Title: Advanced Cuttings Transport Study

Type of Report: Quarterly Technical

Reporting Period Start Date: Jan. 1, 2002

Reporting Period End Date: Mar. 31, 2002

Principal Authors:

Troy Reed, Principal Investigator

Stefan Miska, Co-Principal Investigator

Nicholas Takach, Co-Principal Investigator

Kaveh Ashenayi, Co-Principal Investigator

Mark Pickell, Project Engineer

Len Volk

Mike Volk

Evren Ozbayoglu

Lei Zhou

Date of Issue: April 30, 2002

DOE Award Number: DE-FG26-99BC15178

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

Title: Advanced Cuttings Transport Study

Type of Report: Quarterly

Reporting Period Start Date: Jan. 1, 2002

Reporting Period End Date: Mar. 31, 2002

Principal Authors:

Troy Reed, Principal Investigator

Stefan Miska, Co-Principal Investigator

Nicholas Takach, Co-Principal Investigator

Kaveh Ashenayi, Co-Principal Investigator

Mark Pickell, Project Engineer

Len Volk

Mike Volk

Evren Ozbayoglu

Lei Zhou

Date of Issue: April 30, 2002

DOE Award Number: DE-FG26-99BC15178

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

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government, Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply, its endorsement, recommendation, or favoring, by the United States Government or agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

1. SUMMARY OF CURRENT TASKS FOR ACTS PROJECT

This is the third quarterly progress report for Year 3 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 Jan. 1, 2002 and Mar. 31, 2002.

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

- a) Design and development of an Advanced Cuttings Transport Facility
(**Task 3**: Addition of a Cuttings Injection/Separation System),
- b) Research project (**Task 6**): “ Study of Cuttings Transport with Foam Under LPAT Conditions (Joint Project with TUDRP)”,
- c) Research project (**Task 9b**): “ Study of Foam Flow Behavior Under EPET Conditions”,
- d) Research project (**Task 10**): “Study of Cuttings Transport with Aerated Mud Under Elevated Pressure and Temperature Conditions”,
- e) Research on three instrumentation tasks to measure:
 - Cuttings concentration and distribution in a flowing slurry (**Task 11**), and
 - Foam texture while transporting cuttings. (**Task 12**),
 - Viscosity of Foam under EPET (**Task 9b**)
- f) 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**).
- g) Activities towards technology transfer and developing contacts with Petroleum and service company members, and increasing the number of JIP members.

2. EXECUTIVE SUMMARY OF PROGRESS

Flow Loop Construction (Task 3)

During the third quarter, Year-3 of the ACTS Project, installation has been completed on the Cuttings Injection Hopper, the Three-Phase Separation Tower, Liquid Hold-up valves, and other modifications planned for construction and/or installation in the first quarter of 2002.

In addition, a complete renovation of the instrumentation and data-collection wiring system has been undertaken. Previously all instruments (e.g. pressure transmitters, temperature transmitters, etc.) were individually wired into the control room. New “Field-Point” Terminals now process individual signals at the test loop and transmit them through a single coaxial Ethernet cable into the control room. This relieves considerable congestion in the existing buried conduits and immediately provides a more reliable signal. Furthermore, this new design provides much greater flexibility for the addition of new instrumentation in the future. Additional discussion of the Flow Loop is given in Section 3 of this report.

Study of Cuttings Transport with Foam Under LPAT Conditions, (Task 6).

All cuttings-transport tests with foam in the Low Pressure/Ambient Temperature Flow Loop have been completed. In addition, a 3-layer cuttings-transport model has been developed which includes a set of seven equations (2 mass balance, 3 momentum balance, pressure-drop, in-situ cuttings concentration and slip velocity between the cuttings and the fluid) and seven unknowns (velocities in each layer, thickness for each layer, in-situ cuttings concentration, pressure drop and slip velocity between the cuttings and the fluid). A computer simulator has been developed based on the 3-layer cuttings-transport model. Simulator results have been compared with the experimental data. Some of the details are discussed in Section 4. A Ph.D. dissertation is being completed, and a copy will be provided to the DOE and all JIP members.

Study of Foam Flow Behavior Under EPET Conditions, (Task 9).

This project was completed during the second quarter of Year-3. A summary of the results and conclusions were presented in the DOE Quarterly Report for that period. Copies of the thesis report are being provided to the DOE and all JIP members.

One of the important findings from this research task is that foam texture (i.e., bubble size, shape & size distribution) has a primary effect on the apparent viscosity of a foam. This identified the need to have an instrument that can generate a foam with a controlled bubble size and then measure its rheological properties. This has led to the development of a new concept for achieving these objectives. This will become a new instrumentation task, and it will be designated **Task 9b**. Measurements of foam viscosity will supplement the optical measurements of foam texture that is part of Task 12. TU is currently considering a formal “invention disclosure” for possibly filing a US Patent. If a decision is made to file a patent, the appropriate forms will be submitted to the DOE. Additional discussion of the Foam Generator/Viscometer is given in Section 5 of this report.

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

A literature review on related knowledge and study of the previous works done by TUDRP/ACTS are continuing. A theoretical analysis of cuttings transport phenomena, based on a layered model, is under development. This approach has been applied to cuttings transport with aerated Newtonian fluids in horizontal pipes. Extension of this model to Non-Newtonian fluids and annular geometries is underway. Two-phase, Non-Newtonian, frictional pressure drops for Bingham Plastic, Power Law and Yield Power Law fluids with air are calculated using Kaminsky's method, and modifications are being done to apply the method to large-diameter pipes that are inclined. Calibrations of two nuclear densitometer are underway. These densitometers will be used to measure slurry density, the size of slugs (both of liquids and solids) and their velocity. Flow-loop tests are expected to begin in May, 2002, after the Cuttings Injection and Separation System is installed and commissioned. Additional discussion of this task is provided in Section 6.

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

The previously designed printed circuit board and firmware have been modified and are being tested. The data acquisition software was modified as well. Some preliminary tests have been conducted. The results indicate that we are able to distinguish between different sand concentrations.

In order to account for the nonlinear nature of the fluid flow, a neural network model will be used to analyze the ultra-sonic test data. We will use Qnet software tools from Vesta Services, Inc. to incorporate neural networks into our Visual Basic program.

Tests will be conducted both with and without an inner ring of ultra-sonic sensors to determine if they are needed. This task is reviewed in Section 7.

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

Several minor modifications/improvements to the Dynamic Testing Facility have been completed or are underway. The optical box that is being used to develop alternate methods for bubble characterization has been completed. The status of this work is reviewed in Section 8.

