339	598.55607	0.001535	0.0009253	6.24E-07	5.6820928	9.493

Equations for Calibration

Elements given by rheometer software

Mm = Measured torque (uNm)
A = rpm
Pa = Pressure (Psi)
T = Temperature (°C)
t = time (min)

Elements Calculated by spreadsheet

Shear Rate = $\frac{(2\pi A')}{60} \cdot \frac{((\text{radius of rotor})^2 + (\text{radius of cup})^2)}{((\text{radius of cup})^2 - (\text{radius of rotor})^2)}$

Me = Torque due to end effects (Nm) = $(Mm \cdot 10^{-6}) - ((\text{viscosity}/10^3) \cdot \text{shear rate} \cdot 2 \cdot \pi \cdot \text{radius of rotor}^2 \cdot \text{height of bob})$

Mm-Me = Measured torque minus torque due to end effects (Nm)
Me/Mm = Torque due to end effects divided by measured torque
Shear Stress = $(Mm - Me) \cdot (1/2 \cdot \text{bob height} \cdot \text{radius of bob}^2)$
Calculated Viscosity = Shear stress/Shear rate * 1000 (cP)

Taylor Number

Taylor Number = $\frac{(2\pi \cdot \text{rpm})}{60} \cdot \frac{((\text{radius of rotor})^{1/2}) \cdot ((\text{radius of cup} - \text{radius of rotor})^{3/2})}{\text{kinematic viscosity}}$

The Taylor of vertices begin to form at 41.3. Therefore, discard data with a Taylor number greater than 41.3 and calculate the largest rpm that can be used by solving for the rpm that corresponds to 41.3.

In our case, with the 9.493 cP standardized calibration oil

$41.3 = \frac{(2\pi \cdot \text{rpm})}{60} \cdot \frac{((18)^{1/2}) \cdot ((20-18)^{3/2})}{10.83}$
rpm = 356

Due to this limitation, this fluid should only be used at rpms less than 356.

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

INVESTIGATOR: Zhu Chen

4.1 Summary

This research project is focused on the experimental determination and numerical prediction of volumetric requirements for effective cuttings transport with foam in horizontal wellbores (initially without pipe rotation), a mechanistic cuttings transport computer simulator will be developed, and this simulator will be compared with experimental data from the ACTS Flow Loop.

The emphasis during this period is literature review and preliminary work on cutting transport model development, and preparation for flow loop experiments.

4.2 Preliminary work on cuttings transport model development

Over the past 20 years or so, considerable effort has been expended on solving cuttings transport problem in horizontal and highly inclined wellbores. Two main approaches were used by researchers, one is experiment and correlation approach, the other one is theoretical approach in which one, by analyzing the forces involved in the situation with the use of basic principles, develops a set of equations and then solves them with certain physical or mathematical assumptions.

Based on the previous foam experiments in the LPAT flow loop by Evren Ozbayoglu (for foam flow without polymers added) even at high shear rate, a three-layer-flow pattern was observed. The three layers are a stationary bed of particles with uniform concentration, a dispersed layer in which particle concentrations are varied, and an essentially clear foam flow layer (suspended layer) on top. Based on his observations, Ozbayoglu developed a three-layer model to predict cuttings transport efficiency.

Nonetheless, the three-layer model itself is not good enough for all foam flow conditions. As foam flow rate increases, more and more particles are picked up and the stationary layer will become thinner and thinner. Eventually the stationary bed will disappear, leaving behind the dispersed and suspended layers. A two-layer model will be suitable for this kind of flow conditions. With further increases in annular foam flow velocity, all the particles will be transported in a heterogeneous or homogenous suspension mode, and it becomes a single-layer flow pattern. The schematic representation of different modes of transport is shown in Figure 4.1. As we can see from the figure, a better representation of cuttings transport must take into account different flow patterns. Obviously, the three-layer model can't describe all the different flow patterns existing during particle transportation. Therefore, a "unified model" should be used instead of a single model. The unified model should be capable of predicting flow pattern and cuttings transportation in a wide range of operating conditions.

Figure 4.1 Schematic Representation of Different Modes of Transport (After Nguyen & Rahman)

This concept of “unified model” is very similar to that for gas-liquid two-phase flow. In two-phase flow, the transition boundary for different flow patterns was first determined, and then for each flow pattern, a corresponding combined momentum equation was solved for pressure drop calculation. Similarly, here we can develop transition boundary conditions and predict the transition from three-layer to two-layer or single-layer. Once we know the flow pattern, equations of mass conservation, momentum conservation and closure relationships can be combined to determine cutting bed height, in-situ cuttings concentration, frictional pressure drop, etc.

