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1. ABSTRACT

Experiments on the flow loop are continuing. Improvements to the software for data acquisition are being made as additional experience with three-phase flow is gained.

Modifications are being made to the Cuttings Injection System in order to improve control and the precision of cuttings injection.

The design details for a drill-pipe Rotation System have been completed.

A US Patent was filed on October 28, 2002 for a new design for an instrument that can generate a variety of foams under elevated pressures and temperatures and then transfer the test foam to a viscometer for measurements of viscosity.

Theoretical analyses of cuttings transport phenomena based on a layered model is under development. Calibrations of two nuclear densitometers have been completed. Baseline tests have been run to determine wall roughness in the 4 different tests sections (i.e. 2-in, 3-in, 4-in pipes and 5.76-in by 3.5-in annulus) of the flow loop. Tests have also been conducted with aerated fluids at EPET conditions.

Preliminary experiments on the two candidate aqueous foam formulations were conducted which included rheological tests of the base fluid and foam stability reports. These were conducted after acceptance of the proposal on the Study of Cuttings Transport with Foam Under Elevated Pressure and Elevated Temperature Conditions. Preparation of a test matrix for cuttings-transport experiments with foam in the ACTF is also under way.

A controller for instrumentation to measure cuttings concentration and distribution has been designed that can control four transceivers at a time. A prototype of the control circuit board was built and tested. Tests showed that there was a problem with radiated noise. AN improved circuit board was designed and sent to an external expert to verify the new design. The new board is being fabricated and will first be tested with static water and gravel in an annulus at elevated temperatures.

A series of viscometer tests to measure foam properties have begun using foam generated by the Dynamic Test Facility (DTF). Investigation of techniques to measure foam quality and size, size distribution and shape of bubbles is continuing.

2. EXECUTIVE SUMMARY OF PROGRESS

Flow Loop Construction (**Tasks 3 &4**)
Experiments are continuing. Improvements to the software for data acquisition are being made as additional experience with three-phase flows is gained.

Modifications are being made to the Cuttings Injection System in order to improve control and the precision of cuttings injection. The existing conventional auger is installed in the Injection Tower in a vertical orientation. This has led to problems with controlling the rate-of-feed of the cuttings into the Flow Loop. At this time, it is thought that a Moyno type of pump will provide better control of cuttings injection versus the conventional auger that was used initially.

According to the contractor, Clark Reliance, a 6-inch view port has successfully past a pressure test up to 3,000 psi. We are now waiting for Corning Glass to make two other 6-inch view ports plus a 2-inch and a 3-inch view ports.

The design details for a drill-pipe Rotation System have been completed. A design review meeting was held on March 10 with engineers from Weatherford International (one of the JIP member of the ACTS Project). The various details were discussed and they offered some suggestions for improvements. In addition, U.S. Steel Corp. has agreed to provide some of the piping and machining for the system at no cost to the project.

Also, personnel from the SWACO Company have visited our facilities and are planning to deliver and install one of their Super-Auto Chokes, which includes a Control Console.
This choke valve will be used to reduce pipeline pressures below 1500 psi before any higher-pressure flow goes into the Separation Tower. The Choke and Control system have a retail value of approximately $75,000 and are being donated by Swaco to the ACTS Project.

Development of a Foam Generator/Viscometer for EPET Conditions (**Task 9b**).
A US Patent was filed on October 28, 2002 for a new design for an instrument that can generate a variety of foams under elevated pressures and temperatures and then transfer the test foam to a viscometer for measurements of viscosity. A description of this new Foam Generator/Viscometer was provided in a previous Quarterly Report (first quarter of Year-4, dated Oct. 30, 2002).

Negotiations have been completed with Temco, Inc. to manufacture the first version of a Foam Generator. Temco has agreed to provide the Foam Generator at no cost to the project. In return, Tulsa University has awarded a license to Temco to commercialize and market the device to others. The Foam Generator will be used in tandem with a high-pressure (1500 psi) and high-temperature (150 C) rheometer.

One of the objectives of this research task is to determine the relationship between surface roughness and of “slip” of foams at solid boundaries. Hence, additional cups and rotors are being machined with different surface roughness in order to quantify the affects of wall roughness and how this affects measurements of viscosity. In order to achieve these objectives, four additional rheometer cups and cylindrical rotors are being made with different surface roughness. The initial tests will be conducted over a range of foam parameters that include: foam quality, bubble size, shear rates, wall roughness, and one or more surfactants. The test foams for these initial tests will be generated by using the existing Dynamic Test Facility, a small-scale flow loop. When the Foam Generator becomes available, additional tests will be conducted over a broad range of pressures and temperatures. This research project is discussed further in Section 4.

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

Theoretical analyses of cuttings transport phenomena based on a layered model is under development. Calibrations of two nuclear densitometers have been completed. Baseline tests have been run to determine wall roughness in the 4 different test sections (i.e., 2-in, 3-in, 4-in pipes and 5.76-in by 3.5-in annulus) of the flow loop. Efforts have continued to develop a satisfactory way to inject a precise amount cuttings into the Flow Loop under all test conditions. Tests have been conducted with aerated fluids at EPET conditions. In addition, cuttings transport tests with aerated fluids have also been conducted at EPET conditions. Additional discussion of this task is provided in Sec. 5.

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

As reported previously, a detailed research proposal report was prepared and presented at the November 19th ABM Meeting to the ACTS JIP members, this research proposal was considered acceptable and suggestions were offered during the meeting. Preliminary experiments on the two candidate aqueous foam formulations were conducted, which include rheological tests of the base fluids and foam stability tests. It was confirmed that polymers greatly enhance the stability of foam, as reported by previous investigators. The development of theoretical models to predict frictional pressure losses of flowing foam is in progress. In addition, the preparation of a test matrix for cuttings-transport experiments with foam in the ACTF is also under way. These plans are discussed further in Section 6.

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

A controller has been designed that can control four transceivers at a time. A prototype of the control circuit board was built and tested. Tests showed that there was a problem with radiated noise. The signal read by the microprocessor had a 50% noise that was mainly due to the 75 kHz signal radiated from the two chokes in the circuit. Unfortunately, the chokes are required for the transceivers. In addition, the reed relays, that were used, also leaked a 75 kHz signal that further increased the noise level.

An improved circuit board was designed and sent to an external expert to verify the new design and see if this consultant had any other suggestions for improvements. His recommendations matched our proposed solutions closely. He suggested a different relay that can provide even more isolation from noise interference. But, we decided to hold this suggestion as a back up because the part proposed is hard to get, has a long lead time, and is significantly more expensive than the one our EE team proposed.

The new board is being fabricated and will first be tested with static water and gravel in an annulus at elevated temperatures. Additional discussion of this task in given in Section 7.

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

A series of viscometer tests have begun using foam generated by the Dynamic Testing Facility (DTF). Simultaneously, investigation of techniques to measure foam quality and the size, size distribution and shape of bubbles is continuing. Modifications to the DTF will make development of some new electro-optical techniques for measuring foam properties easier. The importance of residence time on foam stability is being studied. In addition, a new method has been developed for removal of corrosion products on optical windows. Also, a new computer software package for analyses of microphotos of foam has been identified and is being investigated. The status of this work is reviewed in Section 8.

Safety Program for the ACTS Flow Loop (**Task 1S**)
Section 9 provides an update on the Action Plan that has been developed for improving safety during operation of the ACTF. Furthermore, progress on implementation of the Findings, listed in the Hazards Review, is discussed.

Activities towards Technology Transfer, Developing Contacts with Petroleum & Service Company Members, and Addition of JIP Members.
The next ACTS Advisory Board Meeting will be held on May 20, 2003. We are expecting that a representative from ConocoPhillips will attend this meeting for the first time. Invitations to other potential JIP member companies, such as MI Drilling Fluids, are also being planned. Contacts with other petroleum and service companies are being pursued. This subject is discussed further in Section 10 of this report.