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

The Action Plan continues to be the primary focus of Task 1S. Additional discussion of this task appears in Section 9.

Activities towards Technology Transfer, Developing Contacts with Petroleum & Service Company Members, and Addition of JIP Members.

We received notice from the Japanese National Oil Co. that they will be going out of business within the next 2 years. Hence, they will not renew their JIP membership. ConocoPhillips is still considered to be a candidate, and they are expected to attend the May 2002 ABM. In addition, Shell, ExxonMobil, Anadarko Petroleum Co., MI Drilling Fluids, and Northland Energy (Canada) have all been invited to attend this meeting. Further discussion of these activities is given in Section 10.

TABLE OF CONTENTS

DISCLAIMER	2
1. SUMMARY OF CURRENT TASKS FOR ACTS PROJECT	3
2. EXECUTIVE SUMMARY OF PROGRESS	4
LIST OF FIGURES	8
3. ACTF DESIGN AND CONSTRUCTION ACCOMPLISHMENTS	10
4. STUDY OF CUTTINGS TRANSPORT WITH FOAM UNDER LPAT CONDITION	17
5. STUDY OF FOAM FLOW BEHAVIOR UNDER EPET CONDITIONS ...	29
6. STUDY OF CUTTINGS TRANSPORT WITH AERATED MUDS UNDER EPAT CONDITIONS	30
7. DEVELOPMENT OF CUTTINGS MONITORING METHODOLOGY	36
8. DEVELOPMENT OF METHODS FOR CHARACTERIZING BUBBLES IN ENERGIZED FLUIDS	39
9. SAFETY PROGRAM	43
10. TECHNOLOGY TRANSFER	44

LIST OF FIGURES

ACTF DESIGN AND CONSTRUCTION (Task 3)

Fig. 3.1 – Flow Loop: Fall, 2001	10
Fig. 3.2 – Flow Loop: Spring, 2002	10
Fig. 3.3 – New Piping	11
Fig. 3.4 – New Differential Pressure Transmitter	11
Fig. 3.5 – Readout Panels	11
Fig. 3.6 – A Load Cell	12
Fig. 3.7 – A Hold-Up Valve	12
Fig. 3.8 – Air Expansion Tank	13
Fig. 3.9 – New Control Room Wiring	13
Fig. 3.10 – Field Point Module Terminals	13
Fig. 3.11 – One of Two Nuclear Densitometers	14
Fig. 3.12 – Johnson Screen Basket	14
Fig. 3.13 – Cuttings Injection Feed Auger	15
Fig. 3.14 – Portable Loading Auger	15

STUDY OF CUTTINGS TRANSPORT WITH FOAM UNDER LPAT (Task 6, Sec. 4)

Fig. 4.1 – Modes of Cuttings Transport in Horizontal Well Drilling	18
Fig. 4.2 – Experimental vs Calculated Data for 70% Quality Foam	20
Fig. 4.3 – Experimental vs Calculated Data for 80% Quality Foam	21
Fig. 4.4 – Experimental vs Calculated Data for 90% Quality Foam	21
Fig. 4.5 – Bed Area Ratio for Water, Calculated vs Experimental	22

Fig. 4.6 – Total Pressure Drop for Water, Calculated vs Experimental	23
Fig. 4.7 – Bed Area Ratio for Foam, Calculated vs Experimental	24
Fig. 4.8 – Total Pressure Drop for Foam, Calculated vs Experimental	24
Fig. 4.9 – Comparison of Bed Area Ratio determined by using the Model, Empirical Equations and ANN with Experimental Data	26

STUDY OF CUTTINGS TRANSPORT WITH AERATED MUD UNDER EPET (Task 10, Sec. 6)

Fig.6.1 – Schematic Diagram of Radiation passing thru Annulus	32
---	----

DEVELOPMENT OF METHODS FOR CHARACTERIZING BUBBLES IN ENERGIZED FLUIDS (Task 12, Sec. 8)

Fig. 8.1a – Schematic of Dynamic Testing Facility – March 2002	41
Fig. 8.1b – Key to Dynamic Testing Facility Schematic	42

3. ACTF DESIGN AND CONSTRUCTION ACCOMPLISHMENTS

A great number of changes have occurred during this past quarter on the ACTS Flow-Loop. At the end of the last quarter, the ACTS Flow Loop looked like this:

Photo #1

Fig. 3.1 - Fall, 2001

Now, it has two new towers, as shown below!

Photo #2

The Cuttings Injection Hopper is pictured on the left.

The Three-Phase Separation Tower is pictured on the right.

Fig. 3.2 - Spring, 2002

Most prominent of the new features are the Cuttings Injection Hopper and the Three-Phase (gas-liquid-solids) Separation Tower. In conjunction with these, new piping has been added.

Fig. 3.3 - New Piping

New instrumentation:

Fig. 3.4 - New Differential Pressure Transmitter

**Fig. 3.5 - TwoTower Load Cell Readout Panels
and
Single Readout Panel for 2 Densitometers**

A weighing system for the towers has been installed:

Photo #6

Fig. 3.6 – A Single Load Cell

Three load cells support each tower. The load cells for each tower are electronically summed by a micro-processor controller in the control room (see Photo #5).

A differential Pressure Transmitter (see Photo #4) compensates for any change in liquid level in the tower to provide accurate measurement of changes in cuttings volume.

Liquid Hold-up valves are in place:

Photo #7

Fig. 3.7 - A Hold-up Valve

Three Liquid Hold-Up Valves are sequenced to bypass the continuing 3-phase flow and isolate the contents of the Drilling Section. The captured gas volume is subsequently measured by using an Air Expansion Tank (see Photo #8)

The Air Expansion Tank for Hold-up measurements is in place:

Fig. 3.8 - Air Expansion Tank for Hold-up Measurements

This Tank is designed to allow air, captured within the annular (drilling) test section, to expand into a known calibrated volume. Pressure and temperature are first measured in the sealed annulus, then air is allowed to expand into the Expansion Tank, and finally the pressure and temperature in this Tank are measured. This enables a calculation of the initial volume of air captured within the annulus when the Hold-up valves are closed.

New wiring:

Fig. 3.9 - New Control Room Wiring

Fig. 3.10 - Field Point Module Terminals

The new Field-Point Terminals shown above are for all new and existing Flow-Loop instrumentation. The instruments (e.g. pressure transmitters, temperature transmitters, etc.) were individually wired into the control room where the signals were processed and sent to the control-room computer for data acquisition or system control. The new Field Terminals process the signals on the spot and transmit them all through a single coaxial Ethernet cable. This relieves a considerable congestion in the existing buried conduits and immediately provides a more reliable signal. Furthermore, this new design provides much greater flexibility for the addition of new instrumentation in the future.