The unified model for cuttings transport with foam should be capable of modeling three-layer, two-layer and single-layer flow patterns and calculates in-situ cuttings concentration. The major assumptions for developing the unified model are:

1. Isothermal and steady-state foam flow.
2. Uniform cuttings size
3. Porosity of the stationary bed is constant
4. Pipe rotation is not included.
5. Physical and rheological properties of foam changes along wellbore.

Development of the unified model is in progress. The basic method and equations needed for the development of the model have been investigated.

For the three-layer model, there are: two mass conservation equations, one for foam phase, and one for cutting phase; two momentum equations for the dispersed and suspended layers; one equation for the dispersed layer velocity and one equation for the mean cuttings concentration in the dispersed layer. Therefore, six equations will be used to determine six unknowns. In practical applications, the unknowns are mean flow velocities of the suspended and dispersed layers, mean concentration for the suspended layer, dispersed layer height, stationary bed height, and pressure gradient.

For the two-layer model, there are: two mass conservation equations, one for foam phase, and one for cutting phase; two momentum equations for dispersed and suspended layers; one equation for the mean cuttings concentration in the suspended layer. In this case, we have five equations and five unknowns. In practical applications, the unknowns are the

mean flow velocities of the dispersed and suspended layers, mean concentration for the suspended layer, dispersed layer height, and pressure gradient.

For the one-layer model (or fully suspended flow), since the delivered cuttings and foam has the same velocity, the momentum equations are reduced to one equation, and pressure gradient can be solved.

4.3 Preparation for Flow Loop Experiments

4.3.1 Scope of Experimental Test

In this experimental study, at first, baseline test will be conducted with water. Water will be pumped through the 2", 3", 4" pipes and 6"x3.5" annulus, water flow rate will be varied and the pressure differential, temperature, flow rate will be recorded. This experiment can serve as a method to check whether all the transducers give correct reading, and the data can be used to calculate pipe roughness and friction factor.

When we finish the water tests, foam tests will be conducted without cuttings injection. The purpose of the foam test is to obtain the rheological parameters for foam, and study the effect of quality, temperature and pressure on foam rheology, as well as to study wall slip effect. If possible, frictional pressure loss predictions of the hydraulic model developed by Affanso Lourenco will be checked.

Once we finish the first two tests and gain some experience on ACTS Flow Loop and foam flow characteristics, experiments on cutting transport with foam will be conducted. The purpose of these experiments is to study the effect of foam quality, temperature and pressure on cutting transport capacity of aqueous and polymer-based foams. Accordingly, the proposed test matrix has 42 tests that covers a wide range of test pressure, temperature, foam quality and foam flow rate.

4.3.2 Foam Formulation

As mentioned in previous DOE quarterly report, the original foam formulations proposed in the study were:

Formulation A: Bachman chemical's FF-4000 foamer 1% by volume + 2.5 g/L Xanthan Gum + 1 g/L PAC-R+ 0.5 g/L NaCl (pH 9)

Formulation B: Bachman chemical's FF4000 foamer 1% by volume + 2 g/L Xanthan Gum + 0.5 g/L NaCl (pH 9)

An important characteristic of these two formulations is that polymers are added, which is different from previous experiments done in TUDRP studies. These two formulations were reported to have been used in practical underbalanced drilling operations. The initial experimental plan is to start foam rheology test with these two formulations, then screen one of these two formulations and choose only one to do all the cuttings transport experiments because of limited time frame.

According to these two foam formulations, Bachman Chemical's Foam-breaker 5088 will be used, and 10% v/v of the surfactant injection rate will be used for high quality foam and 5% v/v for low quality foam. Alkyl Ether Sodium Sulfonate type of foam surfactant will be used and the dosage is 1% v/v of liquid flow rate.

Recently, we have run out of Bachman Chemical's Foam-breaker 5088 and surfactant, and Bachman Service will no longer be able to provide chemicals for TUDRP. One of the ACTS member companies, Weatherford International Inc., which is a leading company in the field of underbalanced drilling, is willing to donate their chemicals and share their foam formulation for this foam research project.

The advantage of using this new foam formulation is obvious, this foam formulation uses polymers, which shares the advantage of above-mentioned foam formulations A and B. Moreover, since this foam formulation has also been widely used in practical drilling practice. Therefore, the study of cuttings carrying capacity of this foam will be meaningful and more representative. Meanwhile, technical support is available from Weatherford. Two foam experts came to TUDRP and discussed relevant technical problems of this foam system.

The new foam formulation that will be used in my foam cuttings transport experiment is:

Water + 0.2% liquid HEC polymer + 0.1% liquid PAC polymer + 0.13% foamer + 2 ppm NaOH (raise pH to 9.5-10).