SUMMARY OF CURRENT TASKS FOR ACTS PROJECT

This is the third quarterly progress report for Year-4 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, 2003 and March 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 3: Addition of a Cuttings Injection/Separation System,
    Task 4: Addition of a Pipe Rotation System.
b) New research project (**Task 9b**): "Development of a Foam Generator/Viscometer for Elevated Pressure and Elevated Temperature (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) New Research project (**Task 13**): "Study of Cuttings Transport with Foam under Elevated Pressure and Temperature Conditions".
g) 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**).
h) Activities towards technology transfer and developing contacts with Petroleum and service company members, and increasing the number of JIP members.

Note: Research Tasks 6, 7, 8 and 9a were completed during the first three years of this five-year project.

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3. ACTF DESIGN AND CONSTRUCTION ACCOMPLISHMENTS (Tasks 3 & 4)

During this past quarter, a number of two-phase air/water tests have been conducted. Improvements have continued to be made in the data-acquisition software. In addition, a variety of techniques have been investigated for achieving better control of the rate at which cuttings are injected into the ACTF. These were described in the last quarterly report (Oct. – Dec., 2002). For example, a smaller diameter auger, rubber seals near the bottom of the auger, a reduction in drive gears and a reduction in the drive motor speed have all been investigated. Although, rubber seals near the bottom of a conventional grain auger do provide better control, they have only a limited life and do not provide a long-term solution. At this time, a Moyno type of injection pump is being considered in place of a conventional auger. It currently appears that a design similar to a Moyno Pump may be an alternative way to achieve a cuttings feed system that is precise, reliable and has a long life. This type of injector would utilize the positive displacement capability of a progressing-cavity type of pump. This will be investigated next.

Figure 3.1 - Cuttings Injection Hopper (right) and Separation Tower

New construction plans for a drill-pipe rotation are moving ahead on-schedule. The design details for a drill-pipe Rotation System have been completed. A design review meeting was held on March 10 with engineers from Weatherford International (one of the JIP member of the ACTS Project). The various details were discussed, and they offered some suggestions for improvements.

In addition, U.S. Steel Corp. has agreed to provide some of the piping and machining for the system at no cost to the project. United States Steel (USS) is being exceptionally helpful in assisting us in obtaining the drill pipe to meet our special requirements. A Teflon supplier has been identified. Suppliers for the drive system and other component parts have also been identified.

Installation of stainless-steel strainers in the piping downstream of the Separation Tower, which returns flow to tankage after passage through the flow loop, is still pending an appropriate time when this activity will not interfere with experiments. The purpose of these strainers is to remove fine solids from the fluids before they are returned to the storage tanks. This minimizes solids passing through the various pumps that take fluids from the tanks. Solids passing through pumps generally reduce their life and increase maintenance time.

According to the contractor, Clark Reliance, a 6-inch view port has successfully past a pressure test up to 3,000 psi. We are now waiting for Corning Glass to make two other 6-inch view ports plus a 2-inch and a 3-inch view ports. As soon as they are received by Clark Reliance, these remaining view ports will be pressure tested and then sent to Tulsa for installation on the ACTF.

SWACO has re-confirmed their intention to donate to the ACTS Project a Super-Auto Drilling Choke. Personnel from the SWACO Company have visited our facilities and are planning to deliver and install one of their Super-Auto Chokes, which includes a control console. This valve will be used to reduce pipeline pressures below 1500 psi before any higher-pressure flow goes into the Separation Tower. This Choke and control system has a retail value of approximately $75,000 and is being donated by Swaco to the Project. Delivery to the ACTF is expected to occur in either late April or early May.

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

Investigators: Mark Pickell, Troy Reed and Leonard Volk

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 that are free of the influences of drainage (syneresis) and bubble coalescence and can quantify the effects of surface roughness on "wall slip".

4.1 The Need for New Instrumentation and a Process

One of the important findings from Research Task #9, flow-loop tests with 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 revealed that there is currently no commercially available instruments designed to accomplish the above list of measurements for foams.

As noted above the apparatus is termed a Foam Generator/Viscometer. It provides a means by which the rheology of foams, emulsions or other shear-sensitive media may be measured. Liquid components (such as surfactant and water) are selectively combined with a gas (such as nitrogen, air or other gases) in various ratios, mixed to a desired consistency, and allowed to flow under controlled conditions (pressure, temperature, and flow rate) through a modified (variable surface roughness) Couette-type rotary Viscometer at such a rate that the viscosity of the foam is determined while its properties (bubble size, quality, pressure, temperature, and viscosity) are maintained constant.

4.2 Progress – Foam Generator

Negotiations have been completed with Temco, Inc. to manufacture the first version of a Foam Generator. Temco has agreed to provide the Foam Generator at no cost to the project. In return, Tulsa University has awarded a license to Temco to commercialize and market the device to others. The Foam Generator will be used in tandem with a high-pressure (1500 psi) and high-temperature (150 C) rheometer.

A meeting with Temco personnel has occurred, and the details of the design are being finalized. It is expected that the first prototype will be delivered to the ACTS Project sometime in the late spring of this year.

4.3 Progress – Viscometer

Investigator: Aimee Washington (MS Student)

Project Title: "An Experimental Study of the Viscosity of Drilling Foam Using a Foam Generator/Viscometer"

Part of TASK 9b OBJECTIVES

- Discover a method of applying a uniform rough surface to the inside of the cup and the outside of the rotor in a Couette-type Viscometer.
- Discover a way to quantify the rough surface
- Calibrate the RS300 rheometer that will be used for viscosity measurements.
- Conduct preliminary tests using commercially available foams
- Connect the Rheometer and Foam Generator, develop the procedures that are necessary to control bubble size, and measure the viscous properties of a foam under controlled pressure and temperature conditions.

A Thermo-Haake RS300 Rheometer has been selected to measure the viscosity of foams. This rheometer was chosen because it has three essential features. It is designed to: 1) allow flow through the pressurized viscometer cup, 2) operate at pressures up to 100 bars (1500 psi), and 3) at temperatures up to 150 C. It is a Couette type of viscometer with rotors that turn inside a stationary cup.

Part of the research plan is to fabricate up to 4 additional rotors and cups with different amounts of roughness machined on to their surfaces. The purpose is to investigate how this affects the "slip" of foam at a solid boundary. It is known that when slip occurs within a viscometer, the viscosity of a foam will be underestimated because it shears less than a fluid that has no wall slip.

Another factor that is different for a foam compared to conventional liquids is that a foam tends to fill the space between the cup boundaries and the internal rotor. The RS300 is designed to test conventional liquids that are placed in the pressurized cup cell to a level that is only slightly above the rotor. At the top end of the rotor, there is a round magnet that is rotated by an external magnetic drive system. The clearance between the lid to the cup and this rotor magnet is relatively small. When foam fills this space it adds additional drag on the rotor. The purpose of calibrating this device with one or more calibration fluids, that have a certified viscosity, is to correct for end effects and bearing drag. Since the standard calibration fluids are liquids that do not slip at the solid boundaries, they provide corrections that are too high compared to a foam, if the foam is allowed to slip above and below the gap between the wall of the cup and the outer surface of the cylindrical rotor, the primary measurement area. For this reason, the internal surfaces above and below the rotor must have a surface roughness that will not allow wall slip for any of the foam test conditions.

A relative large roughness for the surfaces above and below the rotor has been selected and will be machined inside the four additional cups and rotors. In addition, different values of surface roughness will be machined on the cup and rotor surfaces that face each other to form the gap that constitutes the primary measurement area for determining viscosity. The advantage of machining the roughness is that it maintains the gap clearance between the cup surface and the rotor's cylindrical surface. In addition, it is easier to achieve a uniform roughness on all of the surfaces.