Nuclear Densitometers:

Fig. 3.11 - One of Two Nuclear Densitometers

Johnson Screen basket for cuttings removal:

Figs. 3.12 - Johnson Basket Screen

Feed Auger for the Cuttings Injection Hopper:

Fig. 3.13 - Cuttings Injection Feed Auger

A Portable Auger to Initially load gravel into the Cuttings Injection Hopper:

Fig. 3.14 - Portable Loading Auger

This Loading Auger will only be used to load the Rock Hopper with new gravel. The standard operating procedure will be to hydraulically transfer gravel from the Separation Tower back to the Hopper at the end of a test. After reloading the Hopper, Flow-Loop testing will then be restarted. Samples of the gravel will be collected routinely, and a sieve analysis will be performed. Based on the results, it will be decided when the existing load of gravel has degraded too much in size and needs to be replaced with new gravel.

Other modifications, which have been installed and are now ready for the next series of Flow-Loop tests, include:

- The existing 4-inch Fisher globe choke valve has been moved to the piping with the static mixer. This will allow additional shear energy to be added to the flow during foam experiments. Actuation will be from the Control Room where the input parameters can be carefully controlled.
- Piping modifications have been made to the suction side of both the Moyno and the Halliburton pumps. These modifications will allow both pumps to be operated in parallel to achieve higher flow rates.
- A remote readout for the large Micro-Motion flow meter has been installed on the control console of the Halliburton pump. This will allow the operator to be able to more accurately adjust the flow volume from his station at the pump controls.

Still pending include:

- One 2-inch, one 3-inch and three 6-inch view ports have yet to be received from the manufacturer for a variety of technical problems. A TU representative traveled to the manufacturer and resolved these problems. However, the lead time to complete the manufacture of the glass lenses has been unexpectedly long in spite of numerous request to expedite this work. As of the last check with the manufacturer, these view ports should be received by the first week of May, 2002.
- SWACO has not been able to give us a schedule for the delivery of the Super-Auto Drilling Choke, which is to be donated to the ACTS Project, but they have confirmed that it is on the way. This will be a secondary choke device located between the exit from the 4-inch test section and the Separation Tower. It will be used in instances where additional pressure drop, at that location, will prevent over pressurization of the Separation Tower and/or assist in pumping flow up to the Tower inlet by allowing a controlled amount of gas expansion.

4. STUDY OF CUTTINGS TRANSPORT WITH FOAM UNDER LPAT CONDITIONS (Task 6)

Investigator: Evren Ozbayoglu (Ph.D. Candidate)

OBJECTIVES

- To investigate foam rheology and flow behavior in pipe and annulus.
- To determine (experimentally) and to predict (analytically) frictional pressure losses (with and without cuttings) and volumetric requirements (injection rate, injection pressure and backpressure) for effective cuttings transport with foam flow in inclined and horizontal wellbores.

PROJECT STATUS

- Development of a 3-Layer Cuttings Transport Model has been completed. The Model can determine pressure losses, layer velocities, in-situ cuttings concentration, cuttings bed thickness and slip velocity between the cuttings and the fluid.
- Development of a computer simulator, based on the proposed model, is completed.
- Empirical equations and an Artificial Neural Network model are developed for estimating cuttings bed thickness in the wellbore for a given set of drilling conditions.
- Simulator results are compared with experimental data. Also, bed thickness measurements are compared with simulator results, empirical correlations and the ANN results.
- A Ph.D. dissertation on this work is being prepared

WORK DONE

Literature Survey	Rheology of Foam	99%
	Cuttings Transport Phenomena	99%
Modification of Loop for Foam Flow	Plan	99%
	Construction	99%
Experiments Performed	Foam without Cuttings	99%
	Foam with Cuttings	99%
Model Developed	Rheology Review	99%
	Cuttings Effect	99%
Computer Simulator	Without Cuttings	99%
	With Cuttings	99%

In this DOE Progress Report a summary of the 3-Layer cuttings transport model will be presented. Also, the simulator (based on the developed model) results will be compared with the experimental data. Finally, two other methods will be presented to estimate the cuttings bed thickness in wellbores.

3-LAYER CUTTINGS TRANSPORT MODEL

Figure 4.1 shows the possible modes of transport that can occur in drilling operations.

Figure 4.1 – Modes of Transport in Horizontal Well Drilling

Based on the observations from the cuttings transport experiments using foam, only mode (b) is observed. Therefore, the focus in this study is on a 3-Layer structure (a stationary bed, a layer including cuttings in motion and a layer of clear fluid). Additional details about the layers are discussed in DOE Progress Report, dated October 30, 2001, and will also be included in the Ph.D. dissertation.

Equations for the Proposed Model

The following equations are used in this model. The derivations and detailed explanations of these equations are presented in DOE Progress Report, dated October 2001, and will also appear in the Ph.D. dissertation.

- Mass Conservation

$$v_I A_I \rho_f + v_{II} A_{II} \rho_f (1 - C_{C_{II}}) = \bar{v} A_w (1 - C_C) \rho_f$$

$$v_{II} A_{II} C_{C_{II}} \rho_c = \bar{v} A_w C_C \rho_c$$

- Momentum Conservation

$$\Delta P A_I - \tau_{I-II} S_{I-II} \Delta L - \tau_{I-w} S_{I-w} \Delta L - \rho_f g A_I \Delta L \sin \alpha = 0$$

$$\Delta P A_{II} + \tau_{I-II} S_{I-II} \Delta L - \tau_{II-III} S_{II-III} \Delta L - \tau_{II-w} S_{II-w} \Delta L - \rho_s g A_{II} \Delta L \sin \alpha = 0$$

$$\Delta P A_{III} + \tau_{II-III} S_{II-III} \Delta L - f_{III-w} \rho_b g A_{III} \Delta L \cos \alpha = 0$$

- Slip Velocity Between the Cuttings and the Fluid

$$v_{slip} = \sqrt{\left(\frac{4}{3} \frac{d_c \bar{g}}{(C_L \sin \beta + C_D \sin \theta)} \right) \left(\frac{\rho_c - \rho_f}{\rho_f} (\cos \alpha \sin \beta + \sin \alpha \sin \theta) \right)}$$

- In-Situ Cuttings Concentration at Layer-II

$$C_{C_{II}} = \frac{2 \square_c^2 (C_{C_{bottom}} - C_{C_{top}}) + C_{C_{top}} h_{II}^2 v_y^2 - \frac{(C_{C_{bottom}} - C_{C_{top}}) h_{II} v_y (2 \square_c + h_{II} v_y)}{e^{\square_c} - 1}}{h_{II}^2 v_y^2}$$

- Static Friction Between Cuttings Bed (Layer-III) and Wellbore

$$f_{III-w} = 0.62 \left(\frac{A_{bed}}{A_w} \right)^{0.252}$$

Also, Dodge & Metzner's friction factor equation, Televantos' friction factor (with cuttings), Clift et al.'s drag coefficients and Clark & Bickham's lift coefficients are used to balance the number of equations and number of unknowns for this model.