For breaking the foam, 0.3-0.6% defoamer will be injected downstream of the test section. A detailed estimation of the required chemicals, which is presented in Table 4.1, has been forwarded to Weatherford. This estimation is based on average liquid injection rate of 20 gpm for a given experiment and 2 hours average test run time. Hence, for a given experiment we need 2400 gallons (57.14 bbls) of water.

Table 4.1 Estimation of the required chemicals for foam test

Chemical	Volume Percent	Required for 1 Test (bbls)	Required for 42 Tests (bbls)	Ordered Quantity (bbls)
HEC polymer	0.2%	0.11	4.70	10
PAC polymer	0.1%	0.06	2.56	5
Foamer	0.13%	0.07	2.99	6
Defoamer	0.6%	0.34	14.53	14-29
NaOH	0.0002%	0.00	0.0001	0.0001

Consultations with Weatherford foam specialists are still going on. The relevant technical issues such as how to introduce the polymers into the flow loop and neutralization of waste liquid before disposal are in progress.

4.3.3 Cutting Transport with Foam (test input data calculation)

Unlike single phase flow, a test matrix can not be designed without pre-calculation of experimental input data. For cuttings transport with foam under EPET conditions, some calculations must be made before carrying out actual experiments. Spreadsheets using Mathematica and Microsoft Office EXCEL were developed to calculate the experiment input data. The calculation procedure is as follows:

1. Input desired foam velocity; three different velocities representing high, medium and low foam flow rate will be selected for each foam quality.
2. Input desired foam quality, Γ , test section pressure and temperature.
3. Calculate the foam flow rate in the test section as foam velocity * cross section area.
4. Calculate the amount of air needed for a specific foam quality experiment.
5. Calculate the liquid flow rate. Liquid flow rate is controlled by the liquid injection pump during an experiment.
6. Calculate the gas flow rate at standard conditions, Q_{std} , using the ideal gas equation. Q_{std} is monitored and recorded during the experiment.
7. Calculate the surfactant and polymer injection rate according to the foam formulation.
8. ROP will be set in the range of 50-80 ft/hour.

In this way, all the required experimental input data, such as liquid injection rate, gas injection rate, temperature, pressure, and surfactant and polymer injection rate are determined for a foam experiment with a given foam quality and foam flow velocity.

4.3.4 Test Procedures

Each foam flow test is a combination of a rheology test and a subsequent test of cutting transport. The advantage of running these two tests under the same situation is to allow accurate measurement of foam rheology. As shown in Figure 4.2, the test fluid can flow through the rheology section (2-inch and 3-inch pipes) before entering the annular and 4-inch pipe sections.

Figure 4.2 Simplified Schematics of the Flow Loop

The foam rheology test will be followed by the cuttings transport test. During the cuttings test, foam flows directly to the annular test and cuttings will be injected from the injection tower by an auger. Once cuttings bed buildup in the annulus reaches steady state conditions, liquid holdup will be made by using two quick-closing valves, which are installed at the inlet (V1) and the outlet (V2) of the annular test section as seen in Figure 4.2. The bypass valve (V3) will be opened approximately one second earlier than the two valves to bypass the annular and 4-inch pipe sections. This allows the fluid to flow directly to the removal tower. When the two valves are closed simultaneously, a certain amount of foam and cuttings will be trapped in the test section. The trapped foam will be expanded to an air expansion tank and thus the volume of foam inside of the annular section can be measured. The cuttings concentration in the test section can be determined indirectly. Once we finish foam expansion, we will flush all cuttings downstream of the annular test section to the removal tower, and transfer cuttings back to the injection tower.

Similarly, the cuttings accumulated in the annular section can be flushed back to the removal tower. After sufficient flushing time the pressure drop across the annular section and gross weight of the removal tower become constant. Finally the cuttings accumulated in the removal tower will be flushed into a container and measured using a scale. The efficiency of cuttings transport with foam will be evaluated from the cuttings concentration in the test section. The lower the cutting concentration in the annulus, the better the cutting transport capacity. There are three ways to calculate cuttings concentration in the test section: i) foam expansion; ii) nuclear densitometer reading; and iii) directly weighting the cuttings with a scale. The nuclear densitometers measure the mixture density. Knowing cuttings density, foam quality, temperature and pressure, we can determine the cuttings concentration.

During the experiment, water will be injected using a metering pump placed upstream of the multiphase pump. Compressed air and water will be mixed at the entrance of the multiphase pump. The multiphase pump compresses the air-water mixture to get the desired air flow rate and test pressure. The two choke valves (CV2 and CV3) in the return line will be used to control the backpressure.