The following is a description of how the RS300 is calibrated. The rheometer readings are based on the measured torque acting on a given rotor. In addition to the size and geometry of a rotor, properties of the test fluid, the end effects, and bearing drag all 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 a torque that is due only to shearing of the fluid in the gap.

Three standardized oils with viscosities of 9.493 cP at 20.0 ºC (Cannon Viscosity Standard S6), and 51.92 cP at 20.0 ºC (Cannon Viscosity Standard), and 108.3 cP at 20.0 ºC were used to calibrate over a range of rpms from 10 to 600. The Taylor number was calculated for each situation and it was found that the formation of Taylor vortices begins after 300 rpm with the 9.493 cP oil. Because of this, the standard procedure was modified to step from 50 to 100 to 150 to 200 to 250 to 300 rpm in order to avoid turbulence. An excel spreadsheet was devised to allow the data produced by the rheometer to be converted into the corrected torque values, i.e., without end effects and bearing drag. The corrected torque values are used to compute the correct viscosity for a given fluid. It was also found that the standardized viscosity oils create three distinct curves when the corrected torque divided by the measured torque given by the rheometer is plotted over rpm. This requires an interpolation between the curves when the viscosity of a foam falls between them.

In order to make productive use of time, the rheometer was connected to the small-scale Dynamic Test Facility flow loop. The foam generator will be used when it is completed. Preliminary testing with foam has begun. First, the setup was inspected to make sure all the equipment was working and that the foam flowed through the rheometer without leaks. Some minor adjustments were made to the small flow loop in order to accommodate the attachment of the rheometer and the easy reading of the pressure sensors.

Next, the height to which the foam fills the cup had to be verified. This was accomplished by preparing a starch-dye solution using a mixture of flour, water and dye. The hardening time and composition of the mixture was tested on stainless steel spoons that were allowed to dry upside down for varying amounts of time before stirring violently for one minute in water. This mixture was applied with a paintbrush along the sides of the cup and in the lid. The mixture was allowed to harden for 25 minutes before circulating foam was introduced for 10 minutes at 300 rpm. The cup was then inspected for remnants of the starch-dye mixture. The theory was that the mixture would be washed away everywhere that the foam had been in contact with. This proved that indeed the foam fills the cup when attached to the small flow loop; although, the portion lower than the entrance hole contains a larger volume of the foam than the uppermost portion.

Additional preliminary tests are being performed to determine final test procedures while the rotors and cups are being machined.

4.4 Future Plans

The RS300 will be used to measure the viscosity of foams generated by the Dynamic Test Facility (DTF) flow loop that has been developed as part of Task #12. This loop is currently being used to generate foams and measure their physical properties such as bubble size. Since the Foam Generator will not be available until later in the year, the DTF will be used as a foam generator at low pressures and ambient temperatures.

Once the Foam Generator is available, foam can be generated at higher pressures and temperatures. In addition, cups and rotors with varying degrees of wall roughness will be machined. The corresponding modified versions of the RS300 will then be connected to the Foam Generator, and new foam viscosity data will be obtained to systematically study the effects of wall roughness on measurements of foam viscosity. The initial tests will attempt to repeat the data obtained with the DTF.

Finally, standard procedures will be developed for using the new apparatus to study the viscous properties of foams under a variety of conditions, including elevated pressures and temperatures.

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

Investigator: Lei Zhou (Ph.D. Candidate)

OBJECTIVES

1. Develop two-phase flow model for aerated fluids at elevated pressure and temperature 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 temperature conditions.

5.1 PAST WORK

The porosity of packed cuttings has been measured in the lab. Different volumes in graduated cylinders were used to eliminate the effect of the container surface. A detailed report is available. The average porosity of packed cuttings is 38%. And the cutting density is 2.61g/ml.

The nuclear densitometers have been calibrated for a range of air/water/solid mixtures. The test results (Figure 5.1) show that the radiation field is not uniform across the annular space. This causes different locations to receive different amounts of radiation.

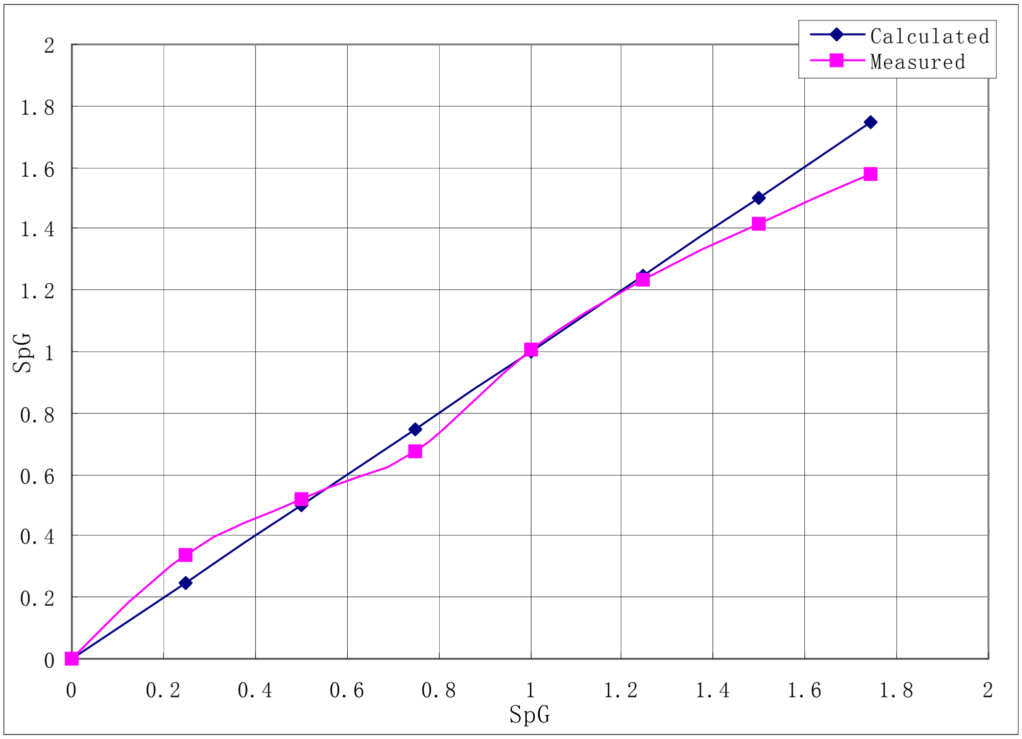

Figure 5.1 - Calibration of a Nuclear Densitometer

In order to measure the effective pipe wall roughness and related friction factors for the hydraulic model, water was pumped through the 3'' and 4'' pipes and the annular section at different flow rates. By recording the differential pressure data, the pipe roughness and friction factor can be back calculated.

Tests have also been conducted with water and cuttings flowing through the ACTF. During these tests, cuttings were injected into the flow loop, and returned to the collection tower. Both water flow rates and cuttings injection rates were varied. As discussed in Section 3 of this report, a variety of ideas have been explored for reducing the free-flow of cuttings through the auger and maintaining precise control of the rate at which cuttings are injected. A smaller diameter auger, rubber seals near the bottom of the auger, and a change of drive gears and a reduction in the drive motor speed have all been investigated. At this time, a Moyno type of injection pump is being considered in place of a conventional auger. The positive displacement, that this type of pump offers, should provide the precise control that is needed for the injection system.