COMPARISON OF MODEL RESULTS WITH EXPERIMENTAL DATA

Experiments were conducted at The University of Tulsa-Drilling Research Projects' low pressure-ambient temperature flow loop. Experiments can be categorized into three major groups: 1) Foam rheology, 2) Cuttings transport experiments with water and 3) Cuttings transport experiments with foam.

Foam Characterization

Detailed procedure for determination of the rheological parameters of foam is presented in DOE Progress Report, January 2000. After an analysis of the experimental data from the rheology section of TUDRP's LPAT flow loop, the rheological model parameters for foam used in this study are obtained as shown in Table-4.1.

Table-4.1 – Rheological Model Parameters for Foam for Different Foam Qualities

	$\tau = \mu(\gamma)$		$\tau = \tau_y + \mu_p(\gamma)$			$\tau = K(\gamma)^n$			$\tau = \tau_y + K(\gamma)^m$			
	μ	R ²	τ_y	μ_p	R ²	K	n	R ²	τ_y	K	m	R ²
70 %	6.0 10 ⁻⁶	0.63	8.14 10 ⁻⁴	4.0 10 ⁻⁶	0.82	1.02 10 ⁻⁴	0.53	0.94	5.8 10 ⁻⁸	1.0 10 ⁻⁴	0.53	0.94
80 %	1.0 10 ⁻⁵	0.58	1.76 10 ⁻³	6.0 10 ⁻⁶	0.80	2.92 10 ⁻⁴	0.45	0.92	1.3 10 ⁻⁹	2.9 10 ⁻⁴	0.45	0.92
90%	1.2 10 ⁻⁵	0.45	2.22 10 ⁻³	7.0 10 ⁻⁶	0.81	4.15 10 ⁻⁴	0.42	0.90	2.0 10 ⁻⁷	4.1 10 ⁻⁴	0.42	0.90

In this table, τ and τ_y are in psi, and μ and K are in lbf sⁿ/in². A regression analysis showed, for all qualities, that a Power-Law model is the best model that describes the rheological behavior of this foam.

Frictional Pressure Losses

Using the information from Table 4.1, frictional pressure losses are calculated for pipes and the annulus. Comparisons of the experimental data and the calculated results are presented in Figs. 4.2, 4.3 and 4.4 for 70%, 80% and 90% foam qualities respectively.

Figure 4.2 – Experimental vs. Calculated Data for 70% Quality Foam

Figure 4.3 – Experimental vs. calculated data for 80% quality foam

Figure 4.4 - Experimental vs. Calculated Data for 90% Quality Foam

As seen in Figs. 4.2 and 4.3, the calculated results are in good agreement with the experimental data. However, in Figure 4.4, for 90% quality, there are a few cases for which the calculated values are much higher than the experimental data. These points are mostly annular flow data. Since there is no backpressure choke in the flow loop, some gas-slugging was observed when the foam quality is 90% and higher. Therefore, a 2-phase flow develops. This causes a significant decrease in the measured frictional

pressure loss. Also, the wall slip is determined from the rheology section. However, the wall slip effects are not the same in the annular section. Therefore, the combination of these phenomena can cause the calculated values to differ from the measured data.

Cuttings Transport with Water

Although the model is developed for compressible fluids, it can be used for incompressible fluids as well. Figs. 4.5 and 4.6 show the comparison of the experimental data and calculated results of the bed area ratio and the total pressure drop, respectively for cuttings transport with water (for wellbore inclinations of 70° to 90° from vertical).

Figure 4.5 – Bed Area Ratio for Water, Calculated vs. Experimental

Figure 4.6 – Total Pressure Drop for Water, Calculated vs. Experimental

As seen from Figs. 4.5 and 4.6, the calculated results are in good agreement with the experimental data. A few points (low bed thickness) are off the window. This is due to the model assumption that there is always a stationary bed present. Therefore, the model cannot identify the boundary between the modes (b), (c) and (d) that are shown in Fig. 4.1.

Cuttings Transport with Foam

Cuttings experiments with foam were conducted for 70%, 80% and 90% foam qualities for 70°, 80° and 90° inclinations considering a wide range of flow rate and ROP. Comparison of the experimental data and the calculated results are presented in Figures 4.7 and 4.8.

Figure 4.7 – Bed Area Ratio for Foam, Calculated vs. Experimental

Figure 4.8 – Total Pressure Drop for Foam, Calculated vs. Experimental

Figure 4.7 shows that, cuttings bed thickness can be estimated successfully. Although Fig. 4.8 is scattered, most of the points are within $\pm 25\%$ error range. The points outside this window belong to high quality foams (90% and above).

Other Methods for Determining Bed Thickness

Although bed thickness can be determined by using the proposed model, the simulator requires an excessive amount of time required, i.e., for a 2000 ft long wellbore with a grid length of 10 ft, approximately 2 hours of runtime on a 700 MHz processor. Of course, when the simulator is used, other information besides the bed thickness can be achieved, i.e., pressure losses, velocities, etc. However, if only bed thickness is of concern, using other methods can shorten the process time. Two other methods are presented below to determine the bed thickness in a wellbore: 1) empirical correlations, and 2) the method of Artificial Neural Networks.