The surfactant injection pump will be used to inject surfactant and polymer solutions downstream of the multiphase pump. There are 3 options for injecting polymers, but the most desirable method is to pre-mix all the chemicals and polymer solutions and inject them together with surfactant injection pump. Capacity of the surfactant injection pump is 0.84 gpm. Injection rate of chemicals and polymer solutions required for the test is less than 0.2 gpm. Hence, the surfactant injection pump capacity is enough for this purpose. The defoamer will be injected downstream of the 4 inch pipe and upstream of removal tower. In order to save chemicals, flushing of the cuttings from the annulus and 4-inch pipe section will be done by fresh water.

4.4 Future Work

1. Conduct flow loop tests with the ACTS Flow Loop.
2. Data analysis of experiments.
3. Continue cuttings transport with foam model development.

5. STUDY OF CUTTINGS TRANSPORT WITH AREATED 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 Re-Calibration of Nuclear Densitometers

Re-calibration work for two nuclear densitometers has been finished. Instead of having plastic pipe under the densitometers, the inner pipe in the annular section has been replaced by thick-wall steel drillpipe. In order to get correct reading, the two nuclear densitometers had to be re-calibrated. A calibration rig shown in Figure 5.1, was used for

Figure 5.1 Calibration Rig

re-calibrating the densitometers. Instead of two-point calibration, an 8-point calibration procedure was used to generate a calibration curve. Table 5.1 shows the mixture

combinations were used in this work. After the calibration curves were re-generated, a known density mixture (gas-liquid-cuttings) was placed in the calibration rig to test the performance of the curve. The densitometer reading was 1.02 for a mixture with specific gravity of 1.0. Figure 5.2 shows the calibration curve for densitometer #1.

Table 5.1 calibration curve for densitometer #1

	Densitometer #1 (downstream)			Densitometer #2 (upstream)		
	RAW COUNTS	Calculated SpG	Measured SpG	RAW COUNTS	Calculated SpG	Measured SpG
100% of air	37165	0.0000	0.000	37120	0.000	0.000
25% water	34150	0.2500	0.376	34291	0.250	0.352
50% water	32420	0.5000	0.595	32494	0.500	0.586
75% water	31010	0.7500	0.780	31140	0.750	0.774
100% water	28510	1.0000	1.155	28642	1.000	1.149
25% cuttings & water	26500	1.2480	1.455	26748	1.248	1.468
50% cuttings & water	25650	1.4970	1.599	25610	1.497	1.665
75% cuttings & water	24500	1.7440	1.795	24395	1.744	1.871

Figure 5.2 Calibration Curve for Densitometer#1

5.3 Installation of Drillpipe Rotation System

From June to August, 2003, the ACTS flow loop was shut down for installing drill pipe rotation system, this task was about one month behind schedule. After installing the rotation system, water flow tests were conducted with drill pipe rotation. The drillpipe was rotated at 50 RPM and 100 RPM. Figure 5.3 shows the measured rotational speed (RPM) of the drill pipe versus time.

Figure 5.3 Drillpipe Rotation Test Data

5.4 Evaluation of Weight Measurement System

As discussed in the last DOE quarterly report (April-June, 2003), the accuracy of weight measurements for cuttings in the annulus was evaluated. Three different types of evaluation tests were conducted. The first test type was to transport cuttings from the injection tower to the collection tower at 215 GPM water flow rate and low pressure. No air was injected. There was no valve operation during the flow test. After certain amounts of cuttings were injected into the flow loop, the injection valve was shut off to stop injection of cuttings. Water was kept flowing through the annulus and 4-inch pipe to flush the residual cuttings to the collection tower. That means almost all the cuttings being injected from the injection tower were delivered to the collection tower. Then those cuttings were flushed out from the collection tower to a 50 gallon plastic container. After water was drained out, the container with cuttings was weighed on a scale. The test was repeated. The results of the tests are presented in Table 5.2. The above data indicate that the load cell measurements for the injection tower and collection tower are fairly good under low pressure flow conditions.

Table 5.2 Result of low pressure flow load cell evaluation tests

		Load Cell measurement (Lb)	Scale Reading (Lb)	ERROR (%)
#1	Injected	518	501	3
	collected	551	501	10
#2	Injected	539	546	-1
	Collected	487	546	-10

The second type of test was conducted to study performance of the load cell under high pressure flow conditions. Water flow rate was 100 GPM and back pressure was set to 100 psi. No air was injected. Cuttings were injected at 50 ROP. When steady state was established in the flow loop, the inlet and outlet valves of the annular section were closed to trap the cuttings in the annulus. The cuttings accumulated in the 4-inch pipe were flushed to the collection tower. After the 4-inch pipe was completely cleaned, the cuttings in the removal tower were flushed to 50-GAL plastic container and weighed on a scale. Similarly, the cuttings deposited in the annular section were flushed to the removal tower. When the annular section was completely cleaned, the cuttings accumulated in the removal tower were flushed into containers for weight measurement. Two additional identical tests were performed at high pressure flow conditions. The results of the high pressure tests are presented in Table 5.3.