Additional three-phase air/water/solids tests have also been conducted at elevated pressures and temperatures. Air/water/cuttings flow tests were run from the proposed test matrix. Cuttings were injected at various rates. Temperature was increased from ambient to 80 F and 120 F. Air was injected at the rate of 60 and 80 SCFM. Water flows rate varies from 100GPM to 250 GPM. Some of the parameters measured during these tests include: temperature, static and differential pressures, mixture density, and liquid holdup. In addition, the changes in response of the injection auger to a two-phase compressible flow were studied. Also, the three-phase holdup system has been tested by trapping mixtures in the annular section. The process of allowing gas to expand from the mixture, captured in the annulus, to an expansion tank provides a way to calculate the gas volume fraction. A noticeable pressure drop in the annular section was observed. This system works quite well and is considered to be very successful.

A computer simulator is under development to predict the cuttings concentration, cuttings bed height, and frictional pressure losses in the pipe and annulus.

5.2 PRESENT WORK

1. Conducting cuttings transport test with aerated fluids under EPET conditions.

2. Data analysis.

3. Solving layered model equations for cuttings transport with aerated fluid in annulus section at horizontal position.

A Mechanistic Model

A two-phase flow model is proposed to calculate the air/water flow in annular section under EPET conditions. The liquid holdup, frictional pressure drop, slug length and slug frequency can be computed based on conservation of mass and momentum equations and empirical correlations.

A three-phase (air/water/cuttings) flow model is being developed to calculate the cuttings concentration, cuttings bed height, fluids velocities, and frictional pressure losses in the annular section. The model is based on mass conservation equations for each phase, momentum equations, and forces balance equations. The following assumptions are utilized to simplify the three-phase model:

1. The flow pattern in an annular is considered to be steady state and both the liquid and cuttings are treated as incompressible materials.

2. Size of the cuttings in the stationary bed and the moving layer will be assumed to be uniform. This simplification also provides a bed with a constant porosity.

3. Liquid density and rheological properties are assumed constant for a given temperature and section of a wellbore. (The proposed model will be applicable to the annular sections of a well by specifying an average temperature and pressure for a given length of the annulus.)

4. Isothermal flow

5. The effects of a rotating inner pipe will not be included in this model.

A layered (liquid/solid) model will be coupled with a two-phase (gas/liquid) model in order to solve the problem. The flow of cuttings with aerated fluids is visually observed in the TUDRP low-pressure loop. Figure 5.2 and Figure 5.3 present the cross-sectional area and side view of cuttings transport with aerated fluids in an annulus, respectively.

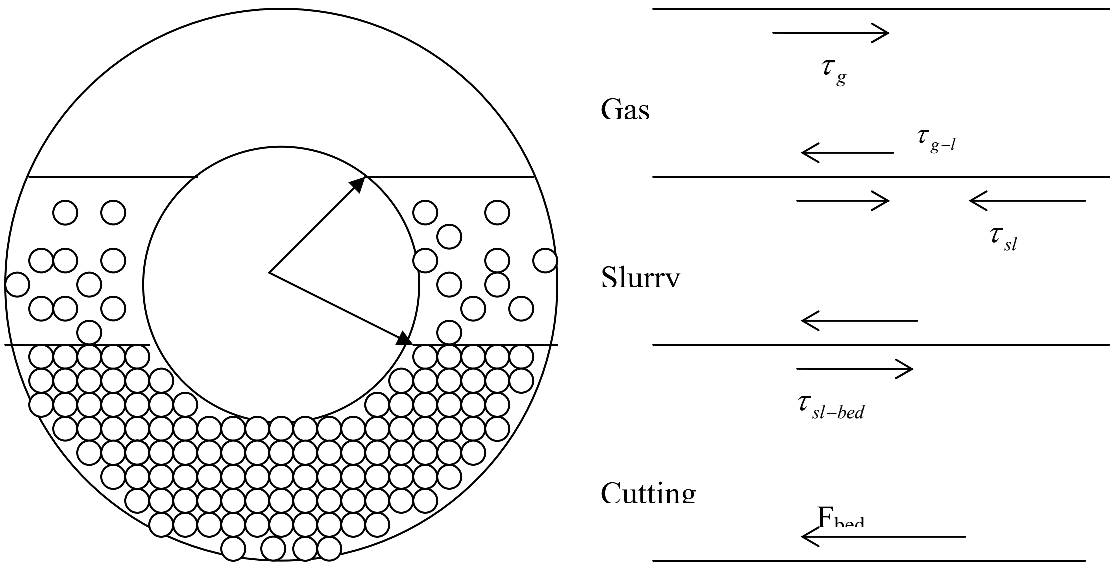

Figure 5.2 - Schematic of Cuttings Transport with Aerated Mud in an Annulus

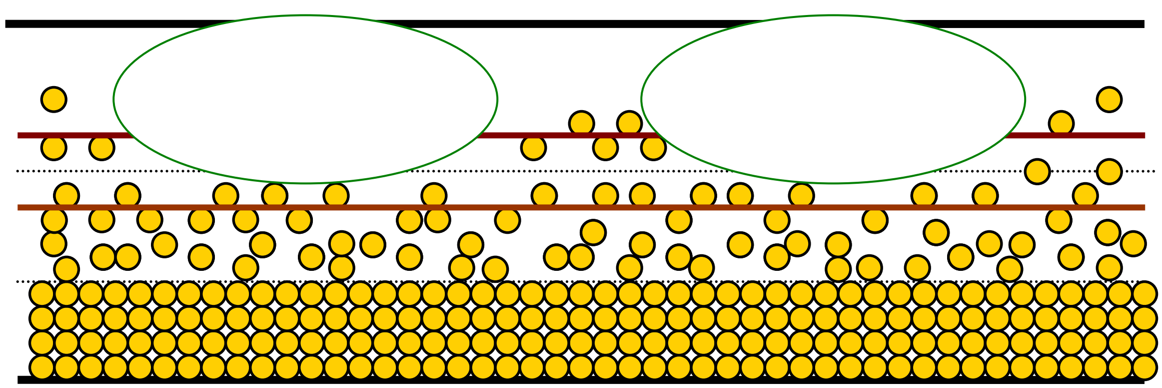

Figure 5.3 - Side View of Cuttings Transport with Aerated Mud in an Annulus

Because of the presence of cuttings, the gas/liquid flow area is narrowed to a smaller space in the top of annulus. This promotes the formation of slugs. Below the slug-flow layer, a heterogeneous layer of dispersed cuttings move in the direction of fluid flow, but with a reduced velocity due to slip between the solids and the transporting fluid. A cuttings bed is deposited at the bottom of the annulus, which may or may not move.

The unknowns in this problem are: in-situ concentrations of cuttings, gas, and liquid; the in-situ flow velocity of each layer; the thickness of each layer. There are a total 9 variables that need to be determined. The equations that can be used are: 3 mass conservation equations for each phase, 3 momentum equations for each layer, sum of concentrations is equal to 1, sum of layers' cross section area must equal the annular area. Also, the mixture density can be measured to give an additional equation. So a total of 9 independent equations can be used to solve the 9 unknowns. This system of equations is highly non-linear.

In addition to mass and momentum equations, the dispersion mechanism of the solid particles in the liquid should be taken into account. Also, empirical correlations will be used to calculate the interfacial frictional factors.

Experimental Setup

The Advanced Cuttings Transport Flow Loop of the University of Tulsa is being used for this experimental study. The test facility consists of 1) pump system, 2) air injection system, 3) heating and chilling system, 4) cuttings injection/ collection system, 5) piping system, 6) multiphase measurement system, 7) water storage tank, and 8) data acquisition system.