Empirical Equations

After analyzing the experimental data developed for water, foam and a polymer-mud, empirical equations are developed for different fluid behavior index ranges. Dimensionless groups are developed and the coefficients of the equations are determined by using the experimental data as described in DOE Progress Report, January 2001. The developed equations are as follows:

For $N \geq 0.9$

$$\frac{A_{bed}}{A_w} = 0.202 (C_C)^{-0.036} (N_{Re})^{0.047} (N_{Fr})^{-0.35}$$

For $0.6 < N < 0.9$

$$\frac{A_{bed}}{A_w} = 0.711 (C_C)^{-0.171} (N_{Re})^{-0.037} (N_{Fr})^{-0.068}$$

and for $N \leq 0.6$

$$\frac{A_{bed}}{A_w} = 0.882 (C_C)^{-0.021} (N_{Re})^{-0.114} (N_{Fr})^{-0.069}$$

Artificial Neural Networks (ANN)

The popularity of ANN is increasing everyday due to its wide range of applicability and its capability of handling complex problems that cannot be adequately modeled by conventional mechanistic approaches. An ANN is trained by using the same dimensionless groups used in the empirical correlations. Detailed information is presented in DOE Progress Report, dated April 30, 2001.

Figure 4.9 shows the performance of the three models (3-layer mechanistic model, empirical correlations and the ANN) when they are compared with the experimental data.

Figure 4.9 – Comparison of Bed Area Ratio determined by using the Model, Empirical Equations and ANN with Experimental Data

As seen in Figure 4.9, the ANN estimates are closest to the experimental data. Also, the ANN model can estimate the bed thickness even when the bed thickness is thin. Results from the 3-Layer Mechanistic Model are also satisfactory except for the small bed-thickness regions.

CONCLUSIONS

The major conclusions from this study are as follows:

- The foam, used in this study, behaves like a pseudo-plastic fluid with a negligible yield stress.
- Pressure losses can be determined using the proposed generalized model in pipes and annular geometries mostly with an error of less than 20%.
- Turbulent flow is the key for effective cuttings transport in horizontal and inclined wellbores. When compared with water, the tendency to build a cuttings bed with foam is higher at the same flow rates for horizontal and highly-inclined wellbores. Very high velocities are required to prevent the development of a thick cuttings bed, when foam is used as the circulating fluid.
- Thickness of the bed increases as foam quality increases for a constant in-situ flow rate.
- Inclination angle has a negligible effect on bed thickness for angles between
- 70° and 90°.

- For horizontal and highly-inclined wellbores, a layered model is used to determine bed thickness and pressure loss. A simulator is developed based on the proposed model. The program can be used to assist designing wells and determining the volumetric flow rates of liquid and gas phase for a particular drilling condition.
- For practical purposes, the empirical correlations or the Artificial Neural Networks (ANN) can be used to estimate bed thickness.

NOMENCLATURE

A	Area (L^2)
C	Concentration, Coefficient
d	Diameter (L)
f_f	Friction Factor
g	Gravitational Acceleration ($\frac{L}{T^2}$)
h	Height (L)
K	Consistency Index ($\frac{mT^{N-2}}{L}$)
L	Length (L)
m	Fluid Behavior Index
n	Fluid Behavior Index
N_{Fr}	Froude Number
N_{Re}	Reynolds Number
P	Pressure ($\frac{m}{LT^2}$)
S	Perimeter (L)
v	Velocity ($\frac{L}{T}$)

Greek Letters

α	Inclination Angle (from vertical)
β	Angle, Slip Coefficient ($\frac{L^3 T}{m}$)
ρ	Density ($\frac{m}{L^3}$)
$\square$	Diffusion Coefficient
θ	Radial Direction, Angle
τ	Shear Stress ($\frac{m}{LT^2}$)
μ	Viscosity ($\frac{m}{LT}$), Friction Coefficient

Subscripts

<i>b</i>	Bed, Buoyancy
<i>c</i>	Cuttings, Capillary
<i>D</i>	Drag
<i>f</i>	Fluid, Foam
<i>I</i>	First Layer
<i>II</i>	Second Layer
<i>III</i>	Third Layer
<i>L</i>	Lift
<i>p</i>	Plastic, Particle
<i>s</i>	Slip, Suspension
<i>w</i>	Wall, Wellbore
<i>y</i>	Yield

ACKNOWLEDGEMENTS

TUDRP, the ACTS Project and the author thank Bachman Chemicals for donating surfactants and foam breaker agents.

5. STUDY OF FOAM FLOW BEHAVIOR UNDER ELEVATED PRESSURE AND TEMPERATURE CONDITIONS (Task 9)

Investigator: Affonso Marcelo Fernandes Lourenço (MS Graduate)

OBJECTIVES

- Perform experimental study of foam flow behavior inside pipes and annuli in a large-scale loop (ACTS) under elevated pressure and temperature.
- Develop empirical correlations to estimate pressure losses during foam flow for a given set of gas-liquid ratio, temperature and pressure conditions.

SUMMARY OF ACTIVITIES

- Work on this research (Task 9) has now been completed. Copies of the thesis report will be provided to the DOE and all JIP sponsors.

One of the important findings from this hydraulic study of foam is that bubble size has a primary effect on the apparent viscosity of a foam. This identified the need to have an instrument that can generate foam with a controlled bubble size and then measure its 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 the following six variables independently. 1) foam quality (ratio of gas to liquid), 2) pressure, 3) temperature, 4) surfactants and other additives, 5) bubble size, and 6) surface roughness inside a viscometer. A survey of different manufacturers of viscometers and rheometers found that there is currently no commercially available instruments designed to accomplish the above list of measurements for foams.

A new and original design for a foam generator/viscometer has been developed which could accomplish the above list of tasks. An "Invention Disclosure" has been submitted to the Tulsa University Intellectual Property Committee for their evaluation. TU is now considering filing a US patent application for this new instrument. If the decision is made to file for a patent, then the appropriate forms will be submitted to the DOE. In addition, the details will be shared with the ACTS JIP members.

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

Investigator: Lei Zhou (Ph.D. Candidate)

6.1 Objectives

1. Develop two-phase flow model for aerated fluids under elevated pressure and temperature conditions inside annuli 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 optimum gas/liquid flow rates for cuttings transport.
4. Develop a computational tool to calculate pressure loss in aerated fluids flowing under elevated pressure and high temperature conditions.

6.2 Past Work

1. Literature review on cuttings transport and hole cleaning.
2. Literature review on two-phase flow in pipe and annular.
3. Particle drag and lift coefficients analysis.
4. Pressure drop and holdup calculation for Non-Newtonian fluid flow with air (two-phase) using R.D. Kaminsky's¹ method.
5. Modified R.D. Kaminsky's method for larger pipe diameters and inclination angles (using Taitel&Dukler's² method to calculate the holdup).

6.3 Present Work

1. Modifying R.D. Kaminsky's method to account for annular geometries.
2. Solving layered model equations for cuttings transport in pipes.
3. Calibrating of nuclear densitometer.
4. Development of a layered model that considers air-liquid-cuttings (a three-phase flow) under slug flow conditions.