Table 5.3 Result of high pressure flow load cell evaluation tests

		Load Cell measurement (Lb)	Scale Reading (Lb)	ERROR (%)
#1	Cuttings in 4" pipe	178	208	-14
	Cuttings in Annulus	304	354	-14
#2	Cuttings in 4" pipe	117	196	-40
	Cuttings in Annulus	442	515	-14
#3	Cuttings in 4" pipe	/	/	/
	Cuttings in Annulus	256	300	-16

From Table 5.3, we can see that the load cell measurement error increases as pressure increases. During the high pressure test run, we have observed that flow disturbance in the flow loop significantly affects the load cell measurement. Figure 5.4 shows the weight changes of the injection tower and collection tower during the test time interval. As seen from the figure, the load cell measurement of weight change in the collection tower during annular flushing shows unreasonable variations with time. Therefore, the load cell measurements are unacceptable for measuring the cuttings weight in the annulus during the high pressure test. In order to resolve this problem, we are planning to install high pressure flexible hoses on pipelines connecting the flow loop to the towers.

The third type of test was to evaluate the effect of gas phase on the load cell measurement. For this test, the flow rates were: 150 GPM of water and 80 SCFM of air; pressure was 200 psi; temperature was 120 F; cuttings injection rate was 50 ROP. These data points were also done four times during the previous test runs (May, 2003). The only difference at this time is cuttings were flushed to the plastic container and weighed on the scale. The procedure for the most recent test was: i) Establishing a steady-state condition; ii) Trapping

the cuttings and the fluid in the annulus using the inlet and outlet valves; iii) Flushing cuttings from the 4-inch pipe to the collection tower; iv) Transferring cuttings from collection tower to injection tower; v) Flushing cuttings from the annulus to collection tower; vi) Opening the discharge valve to flush cuttings from collection tower to a small container; vii) Disconnecting the container from the peripheral pipes; viii) Draining water from the container; and ix) Weighing the container on the scale.

Figure 5.4 Cuttings Injection and Collection Weight

After completion of the test run, we found that the cuttings accumulated in the annulus were weighed 100 lb. The same test was repeated again and the cuttings' weight in the annulus was found to be 70 lb. Table 5.4 presents load cell measurements of the three-phase tests performed previously and the scale readings from the recent tests. By comparing the average value of the recent scale measurements (i.e. 85 lb) with the average value of previous load cell measurements (i.e. 233.5 lb), we can easily evaluate the reliability of load cell measurements. According to Table 5.4, the average load cell measurement shows more than 100% difference from the average scale measurement.

Table 5.4 Comparison of load cell measurements with scale measurements

Test No.	Load Cell Readings	Scale Measurement
1	251	100
2	317	70
3	221	
4	273	
5	106	
Average	233.6	85

Figure 5.5 presents plots of recorded test data. The figure indicates that the injection rate and removal rate were constant and nearly equal when the steady-state was maintained. As seen from the figure, it is apparent that during flushing of the annular section, the load cell readings were highly influenced by the piping stress change and became unstable.

Figure 5.5 Test Data Recorded during Injection and Flushing

From these three types of test, we can draw the following conclusions:

1. Load cell weight measurements are fairly good under low pressure flow condition.
2. At high pressure, the load cells performance become unsatisfactory.
3. Rigid pipe connections have the ability to transfer the stress in the piping system to the load cells, which cause inaccurate reading.
4. Flexible hoses or other type of flexible connection should be installed to minimize external forces acting on the towers.
5. Flushing to a container and scale weighing of cuttings will continue until accurate load cell measurements or concentration measurements (densitometer, gas expansion and ultrasonic method) become operational and reliable.

5.5 Installation of View Port

Three view ports were installed when the ACTS flow loop was shut down for installation of the drillpipe rotation system. Two of them were installed in the 2-inch and 3-inch pipes. The third one was installed in the annular section. Visual observations of the annulus and the pipe sections is now possible while running an experiment. Interesting gas-liquid flow patterns and moving cuttings dunes were observed through the view port. The dunes were moving slowly relative to the flow field. The ability to see the cuttings flow pattern is very important for mathematical model development and theoretical work. It helps investigators describe the physics of cuttings transport phenomena more reasonably. Moreover, flow pattern observation can be used to develop flow regime maps that can be very practical to select appropriate models for predicting cuttings transportation under borehole conditions. Figure 5.6 presents a photo of the view port during a test run. As seen from the figure, the view port clearly shows the presence of a cuttings bed in the annulus. With the view port we can see about 70% of the annular cross section.