The cuttings injection and collection system (Figure 5.4) consists of: 1) injection tower, 2) collection tower (3-phase separation tower), 3) auger to fill the injection tower, 4) injection auger to feed cutting into the flow loop, and 5) weight measurement system. Injection Tower is 22ft high and is used to hold the cuttings. The Collection or Separation Tower is 36ft in height, which is used to separate the three phases (gas, liquid, solids). The cuttings are fed to the injection tower by using the transfer auger. A grain auger is used to load gravel into the injection tower. (A sieve analysis was done to determine whether this auger causes any significant grinding and reduction in size of the gravel during the loading process. The sieve data indicate that the loading process does not cause any significant degradation in particle size.) A motor-driving auger is installed inside the injection tower in a vertical position. By turning this auger, cuttings are fed into a 4-inch pipe, which is at the bottom of the injection tower, and are then transported by the air/water mixture. The weighing system consists of load cells, transducers, and a digital indicator. At the bottoms of the injection and collection towers, there are three load cells, installed at 120^{o} apart, to measure the weight of each tower. The real-time readings of the weight can be shown on the indicators and a computer screen in the control room. This enables the cuttings injection and collection rate to be known and controlled.

Figure 5.4 – Cuttings Injection (right) / 3-Phase Separation System (left)

The multiphase measurement system (Figure 5.5) has five components: 1) two-quick close valves, 2) one bypass valve, 3) two nuclear densitometers, 4) flushing lines, and 5) an air expansion tank. When the steady-state flow is established in the annular section, the weight change of the Injection Tower equals the weight change of the Separation Tower. At that point, the quick close valves can be closed nearly instantaneously. At the same time, a bypass valve is opened to allow the slurry to flow directly to the collection tower. This enables a certain amount of air/water/cuttings to be trapped in the annular test section. Then, an air expansion tank can be used to help measure the volume of air inside the annular section based on the appropriate equation of state. Also the nuclear densitometers can measure the mixture density, which, in turn, can be used to back calculate the volumetric concentrations of each phase. A flushing system is installed in the annular section. Its purpose is to provide a water flow to flush solids, trapped in the annulus, to the Separation Tower so that they can be weighed.

Figure 5.5 – Expansion Tank for Multiphase Measurement System

5.3 FUTURE WORK

1. Complete development of a model for the flow of two-phase fluids (gas/Newtonian liquids) through pipes and concentric annuli geometries at Elevated Pressures and Temperatures (EPET).

2. Complete the derivation of a mechanistic model for cuttings transport through concentric annuli with aerated fluids (gas/Newtonian liquids) at EPET.
   (No pipe rotation.)

3. Develop a computer program, based on the mechanistic model, that will quantify how well cuttings are transported through annuli over a range of liquid and gas ratios and flow rates at EPET.

4. Conduct a series of flow loop tests over a range of air/water ratios and flow rates at EPET, with and without cuttings, in a horizontal annulus.

5. Analyze experimental results and make comparisons with the mechanistic model.

5.4 DELIVERABLES

1. Semi-annual Advisory Board Meeting (ABM) reports.

2. A two-phase flow model for mixtures of gas and Newtonian liquids flowing through pipes and concentric annuli under EPET conditions.

3. A mechanistic model for cuttings transport through concentric annuli with two-phase fluids (gas/Newtonian liquids) at EPET. (No pipe rotation.)

4. Experimental data from tests with two-phase (air/water) fluids flowing through a concentric annulus at EPET, with and without cuttings, in a horizontal annulus.

5. Practical guidelines and/or graphs to determine the amount of cuttings that exist in an annulus over a range of gas/Newtonian liquid flow rates at EPET.

6. Study of Cuttings Transport With Foam Under Elevated Pressure and Elevated Temperature Conditions (Task 13)

Investigator: Zhu Chen

6.1 Introduction

This research is a continuation of the two research projects (Tasks #6 and #9) done in the University of Tulsa Drilling Research Projects (TUDRP) on foam rheology and cuttings transport. Task 6 investigated cuttings transport with foam under low pressure and ambient temperature conditions, and Task 9 studied foam rheology under Elevated Pressure and Elevated Temperature (EPET) conditions.

Foam is a currently being used as drilling fluid in Underbalanced Drilling (UBD) because it can provide downhole pressured that are less than formation pressures, which is the definition of "underbalanced". Foam can also provide control of the Equivalent Circulating Density (ECD). Drilling with foam has demonstrated that it can provide such advantages as minimizing formation damage, increasing rate of penetration and preventing lost circulation, etc. However, when compared with traditional incompressible fluids, such as water-based or oil-based drilling fluids, foams are significantly more complex. There is no general agreement on a foam rheology model, and little research has been done on foam rheology for practical downhole conditions. Furthermore, there is an absence of reliable data on cuttings transport with foam. Little work has been done, and there is almost no publicly available knowledge on foam cuttings transport properties under practical down-hole conditions. A better understanding of foam cuttings transport characteristics may lead to advancements in the technology of underbalanced drilling with foams.

In order to meet the increasing interest in foam drilling by the petroleum industry, based on the issues discussed above, the University of Tulsa ACTS/JIP proposes an extended research program in this field. The title of this project is indicated above. It includes two research areas: foam rheology study under EPET conditions and cuttings transport study with foam under EPET conditions.

6.2 Objectives

The objectives of this research are to:

1. Conduct an experimental investigation of foam rheology in pipes and an annulus under ETEP conditions.

2. Experimentally determine and numerically predict volumetric requirements for effective cuttings transport with foam in horizontal wellbores under EPET conditions, initially without pipe rotation.

3. Develop a mechanistic cuttings-transport computer simulator for foam under elevated EPET conditions for down-hole drilling applications.

4. Verify the computer simulator via comparisons with experimental data.

6.3 Project Status

Literature Review	Foam Rheology	80%
	Cuttings Transport	75%
Learn Operations of ACTF		80%
Conduct Experiments	Foam Rheology	5%
	Cuttings Transport	0%
Model Development	Mechanistic model	0%
	Computer Simulator	0%
	Simulator Verification	0%

6.4 Summary of Activities

The following major tasks have been undertaken since September 2002:

- Literature review on foam rheology and cuttings transport.
- Research proposal preparation and presentation at the ABM meeting.
- Preliminary experiments with base fluids for foam and foam stability.
- Flow loop experiment preparation, getting familiar with ACTF and test procedures.
- Began development of a model to predict frictional pressure losses of foam flow.

6.5 Literature Review on Foam Rheology and Cuttings Transport

A literature review of theoretical and experimental works on foam rheology and cuttings transport with foam under EPET conditions was carried out. From the literature, it was found that foam rheology has been studied extensively. Foams can be characterized by the Power Law model, Bingham Plastic model, or Herschel–Bulkley model. Though there are extensive papers on foam properties, there are only a limited number of papers addressing the problem of characterizing foam rheology under EPET conditions. The first detailed systematic study of pressure and temperature on foam rheology was done by Lourenco (1). He carried out experiments on how pressure and temperature influence foam rheology with the ACTS Flow Loop and developed a hydraulics model based on a Power Law rheological model and use of the Volume Equalized Principle. This task will be a continuation of his research in the field of foam Rheology. The research will include cuttings transport with foam under EPET conditions. It was found that little research has been done in this area. There are a number of papers on cuttings transport with conventional fluids, but there are very few published papers on cuttings transport with foam. Cuttings transport with foam was studied by Okpobiri (2) in vertical wells in 1982, and in horizontal wells by Özbayoglu (3) recently, but these experiments were conducted under low pressures and ambient temperatures, no literature was found on systematic experimental studies of cuttings transport with foam under EPET conditions. Hence, this confirms that there is a definite need for research in this subject. The proposed experimental research will be conducted with the ACTF. In addition, a mechanistic model for cuttings transport with foam at EPET conditions will be developed. This mechanistic model is expected to have an advantage over traditional correlation methods and should produce more accurate cuttings transport prediction over a wider range of foam drilling conditions.