5. Study of the corresponding two-phase (air-liquid) flow with the principle of volume equalization.
6. Conducting experiments to measure the porosity of packed cuttings.
7. Calibrating the nuclear densitometers.
8. Developing a computer simulator for prediction of cuttings transport and two phase flow at EPET conditions.

6.3.a Calibration of Nuclear Densitometers

Two Ronan nuclear density monitor were installed in order to measure the mixture density and trace the movement of slugs through the annular section. Calibration will be needed to make the densitometer work properly for our special application. After some primary tests, it was learned that the radiation passing through an annular space is not uniform, and therefore, a Dual-Point calibration will not be sufficient to enable accurate density measurements. It is currently thought that eight calibration points will be necessary. These eight points will be obtained by using a specially-designed calibration gig which enables a measured amount of fluid and solids to be placed in an annular geometry that is identical to the annular test section in the ACTS Flow Loop. The following measured amounts of water and solid cuttings will be placed in the calibration gig.

1. 100% Air in the annuli.
2. 25% of annulus filled with water and 75% air.
3. 50% of annulus filled with water and 50% air.
4. 75% of annulus filled with water and 25% air.
5. 100% of annulus filled with water.
6. 25% of annulus filled with cuttings and 75% filled with water.
7. 50% of annulus filled with cuttings and 50% filled with water.
8. 75% of annulus filled with cuttings and 25% filled with water.

Two sets of reference ranges or spans will be programmed for the densitometers. A lower range or span from zero (air) to 1 gm/cc (water) will be used for two-phase flow experiments. The zero is set when the annulus contains only air. The high end of this span is set when the annulus is full of water.

The second span will be set to cover a density range from 0.90 gm/cc to 1.8 gm/cc. This range will be used primarily for measurements of slurry density. The eight calibration points will be used to relate meter readings from the densitometer to a known fluid or slurry density.

A fiber-reinforced nylon plastic pipe is placed at the center of 6" steel pipe to simulate the geometry of a drillstring within a wellbore. The purpose of using the nylon inner pipe

is to avoid corrosion from exposure to air and water and also to minimize erosion caused by a slurry flowing through the annular test section.

Fig. 6.1 Schematic Diagram of Radiation passing thru Annulus

6.3b Prediction of Two-Phase Non-Newtonian Flow Behavior In Pipes

Existing experimental studies of two-phase non-Newtonian flow is very limited in the literature. Practical prediction methods are also fairly limited. Eisenberg and Weinberger³ (1979) derived a model for annular flow. A predictive model for stratified flow has been given by Heywood and Charles⁴ (1979) and has been partially validated by Bishop and Deshpande⁵. Shu⁶ presented models for power-law fluids for several flow regimes. A correlation has been published in the literature. Dziubinski⁷ correlated a large number of pressure-drop data for power-law fluids in horizontal intermittent flow. Experimental studies of how non-Newtonian fluid behavior influences two-phase flow regime transitions suggest the influence is modest at most. It may be explained that the stability of two-phase flow regime are primarily functions of the gas and liquid superficial velocities and densities,

In the study done by Kaminsky, pressure-drop is assumed to be dominated by the liquid contribution, which is the case except for very low liquid-holdup systems, the shear stress at the wall of the liquid may be approximated as:

$$\tau_{w,ave} = \frac{dp}{dl} \frac{D}{4} \frac{1}{S}$$

An “S” factor is introduced for two-phase flow systems. Which is the effective fraction of the surface wetted by the fluid and in full-forward motion. For annular flow, the wetted area is the entire surface, i.e. S=1.

A correlation is given by Kaminsky for values of "S". For smooth segregated horizontal flow, "S" is equal to the wetted fraction of the pipe

$$S = \frac{g(H)}{2g(0.5)} \quad \text{if } H \leq 0.5$$

$$S = 1 - \frac{g(1-H)}{2g(0.5)} \quad \text{if } H > 0.5$$

where $g(x) = 0.526x^{0.335} + 0.175x^{1.350}$

The calculation procedure for determining two-phase non-Newtonian flow behavior is as follows:

1. Make initial estimate of the wall shear stress and liquid holdup fraction.
2. Calculate the effective power-law exponent n by

$$n = 1 + \frac{d(\ln \mu_a)}{d(\ln \gamma)}$$

and effective surface roughness by

$$\left(\frac{e}{D}\right)_{eff} = \exp(2.193\left(\frac{1-n}{n}\right))\left(\frac{e}{D}\right)^{\frac{1}{n}}$$

3. Calculate the apparent viscosity for the wall shear rate via the fluid Rheology model.
4. If the liquid flow is laminar, multiply apparent viscosity by $\left(\frac{3n+1}{4n}\right)^n$
5. Calculate pressure drop, liquid holdup via existing Newtonian two-phase flow model using an effective surface roughness.
6. Calculate effective wetted surface fraction S.

7. Calculate shear stress at wall by

$$\tau_{w,ave} = \frac{dp}{dl} \frac{D}{4} \frac{1}{S}$$

8. Calculate wall shear stress by

$$\tau = \mu_a \gamma$$

9. Go to Step #2 until the wall shear rate converges.

In Kaminsky's work, the Lockhart-Martinelli⁸ approach (see Chisholm⁹) was used to calculate the Newtonian two-phase flow pressure drops and liquid holdup fractions. This method is limited to low-pressure, small pipe diameters and a horizontal orientation. A more sophisticated approach by Taitel & Duklar can be used to predict the liquid holdup in inclined positions and for large pipe diameters.

A program using MATHCAD has been developed to predict the two-phase non-Newtonian fluid flow behavior in inclined pipes. Further work will continue for predicting the two-phase non-Newtonian fluid (Bingham Plastic, Power-Law and Yield Power-Law) behavior in annuli.

A layered-model for cuttings transport with aerated Newtonian fluid has been simulated in horizontal pipes. Seven unknowns are calculated by solving 7 equations simultaneously. The stationary bed height, concentration within the layer of moving cuttings, height of the moving slurry, velocity of the moving slurry and pressure gradient can all be calculated. An annular geometry will be considered next for applications of the layered model to cases with non-Newtonian behavior of aerated fluids.

6.4 FUTURE WORK

1. Develop a model to predict Non-Newtonian fluid/air two-phase flow pattern.
2. Continue to develop computer simulator for cuttings transport.
3. ACTS flow loop test.

6.5 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 optimum gas/liquid rate to get the maximum cuttings transport capacity of aerated fluids 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.