Figure 5.6 View Port in the Annulus

5.6 Modified Test Matrix

Based on the visual observation of cuttings movement in the annulus, the test matrix was modified to meet the research interests. It has already been found that the annulus is sufficiently clean when water flow rate reaches 150 GPM. There is no need to run tests at a higher flow rate than 150 GPM. Tests will be conducted in a lower range of water flow rates. Our interests are focused in the range of 80 GPM to 150 GPM. Table 5.5 shows one set of the modified test matrix at 120° F and 200 psi (base case). The pressure and temperature will vary in different test sets. Test temperatures and pressures will be in the range of 80° F to 180° F and 180 psi to 500 psi respectively. The gas-liquid ratio ($GLR = Q_g/(Q_L + G_g)$) ranges from 0.0 to 0.38.

Table 5.5 Modified test matrix for the basecase

T(F°) P(psi)	120		120		120		120	
	Qg (SCFM)	QL (GPM)	Qg (SCFM)	QL (GPM)	Qg (SCFM)	QL (GPM)	Qg (SCFM)	QL (GPM)
200	0	80	0	100	0	120	0	150
	GLR=0		GLR=0		GLR=0		GLR=0	
200	17	80	21	100	24	120	33	150
	GLR=0.12		GLR=0.12		GLR=0.12		GLR=0.12	
200	39	80	49	100	62	120	78	150
	GLR=0.24		GLR=0.24		GLR=0.24		GLR=0.24	
200	76	80	95	100	120	120	150	150
	GLR=0.38		GLR=0.38		GLR=0.38		GLR=0.38	

5.7 Experimental Results on Cuttings Transport with Aerated Fluids

At this stage, 70% of the planned test runs have been completed. Table 5.6 presents cuttings' weights in the annulus that were measured by flushing into a plastic container and weighing on a scale. The table shows that the cuttings accumulated in the annulus under steady state conditions range from 70 lb to 550 lb for the base case.

Table 5.6 Test result for the basecase

GLR	QL=80 GPM	QL=100 GPM	QL=120 GPM	QL=150 GPM
0.00	550	372	257	133
0.12	500	372	264	113
0.24	534	400	336	100/70
0.38	555	417	154	70

Figure 5.7 shows relative cuttings weight in the annulus versus gas liquid ratio (GLR) at different liquid flow rates. Relative cuttings weight is the ratio of the cuttings weight measured at a given GLR to that of 0.0 GLR (100% liquid flow). At 150 GPM liquid flow rate, cuttings weight in the annulus decreases as GLR increases. This means that the injection of air has a positive effect on the cuttings transportation at high liquid flow rate. However, at 120 GPM the effect of air injection on the cuttings transportation is negative for low gas-liquid ratio (i.e. $GLR < 0.25$); and the effect is positive for $GLR > 0.25$. At low liquid flow rates (80 and 100 GPM) the effect of gas injection is small.

Figure 5.7 Cuttings Weight Vs GLR

Figures 5.8 and 5.9 show, that cuttings weight and concentration decrease as the liquid flow rate increases for a given GLR. The curves clearly indicate that the cuttings weight in the annulus is sensitive to liquid flow rate. Small variation in liquid flow rate can cause significant change in cuttings transport capacity of an aerated mud.

Figure 5.8 Effect of Liquid Flow Rate on Cuttings Weight in the Annulus

Figure 5.9 Cuttings Volumetric Concentration Vs Liquid Flow Rate

5.8 Future Work

1. Continue air/water/cuttings three-phase tests at EPET conditions.
2. Any necessary loop modification.
3. Perform data analysis.
4. Continue development of the hydraulics model for cuttings transport.

5.9 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 consists of Dr. Gerald R. Kane and Dr. Kaveh Ashenayi, both registered professional engineers and professors of Electrical Engineering Department at the University of Tulsa. MS level graduate students are assisting them. These students have BS degrees in EE and CS. 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 previous version of the sensor control board developed by our team had two different kinds of noise signals that were interfering with the proper operation of the sensors. The first was a high frequency (300 kHz) ground noise that can be filtered out. The second signal was at 75 kHz. This second noise was our main problem.

We worked with an external noise elimination expert to eliminate the radiated noise. The board layout was modified and some parts were replaced. The new board has been assembled and tested. The radiated 75kHz noise is significantly reduced.

We are using a standard low pass filter to eliminate the high frequency noise. That seems to be effective.

We have also conducted tests with the static plastic pipe to evaluate sensor response.

The data collection software revision is proceeding. The software will start by allowing the user to setup the communication characteristics of the system. Then we will proceed to identify the number of boards connected. The data received from the sensor board is in the

form of ASCII characters. We developed and tested the conversion algorithm that allows us to calculate the numerical voltage value corresponding to the character combinations that are received.

We conducted more tests with the new board and software. The results still indicate we can see differences in sand concentration.