6.6 Preliminary Experiments on Foam Base Fluids and Foam Stability

It has been found that foam texture and foam formulation play a great role in foam rheology. in order to better represent actual drilling practice, this research will include a study of the effects of adding polymers to the foam formulation, which has been reported previously (4). Since this type of base fluid is different from earlier experiments done by TUDRP, it is necessary to characterize the base fluid with varying pressure and temperature, and study the relationship between foam prosperities with respect to the base-fluid properties.

The following experiments were run in order to estimate the effect of pressure and temperature on rheological properties of some polymer base fluids. The test matrix with Fann75 Viscometer (or possibly with Chandler Model 3500LS Viscometer, which can only measure base fluid viscosity at temperatures below the bubble point) is proposed. The proposed test matrix is given in Table 6.1. It can be seen that in these base-fluid rheological experiments, the pressure and temperature are wider than that in the test matrix of the ACTS flow loop experiment (see Tables 6.3 and 6.4). The test temperature and pressure of the Fann 75 HPHT viscometer are somewhat higher than the flow loop capabilities because the purpose is to define the viscous properties of the base fluids. Tests within the ACTF flow loop will be multiphase tests, and the maximum test pressure is determined by the available compressor and the Moyno pump. It is expected that the wider range of rheology test with a Fann75 Viscometer will give a better understanding of the behavior of the foam base fluid.

Table 6.1 - Fann 75 HPHT rotational viscometer experiment test matrix

	Pressure, psig			
Temperature, ^oF	200	400	600	800
80	θ600-θ3*	θ600-θ3	θ600-θ3	θ600-θ3
130	θ600-θ3	θ600-θ3	θ600-θ3	θ600-θ3
180	θ600-θ3	θ600-θ3	θ600-θ3	θ600-θ3
230	θ600-θ3	θ600-θ3	θ600-θ3	θ600-θ3

*Shear Rates: 600 RPM, 300 RPM, 200 RPM, 100 RPM, 6 RPM, 3 RPM

The operation manual of Fann75 HPHT Viscometer has been studied, the F0.2 spring and other parts of this instrument to study foam base fluid have been ordered, the parts are expected soon. These experiment will be done as soon as the parts are available. Also, the newly arrived Chandler Model 3500LS Viscometer has also been calibrated and is now ready to use. Hence, the Chandler viscometer is being used first to study the effects of varying temperature on base fluids for a foam.

To date, the rheology of two candidate aqueous foam base fluids have been measured with a standard Chan 35 at ambient temperatures. Two types of polymers were added to the base fluid, which consists of water and a foaming agent. Table 6.2 shows some of the measured data for the two base fluids.

Table 6.2 - Rheological Data for Base Fluids using Chan 35 Viscometer

Formulation	Reading						Rheological model (PL)
	θ3**	θ6	θ100	θ200	θ300	θ600	
Formulation A*	3	4	9	12	13.5	18	$\tau = 1.60\ \gamma^{0.35}$
Formulation B*	2	2.5	7.5	10	11	14.5	$\tau = 1.14\ \gamma^{0.37}$

*Formulation A: 5g foaming agent + 1.25g Xanthan (polymer) + 0.5g PAC(polymer) 495g water + 0.25 Nacl (pH=9) ; Formulation B: 5g foaming agent + 1g Xanthan (polymer) + 495g water + 0.25 Nacl (pH=9)
**Shear Rates: 600 RPM, 300 RPM, 200 RPM, 100 RPM, 6 RPM, 3 RPM

In addition, foam stabilities were also measured using the parameter "half-life" time. The half-life time is the time when half of the foam volume is lost through drainage. A high half-life time indicates a more stable system. These tests were also performed under surface conditions. Figure 6.1 shows the results of a specific foam stability test, and the first results are encouraging, it can be seen that with the polymer added in both of the foam base fluid, the foam stability increases significantly. With better foam stability, the foam will expect to increase the carrying capacity and resistant to influx of formation water into the foam system.

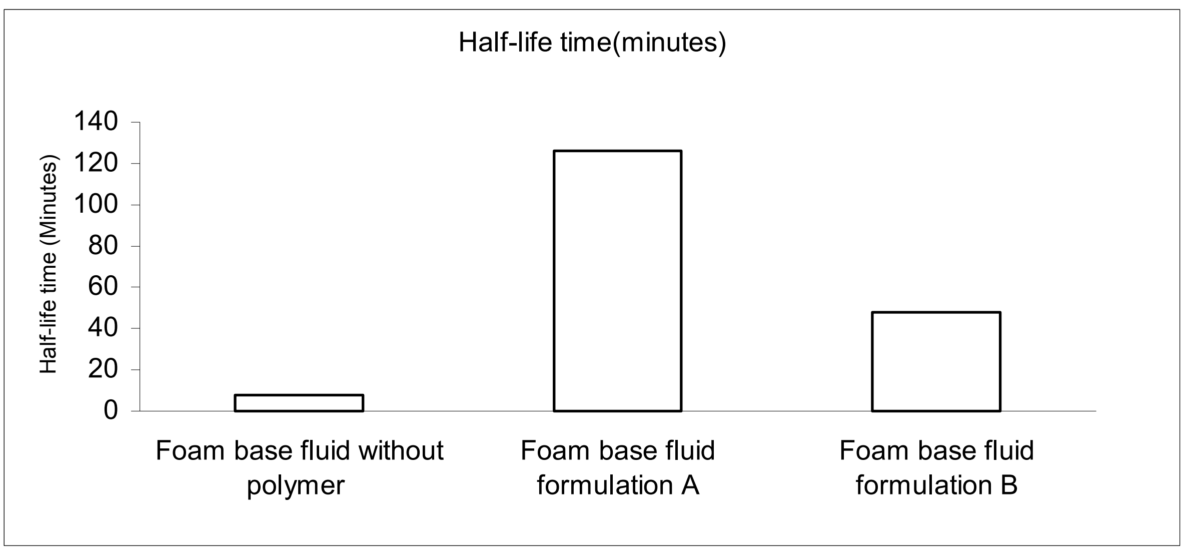

Figure 6.1 - Comparison Tests of Foam Stability with and without Polymers

6.7 Preparations for Flow Loop Experiments

Since September 2002, work is continuing becoming familiar with the flow loop and its operation during tests. The main activities during this period were: cuttings injection rate control and calibration; calibration of the weighing systems for both the Injection Tower and the Separation Tower; and experiments on cuttings transport with aerated mud for Task 10, which includes three-phase flows with solids, air and water.

At present, this flow loop has all the 5-year design capabilities except pipe rotation and annulus inclination. The ACTF has all the equipments utilized in the cuttings transport with foam experiment, i.e., liquid storage tank, liquid injection pump, tri-phase Moyno pump, surfactant metering pump, defoamer metering pump, air compressor, boiler, heat exchangers and chiller, foam generator, cuttings Injection Tower and cuttings Separation Tower, data acquisition system, pressure control valves, etc.

After Lourenco conducted foam flow experiments in the ACTF, a great number of changes have occurred since then, the most prominent of the new features are the cuttings Injection Tower and Separation Tower, densitometers, liquid hold-up valves and an air expansion tank. In conjunction with these, new piping has also been added. But some preparation work is still needed and is now in progress. This includes such items as installation of pipes and injection quills for the defomer to break a foam before it enters the Separation Tower, debugging the LabView control system for foam tests, polymer mixing and pre-hydration before making foam, making sure the flow loop can still generate a foam flow in a safe and controlled way, developing spread sheets to analyze the experiment data and perform some pre-calculations, updating test procedures for foam experiments, as well as developing a checklist for safety and foam-specific operational issues.