6.6 Nomenclature

$\frac{dp}{dl}$	= pressure gradient, pa/m
H	= no slip holdup
τ	= wall shear stress
D	= pipe diameter, m
e	= absolute pipe roughness, m
n	= effective power-law exponent
μ_a	= apparent viscosity , pa.s
γ	= shear rate, 1/s

6.7 References

1. R.D.Kaminsky,:" Predicting Single-Phase and Two-Phase Non-Newtonian Flow Behavior in Pipes," ASME vol.120 March,1998.
2. Taitel ,Y. and Dukler, A.E.:"A Model for Slug Frequency During Gas-Liquid Flow in Horizontal and Near Horizontal Pipes," Int. J. Multiphase Flow (1977)3, 585.
3. Eisenberg, F.G. and Weinberger, C.B., 1979 " Annular Two-Phase Flow of Gases and Non-Newtonian Liquid," AIChE Journal, Vol 25(2), pp.240-246.
4. Heywood, N.I., and Charles,M.E. 1979, " The Stratified Flow of Gas and Non-Newtonian Liquid in Horizontal pipes," Int. J Multiphase Flow vol. 5, pp. 341-352.
5. Bishop,A.A, and Deshpande,S.D., "Non-Newtonian Liquid-Air Stratified Flow Through Horizontal Tubes", Int. J Multiphase Flow vol.2(6), pp. 977-996, 1986.
6. Shu, M.T. 1981 " Horizontal Two-Phase Flow of Gases and Non-Newtonian Slug Flow," Ph.D thesis, Drexel University.
7. Dziubinski,M., "Flow Pattern Map for Two-System: non-Newtonian Fluid-Gas in horizontal Pipes," Inzynieria Chemiczna I Procesowa, Vol. 7(1), pp.3-19.
8. Lockhart, R.W., and Martinelli, R.C. " Proposed Correlation of Data for Isothermal Two-Phase, Two-Component Flow in Pipes," Chemical Engineering Progress, Vol.45(1), pp. 39-48.
9. Chisholm, D., 1967," A Theoretical Basis for the Lockhart-Martinelli Correlation for Two-Phase Flow," International Journal of Heat Transfer, Vol 10 pp. 1767-1778.

7. DEVELOPMENT OF CUTTINGS MONITORING METHODOLOGY (Task 11)

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

Objectives

The ultimate objective of this task (Task 11) is to develop a non-invasive technique for quantitatively determining the location of cuttings in the annular (drilling) section of the ACTS Flow Loop. 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/Gamma-Ray and Optical. Of these, we are concentrating on Ultrasound Transmitters and Sensors for Task 11.

Team Composition:

The team responsible for developing instrumentation to measure cuttings concentration and distribution within an annulus consists of Dr. Gerald R. Kane and Dr. Kaveh Ashenayi. Both are 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 since successful completion of this project requires skills from both disciplines. To achieve the objectives of this task, we will need to develop a very complicated electronic hardware/sensor and a software package that correctly interprets the ultra-sonic data received.

Progress to Date

The PC board developed by our team has been modified, and the new board has mostly been debugged in the bread-board environment. The set of commands to accommodate the new board have been modified, and we are in the process of finalizing the commands. Also, we have tested the data averaging on board.

In addition, new software have been developed for the PC that will be used to collect and analyze data. The data collection procedure was further revised and tested in conjunction with the new board. The software will start by allowing the user to setup the communication characteristics of the system. It then proceeds to identify the number of boards connected.

A set of software tools have been identified that will allow the use of a neural network package for data analysis. The software tool is called Qnet from Vesta Services, Inc., and it works with Visual Basic. It can receive data from an ASCII file, which can be generated by Access.

Also, a clear plastic test cell has been used to conduct some preliminary tests. The objective is to use this test cell and visually verify the results obtained from the sensor

boards. The results seem to indicate that it is possible to see and distinguish between different concentrations of gravel. The next step is to classify the shapes.

Approach

One of the subtasks of Task 11 is to develop a static radial test cell and to design a preliminary set of instruments to detect the presence and concentration distribution of cuttings in this cell.

The main approach being investigated is the use of ultrasound transmission and reception. The need for an inner ring will be investigated by comparing the results from two types of experiments. First, a set of rings will be placed in both the outer pipe and the inner pipe. The inner ring will act as source and the outer ring will act as receivers. The angle, at which the sound is being transmitted, will be rotated around the circumferences of the inner pipe. The sound received will be measured and compared with sound transmitted. After suitable data processing, it should be possible to get an acceptable picture of what is inside the pipe (also known as tomography). This is very similar to the MRI technique used by physicians.

In the second experiment we will repeat the same experiment except we will not use the transmitters nor sensors on the inner ring. Instead, sound transmission will be programmed to rotate around the circumference of the outer pipe from one sensor to another as each of the other sensors will serve to receive and measure the transmitted sound. A total of 4 sensors are being located around a pipe circumference at each of 3 stations in these preliminary tests.

Future Work:

The firmware will be finalized and tested. The same will be done for the data analysis software.

In this stage, the clear-plastic cell will be used to conduct two sets of experiments. First a set of rings will be located in the outer pipe and a corresponding ring in the inner pipe. The inner ring will act as source and the outer ring will act as receivers. We will measure the sound received and compare it against sound transmitted. After suitable data processing, it is expected that an acceptable picture of what is inside the pipe will be obtained.

In the second experiment, the same experiment will be repeated except we will not use the inner ring. The same clear-plastic cell and gravel will be used for calibrating the system.

After tests are completed in the clear-plastic cell and it is determined whether sensors are needed on both the outer and inner pipes or only on the outer pipe system, the next step will be to then proceed to apply the ultra-sonic system to an all steel annulus. This step is necessary since the ACTS Flow Loop has only steel pipes.

A PC based data acquisition/analysis system will be further developed and tested. The software will be finished and then it will be used to store and process information received from the set of sensors. We will use neural networks to model the effects of fluid flow on the signal received, as well as the shape of the gravel particles. This is needed due to the highly nonlinear nature of the flow. It has been shown that neural networks can successfully model nonlinear systems.

We will use the QNET DLL (<http://www.qnetv2k.com>) from Vesta Services to incorporate a neural-network software package into our program.

Next, dynamic testing will be designed and implemented in the Dynamic Test Facility developed as part of Task 12. Once the ultra-sonic measurement system is verified and confirmed in the small-scale DTF, then the system will be deployed on the ACTS Flow Loop. If it is found that sensors on the inner pipe in an annulus is essential for successful measurements with the ultra-sonic system, then the system will be limited to cases of fluid flow without any rotation of the inner pipe. On the other hand, if a system can be developed that uses only sensors on the outer pipe, then the system may possibly be used even when the inner pipe rotates to simulate drilling.