Also, tests indicate that we may not need the inner ring.

We have identified a potential problem with the sensors being used. 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.

Also, our PC used for development purposes failed. A replacement has been ordered.

A small-scale test cell was designed and manufactured.

6.4 Approach

In subtask one of the 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 setup a set of rings in the outer pipe. We will rotate the angle at which the sound is being transmitted relative to the sand bed. We will measure the sound received and compare it against sound transmitted. After 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 set up 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.

6.5 Future Work

Using a newly designed cell we will conduct two sets of experiments. First we will set up a set of rings in the outer pipe. We will measure the sound received and compare it against sound transmitted. After data processing we believe it is possible to get an acceptable picture of what is inside the pipe.

In the second experiment we will repeat the same experiment except we will use an inner ring of sensors. This consists of a ring of sensors in the inner pipe. The inner ring will act as source and the outer ring will act as receivers. We will use the same setup for calibrating the system.

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.

We will setup a uniform bed of sand at the bottom of the clear plastic pipe. Shaking the pipe and letting the sand settle in water accomplishes this. Then we will make several measurements. This process will be repeated for different sand volumes. This way we will have different heights of sand at the bottom of the pipe. We will also set up different heights of sand at an angle with respect to the sensors and collect some data. This is the static test condition.

Upon successful completion of this stage then we will proceed and introduce motion in the fluid and see how the system responds. This will be the first of our many dynamic tests.

Upon successful completion of this phase we will use the small-scale flow loop setup at north campus and test with conditions that are closer to the actual intended environment.

7. DEVELOPMENT A METHOD CHARACTERIZING BUBBLE IN COMPRESSIBLE FLUIDS (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 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 cameras referred to in the last quarterly report have been received along with a signal processing card (National Instruments) and power supply for each camera.

A stop-flow cell is being designed for the DTF, the ACTF and Foam Generator/Viscometer which will allow us to capture bubble images without the need for ultra fast shutter speeds or microsecond flash system.

An SMZ-800 Nikon stereo microscope has been received for use on the ACTF for capturing bubble images.

7.3.1.2 Dynamic Testing Facility

Major modifications to the DTF have almost been completed. These include the following:

- Addition of a bypass loop for the optical cell, which will allow us to operate the DTF in a stop-flow mode.
- Installation of a bottom drain on the corrosion inhibitor tank.
- Installation of a 1-1/2" magnetic flow meter.
- Installation of a 1/2" magnetic flow meter on the foam line to the RS300 (waiting for fittings to complete installation).
- Replacement of the nitrogen manifold needle valve for better metering of nitrogen into the DTF loop.
- Replace the Screening Cell with a tee and re-design the connection to the bladder accumulator to reduce the dead volume of the DTF.
- Construct a drain system to collect waste fluid from various parts of the DTF for disposal.
- Install a foam dump through a needle valve to meter foam removed from the DTF for increasing foam quality in a smooth, predictable manner (waiting on fittings to complete installation)

Figure 7.1 gives the schematic of the DTF with the modifications. "W" identifies waste fluids that are directed toward the 55 gal waste tank, and "Drain" fluids are those to be collected by the drain system and directed to an external drain. The definition of other symbols is given below:

V: Shut-off valve
NV: Needle or metering valve
CI: Corrosion Inhibitor
P: Pump

R: Relief valve or system
 C: Check valve
 G: Pressure gauge
 PD: Photodiode
 S: Strainer or filter
 T: Thermocouple with digital readout

Double lines represent 1-1/2" steel pipe. Solid lines are either stainless tubing or schedule 40 PCV pipe.

Figure 7.1 Schematic of Dynamic Testing Facility

Currently, 1-1/2 to 2 hours is required to generate foam. With the new system, this should be reduced to ~15 minutes. Figure 7.2 shows how the foam quality changes with time as gas is introduced into the DTF and an equal volume of foam (or foamy liquid) is removed (at system pressure) under a particular set of conditions. By this method, the system pressure will remain constant. The foam quality will gradually increase because liquid (in the foam) is being removed but only gas is being added. One can vary the time required to attain a particular foam quality by changing (1) the system pressure, (2) the fluid flow rate and/or (3) the fraction of flow being replaced by gas. The fraction of flow being replaced by gas should be low (0.1 to 0.15) to maintain uniform flow, pump lubrication and reduce the risk of foam collapse. This method depends on ultrasonic nitrogen flow from a calibrated metering valve. Corrosion and bacterial inhibition aqueous fluids in steel pipes inevitably lead to corrosion and corrosion products in the flow stream. This can be problematic especially if optical windows are being used. We found that “Iron Out”, a commercial form of NaHSO_3 , removes oxidation products from glass windows far better than acids, even HNO_3 . Fe^{+3} is reduced to Fe^{+2} , which is soluble up to a pH of 6.