In order to achieve the objectives of measuring foam rheology and flow loop tests to investigate cuttings transport with foam, the initial test matrices are shown in Tables 6.3 and 6.4. In both experiments, polymers will be added in the foam formulation. For foam rheology study, measurements will be made on volumetric flow rate, pressure drop in the 3 pipes and the annular test section for each condition. Also, foam rheology and foam texture will be studied with the Foam Generator/Viscometer. The cuttings transport tests will include ROPs in the range of 50–80 ft/hour, and measurements will include frictional pressure drops and in-situ cuttings concentration in the annulus at each condition.

Table 6.3 - Proposed Test Matrix for Foam Rheology Tests

Temperature (°F)	100	160	
Pressure (psi)	200	600	
Quality	70%	80%	90%
Flow rate (ft/s)	3 different flow rates for each test		
Pipes (in)	1.918"	2.9"	3.826"
Annulus (in)	5.76" x 3.5"		

Table 6.4 - Proposed Test Matrix for Cuttings Transport with Foam

Temperature (°F)	100	160	
Pressure (psi)	200	600	
Quality	70%	80%	90%
Flow rate (ft/s)	3 different flow rates for each test		
Annulus (in)	5.76" x 3.5"		

These test matrices represents the first effort to build a data bank necessary to further development a model for cuttings transport with foam under simulated down-hole conditions. The test matrices may be modified, reduced or expanded based on the time required to run a specific test and flow loop capabilities.
Some preliminary tests flow loop tests may be conducted prior to the May Advisory Board Meeting. However, it is currently expected that the majority of the flow-loop tests with foam and cuttings will begin in September 2003.

6.8 Development of Theoretical Model to Predict Fictional Pressure Losses of Foam Flow

The last activity is the development of a theoretical model to predict frictional pressure losses for foam flowing through an annulus. This process has been started and will build upon previous research done at TU and by others. Initial efforts are focused on understanding the existing flow models and determining how applicable they are to foam flow. It is anticipated that this will then lead to some necessary modifications to the model and/or models that are judged to be the most useful.

One possible approach is to modify Reed and Pilehvari's (5) model so that it can be applied to foam flow. Some of its advantages is that it is utilizes an "effective" diameter concept, it is valid for all flow regimes and it was developed for Herschel-Buckley fluids, which is generally valid for most fluids. Since foams can have significant yield stresses, which increase with foam quality, this approach may be useful for modeling foam hydraulics. Another possible model is that of Valko and Economides (6). By introducing the volume equalized principle they developed constitutive equations for compressible non-Newtonian flow. In foam flow, the expansion ratio was used to construct a master rheogram curve for different pressures, qualities and pipe diameters for isothermal flow. Then through the mechanical energy balance and a "constant" volume equalized friction factor, pressure loss can be predicted for an isothermal pipe flow. Also, Gardiner B. S., et al. (refs. 7 & 8) developed a relevant foam flow model that may be useful. Finally, the recent hydraulic models for foam developed by Kakadjian, et al. (9) will also be considered.

Another alternative for a foam hydraulics model is to use a software package called "MATHMATICA", which can solve higher-order nonlinear differential equations. This possibility is also being investigated. In addition, there are still other problems to solve, which will be discussed and reported later. The subject model will be based on the following assumptions: steady state, non-Newtonian behavior, slip velocity exists, two-dimensional flow, and elastic behavior will not be considered.

6.9 Future Work

- The literature review on foam rheology and cuttings transport will be continued. The intent is to keep up-to-date with any new developments in this area. The foam flow pressure loss prediction model will be developed during the first half of year 2003, and a preliminary cuttings transport with foam mechanistic model will be developed by the end of year 2003.

- Continue rheological studies of base fluids for foams over a range of temperatures and pressures with three different viscometers.
- Conduct preliminary flow-loop tests on foam rheology and cuttings transport before May 2003 Advisory Board Meeting, but this is subject to delay if the flow loop's schedule is full during this time period.
- Conduct foam rheology studies with the new Foam Generator/Viscometer, which is being development as part of Task 9b.
- Began the primary flow-loop tests with the ACTF in the fall of 2003.

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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 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 are professors in the Electrical Engineering Department at the University of Tulsa. MS level graduate students are assisting them. These students have BS degrees in EE and Computer Science. This particular combination works well 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 that is transmitted through a flowing slurry.

7.1 Approach

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

The main approach being investigated is ultrasound transmission. The need for an inner ring will be further investigated by comparing the results of two experiments. The first experiments will be done with a set of rings mounted only on the outer pipe. The angle, at which the sound is being transmitted, will be rotated relative to the sand collection. We will measure the sound received will be measured and compared with the transmitted sound. After suitable data processing, it should be 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 add one or more rings of sensors on the inner pipe. The inner ring will act as a source and the outer ring will act as receivers. Then we will repeat the experiments.

7.2 Progress to Date:

The EE team has designed a controller that can control four transceivers at a time. The prototype of the control board was built and tested. The test showed that there was a problem with radiated noise. The signal, read by the microprocessor, had a 50% noise level that was mainly due to 75 kHz signals radiated from the two chokes in the circuit. Unfortunately, the chokes are required for the transceivers. In addition, the reed relays, used in the design, leaked additional noise at 75 kHz, which added to the noise interference problem.

The board was sent to an external expert to confirm our findings and verify that our proposed solutions will solve the problem. His recommendations matched our proposed solutions closely. He suggested a different relay that has even further isolation capability. We decided to hold his suggestion as a back-up because the proposed part is hard to get, has a long lead time and is significantly more expensive than the one selected by the EE team.

The first step in reducing the noise was to replace the reed relays with a new solid-state relay. In order to reduce radiated noise, the board layout was modified. The new layout provided physical separation between the chokes and the rest of the circuit. This was needed since radiated noise is inversely proportional to the distance it is being radiated. In addition, a mu-metal shield will be placed on the chokes and the rest of the 75 kHz signal generation subsystem. The shield will be grounded to even further reduce the radiated noise problem.

The proposed modifications were tested in the bread-board environment. We have modified our set of commands to accommodate the new board functions and are in the process of finalizing the commands. Also, we have tested the data averaging capabilities of the board. We used the values received for this purpose. Even though the noise at this stage was a significant part of our signal, it was still provided good values for testing of the averaging function.

We have further developed and tested the data-collection software on the PC that will be used to collect and analyze data. The data collection software provides the user with the ability (through a Graphical User Interface) to setup the communication characteristics of the system and to time stamp the data being collected. Then it will proceed to automatically identify the number of boards (hence number of sensors) connected.

We have developed the skeleton of the analysis software. It uses an artificial neural network to classify and identify the cutting's distribution. To finish the development and fully test we need to have a noise-free signal. It is expected that this will be achieved with the new board design.

Using the bread-board implementation of our controller, some preliminary tests were conducted using a clear plastic test cell with a steel inner pipe. The objective was to use this test cell and visually verify results obtained from the sensor boards. These results seem to indicate that we are able to see and distinguish between different concentrations of sand. The next step is to classify the shape.

7.3 Future Work:

The firmware will be modified to accommodate the new hardware changes. It will also be fully tested in the real environment.

In addition to the firmware, we will be implementing our data-analysis software. Since the fluid flow is highly nonlinear in nature, we will need to account for the impact of these nonlinearities on the signal received.

We propose to use Artificial Neural Networks (ANN) to solve this problem. It has been shown that ANNs can successfully model nonlinear systems. ANNs learn by example. A given collection of representative data is needed to train ANN for a given task.

Our basic approach for training an ANN is to collect data for known flow conditions and concentration of sand and use that to train the ANN. Then the trained ANN will be able to interpolate and provide needed information. We will also use the existing density measurement system (two nuclear densitometers), that is part of the ACTS Flow Loop instrumentation, to verify our readings and use them to help calibrate the ultrasonic system.