8. DEVELOPMENT OF A METHOD FOR CHARACTERIZING BUBBLES IN ENERGIZED FLUIDS (TASK 12)

Investigator: Leonard Volk (ACTS Research Associate)

8.1 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.

Task 12 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.

8.2 Objectives

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

8.3 Project Status

8.3.2 Dynamic Bubble Characterization

8.3.2.1 Dynamic Imaging

As mentioned last quarter, the static mixer did not seem to impart sufficient energy to form good foam. As viewed through the sight glass cell, there seemed to be a liquid phase and the bubbles in the foam on top of this liquid phase were large. As an alternate method of foam generation, Valve 2 (see Figure 8.1) was partially

closed while the Moyno pump was circulating fluid to provide a pressure drop. Visual observation through the sight glass cell showed that only uniform foam was flowing and that the bubble size was very small. Foam quality calculated from the fraction of water (with surfactant) removed from the system agreed with the foam quality calculated of a sample removed from the loop after adjusting for the change in pressure. For a permanent solution, a needle valve with a rather large flow coefficient has been ordered and will be installed in a leg parallel to the static mixer (see Figure 8.1).

8.3.2.2 Dynamic Testing Facility

During this quarter, a shaft stabilization assembly has been designed, constructed and installed. It eliminates almost all the shaft vibrations previously observed.

A cover for the mixing tank was constructed of 1/4"-thick clear polymethylmethacrylate. This reduces splash while filling the mixing tank, and eliminates "fountains" when valve 5 is mistakenly opened while the system is pressurized. The cover is split diametrically for easy removal.

The RPM of the Moyno pump was calibrated manually up to ~150 RPM, about 60% of its estimated maximum. We found that at higher power readings the RPM varied depending on whether one approached this reading from higher or lower RPM's. As a possible, inexpensive method of accurately measuring the pump RPM, we are considering attaching a cycle computer to the motor shaft.

A length of 1/8"-diameter stainless tubing was inserted up the 1-1/2" pipe connecting the bladder accumulator to the flow loop to remove air that accumulates beneath it (see Figure 8.1). This air is released using Valve #36.

A section of 1" clear schedule 40 PVC pipe was placed around the sight tube that runs parallel to the separator to indicate fluid level. This PVC pipe will serve as a safety shield if the sight tube (nylon-reinforced soft PVC tubing) ruptures.

A chemical injection pump was ordered and received from Milton Roy. This pump will inject foam breaker into the system whenever experiments have been completed. It can also be used to inject additional surfactant, co-surfactants, shale stabilizers, corrosion inhibitors, etc to determine their effect on bubble characteristics.

A cell (Sight Cell in Figure 8.1) consisting of a clear section of high-pressure glass tubing supported on either end by two steel end pieces and connecting rods have been ordered. This cell will allow 360-degree visual observations of the fluid without the usual restrictions of ported sight-glass cells. Because of its construction, stress relief must be provided to remove any lateral or torsional stress. These stress-relieving devices have also been ordered.

Figure 8.1b. Key to Dynamic Testing Facility Schematic

The following still need to be addressed:

- Calibrate the nitrogen manifold needle valves
- Design/construct emergency foam storage (in case we cannot break foam in real-time following a run)

8.3.3 Novel Techniques for Bubble Characterization

The 32" x 22" x 9" optical box described last quarter has been completed and the internal optical components and light baffles have been installed in preparation for verifying the instrumentation to measure foam texture and quality. A port is being installed on the Dynamic Testing Facility (Valve #42 in Figure 8.1) so that foam can be extracted and tested in the optical box.

8.4 Planned Activities

8.4.2 Dynamic Bubble Characterization

- Complete construction/installation of items listed in Section 8.3.2.2.
- Using the imaging instrumentation and software, develop a routine for bubble analysis.

8.4.3 Novel Techniques for Bubble Characterization

- Continue development of foam quality method
- Continue development of techniques for measuring foam texture.

9. SAFETY PROGRAM (TASK 1S)

Chairman, Process Hazards Review Team: Leonard Volk (ACTS R.A.)

9.1 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.

9.2 Objectives

The objectives of this task are 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.

9.3 Project Status

Most of this quarter's effort has been directed toward preparing the Action Plan. Meetings were held with Dave Hensley of Tulsa Technology Center on March 28 and April 11 to develop the training program. This will address several findings listed in the Hazard Review.

9.4 Planned Activities

- Complete the Action Plan
- Submit Action Plan to ACTF Advisory Board Members for their input.
- Issue final Hazards Review report on ACTF.
- Implement Action Plan

10. TECHNOLOGY TRANSFER

Meetings with Petroleum and Service Companies

During this past quarter (Jan, Feb & March), some of TU's ACTS personnel attended the annual Drilling Conference sponsored by the International Association of Drilling Contractors & the Society of Petroleum Engineers. This conference was held in Dallas, TX, Feb. 25 – 28. In addition, the PI attended an SPE sponsored forum on Underbalanced Drilling, March 10 - 15. These meetings provided new contacts and generated new interest in the ACTS Project. Part of the results are that Shell, MI Drilling Fluids, and Northland Energy (Canada) have been invited to attend the May 21 ABM. In addition, we have been contacted by ExxonMobil indicating they are interested in the ACTS Project. We currently expect all four of these companies to send representative to the May ABM.

ConocoPhillips continues to be a candidate, and we expect that one of their reps will attend the May ABM. Anadarko Petroleum joined TUDRP in December, 2001, but they have not yet joined the ACTS Project. They will also be attending the ACTS ABM.

Unfortunately, we have been informed that the Japanese National Oil Co. is going out of business within the next two years. For this reason, they have informed us that they will not continue to participate in the ACTS Project. Their membership will expire on July 13, 2002.

We will continue to identify and contact additional oil and service companies that will benefit by participating in this project.

ACTS-JIP Advisory Board Meeting

The next Advisory Board Meeting will held on May 21, 2002. In addition to the DOE, there are currently 11 member companies participating in the ACTS-JIP Project. They are: 1) BP-Amoco, 2) Baker-Hughes , 3) ChevronTexaco, 4) Schlumberger Dowell, 5) Halliburton, 6) Intevep, 7) Japan National Oil, 8) Petrobras, 9) Statoil, 10) TotalFina-Elf, and 11) Weatherford International.

As noted above, the JNOC membership will expire at the end of Year-3.