Figure 7.2 Theoretical Increase in Foam Quality with Time as Gas Replaces Foam at a Constant Pressure

The corrosion inhibitor currently in use in the DTF and ACTF is an iron sequestering agent. Tests with this corrosion inhibitor and short sections on 1-1/2" steel pipe exposed to the air will darken as corrosion progresses until all the corrosion inhibitor is consumed. At this point, the steel pipe will begin to rust. Glass will remain free of corrosion products until the corrosion inhibitor is consumed. Additionally, the corrosion inhibitor (0.1 to 0.2%) promotes bacterial growth. Corrosion inhibitor stored in a 30 gal plastic drum and exposed to the air exhibits extensive bacterial growth. In an effort to reduce the corrosion rate and retard bacterial growth, corrosion tests were set up using 1% surfactant with 0.1% corrosion inhibitor in a 0.1 molar phosphate buffer adjusted to a pH of 8.5 - 9. After five days exposure, the steel pipe in an unbuffered solution showed extensive oxidation but the steel pipe in the buffered solution showed none. Also the color of the buffered solution was unchanged from its original light yellow color. Tests for bacterial growth were admittedly crude but indicated that pH 8.5 - 9 did not support growth of the bacteria previously found in the 30 gal drum, even after inoculation.

7.3.1.3 Quantification of Foam Bubble Texture using Computer Software

An agreement with a software vendor for developing a bubble imaging plug-in took place in the summer of 2003. Due to very limited progress made by the vendor, a search for a commercially-available imaging software package was initiated. A package called "Particle Analysis" was found and appeared to be promising. Crystal Redden, who has been assisting Dr. Len Volk with the ACTS project was asked to investigate a trial version of the package. This investigation is in progress.

The main difficulty with our images, which no software explored to date has been able to resolve, is that we do not have defined boundaries with respect to gray scale. We have a defined arc. The reason for the problem is our method of illumination. The foam is merely a white field if it is not illuminated from an angle. We have successfully enhanced the image, but the boundary problem is still unresolved. Either we have to write a program that will define the circle from the arc or that will recognize the arcs as a circular boundary, or find a package that can deal with this.

"Particle Analysis" is used for the delineation of froth, which counts and measures bubbles similar to our foam bubbles. However, using the algorithms constructed for the froth application has been unsuccessful. This software was also used for measuring bubbles in images of foam by another research group. The description of their treatment of the images has not been helpful. Attempts to contact the other group, as well as to contact the vendor for "Particle Analysis," have thus far been unsuccessful.

Investigators at the French Institute of Petroleum published a paper earlier this year in which they claim to have quantitatively processed images of foam bubbles. We will also attempt to contact these investigators.

In the interim, other methods of illuminating the foam, using polarized light, are also being explored

7.3.2 Novel Techniques for Bubble Characterization

No progress has been made on this task. Activity on this task will commence at some future date.

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

- Install new digital camera on DTF.
- Complete modifications to the DTF.
- 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. A Hazards Review is an industry accepted method used to improve the overall safety characteristics and reduce the possibilities of accidents in the work place. Each individual component of the ACTF is examined as to the effect and consequences on safety, health, and the environment, of the component in all possible operational modes. A Hazards Review can result in equipment modification, inspection and testing, documentation, personal protective equipment, personnel training, and/or emergency training.

The hazards review process begins by selecting a review method. Next a team of qualified individuals must be formed. This team should include those knowledgeable in the review process and those familiar with the process to be reviewed. Prior to beginning the review, all available documentation needs to be gathered. This includes schematics, organized training, periodic inspections and testing results, design and construction documents, operating procedures, etc.

Once the schematics have been verified and the operator of the equipment or process has reviewed its operation with the team, the Hazards Review begins. The review should continue uninterrupted until completed. After the findings and recommendations have been completed, a draft report is issued and reviewed by all team members, and the operator of the process or equipment. Following this review, any changes are incorporated and a final report issued. This completes the Hazard Review process. The operator then needs to develop an action plan to implement the recommendations from the Hazard Review. In our case, team members will participate in developing this plan.

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 no 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.

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

- The next Advisory Board Meeting will be held on November 18, 2003. 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) TotalFina-Elf, and 10) Weatherford International. Preparation of technical documents for the ABM meeting is in progress.
- We had three technical meetings with Halliburton, Baker Hughes and Weatherford International.
- An abstract for the next SPE/ICoTA Coiled Tubing Conference has been prepared for submission.
- While at this stage we do not anticipate new members, it is possible that perhaps JNOC may rejoin the TUDRP/ACTS.
- We also have begun some preliminary discussion with the current members about the future of the ACTF and the funding model.