We also need to determine if we need a set of sensors mounted on the inner pipe of an annulus. In this stage, a clear plastic cell will be used to conduct two sets of experiments. First, a series of experiments will be conducted with transceivers mounted on the wall of the clear plastic pipe. Then a variety of different conditions, such as sand concentration and fluid level, will be tested. The received signals will then be compared with the transmitted signals for each of these known conditions.

Next, a second series of tests will be conducted with a ring of transceivers mounted on both the outer pipe and the inner pipe. The inner ring will act as ultrasound sources, and the outer ring will act as receivers. Tests will then be repeated. Again, the same setup will be used for calibrating the system. By comparing the results from these two methods of mounting the transceivers, it is expected that a conclusion can be reached as to whether it is necessary to have sensors on the inner pipe. If not, this will greatly simplify the installation and use of the system on the ACTS Flow Loop.

The data collected in these experiments will be used for training the ANN analysis tool. A well-known ANN algorithm called a “BackPropagation” (BP) network will be used.

Next, the dynamic tests will be designed and implemented. Then the developed system will be used for measuring the concentration of solids in flowing slurries. The first dynamic tests will be conducted in the Dynamic Test Facility that has been developed as part of Task 12. The final step is to install the system on the ACTS Flow Loop.

7.4 Deliverable

A fully operational ultrasonic system installed on the ACTF that is calibrated over a range of slurry flow conditions.

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.

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.

8.2 Objectives

One of the primary objectives of this task is to develop the methodology and apparatus needed to measure the 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

A temporary copy of the "Optimas" software has been received, however, we have only been able to review and work with the images supplied in the software package. Attempts to get a temporary key that would allow us to work with our bubble images have been unsuccessful. However, the Optimas software is being discontinued and replaced by a new software package called “Image-Pro”. Meyers Instruments will demonstrate the new software April 10-11 at Tulsa University. In the mean time, we continue to process the bubble images manually.

8.3.2.2 Dynamic Testing Facility

As discussed last quarter, corrosion products have slowly been deposited on the optical windows. Tests have indicated that the primary culprit has been iron oxide. The presence of pipe dope, cutting oil and corrosion inhibitor did not significantly contribute to the deposition on test microscope slides. The corrosion inhibitor appears to chelate the iron rather than significantly retard corrosion. However, iron chelation did prevent deposition on glass microscope slides. Further testing revealed that we would benefit considerably by increasing the corrosion inhibitor from 0.1 to 0.2% and incorporating corrosion inhibitor in our foam tests. Furthermore, sodium bisulfite readily removed the oxidation products from the microscope slides (and optical windows), much better than a variety of common acids. The mechanism is most likely the reduction of iron (III) to iron (II), which is soluble at pHs up to 6.

8.3.3 Novel Techniques for Bubble Characterization

Average bubble size. With the arrival and installation of the second light source, we are routinely measuring the light transmitted across the loop as foam passes. As with any new techniques, we have encountered a few problems. These are itemized below.

- Deposition of corrosion products on the optical windows can modify the measured signal. Increasing the concentration of corrosion inhibitor helps. We also have a new fitting design so that it can be easily and quickly removed for cleaning the windows. We will also be examining coatings to retard the deposition of corrosion products.
- Light intensity is low for foams with very small average bubble diameters. We are designing a better signal processing electronics using an op amp to increase signal strength an improve linearity. The new electronics package is also being designed to speed up removal of the device for cleaning.

When generating foam, there are several considerations when developing correlations to the average bubble size. For a given surfactant formulation, the average bubble size is determined by:

- The opening of the needle valve that serves to generate the foam,
- The volumetric flow rate,
- The residence time in the loop
- The length of time the fluid is exposed to shear (passed through the needle valve).

In this work, we attempt to run the tests long enough so that the foam is in equilibrium. This means that the bubbles are draining and coalescing at the same rate that they are being made. The residence time in the loop determines how long the foam has to drain and coalesce between subsequent exposures to high shear of the needle valve. The residence time can be calculate as follows:

$$R_H = V_H/F_H = \frac{V_H}{F_L \{1 + Q_L [(P_L/P_H) - 1]\}}$$

$$R_L = V_L/F_L$$

$$R_T = R_H + R_L$$

Where

F = Flow Rate
Q = Foam Quality
P = Pressure
V = Volume
R = Residence time

And the subscripts are defined as:

L = Low pressure section
H = High pressure section
T = Total

Note that V_L is the volumetric flow rate of the Moyno pump. Figure 8.1 shows a much simplified schematic of the loop for ease of understanding the above equations.

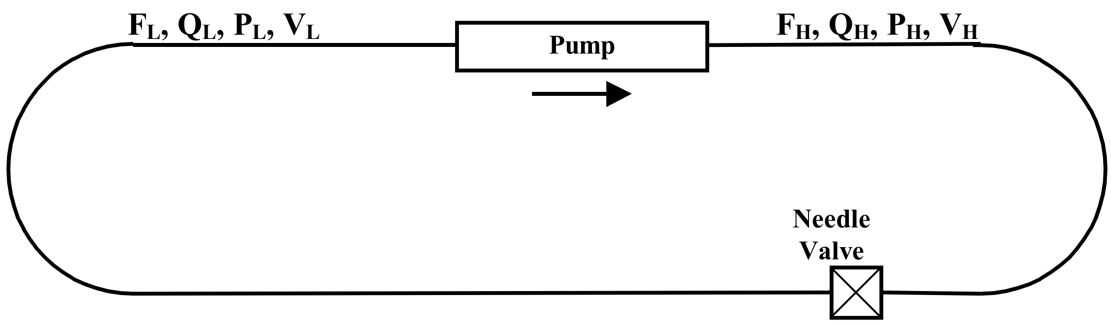

Figure 8.1. Simplified Schematic of Dynamic Testing Facility

Typical residence times vary from 30 to 60 s.

Foam Quality. Until now, the foam quality has been measured by withdrawing a foam sample from the pressurized loop into a graduated cylinder, allowing it to collapse, and compensating for bubble expansion. This technique has a few problems: (1) As a foam is withdrawn from the loop, large bubbles are formed in the withdrawal process, changing the foam quality. (2) As the foam quality increases and the bubble size decreases, considerable time is required for the foam to collapse and yield a constant foam quality. To circumvent these problems, a stainless cell has been purchased and valves installed at each end. After weighing the empty cell and cell filled with water, we can calculate the cell volume. To measure foam quality, the cell is first completely filled with water and attached to a port on the loop. Then the water in the cell is slowly displaced by foam. This process allows the foam to remain at essentially loop pressure, preventing flashing. Some additional foam is allowed to slowly flow out of the cell to displace foam that was at the foam-water interface. Repeated tests produce foam qualities within ±0.1. This technique allows us to directly measure foam quality compare this with data from the optical techniques that are under development. Since this stainless cell and associated valves are pressure rated to 1800 psi, the technique can also be used on the ACTF Flow Loop.

8.4 Planned Activities

8.4.2 Dynamic Bubble Characterization

- Locate a vendor with software adequate for our use.
- Locate a camera to give us clearer microscopic images.

8.4.3 Novel Techniques for Bubble Characterization

- Determine optimum method of maintaining clean optical windows
- Modify average bubble size device for ease of removal
- Improve electronics for average bubble size determination
- Calibrate the average bubble size prototype
- Complete construction for the foam quality prototype and calibrate.

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 Objective

The first 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.

A second objective is to establish standards for when a hazards review for the ACTS Flow Loop should be repeated.

A third objective is to develop a safety training course for all personnel that are involved in using the ACTS Flow Loop and equipment.

9.3 Project Status

As work has progressed on addressing the findings given in the Hazards Review, the Action Plan has grown. It now consists of the following sections.

- Introductory description of Action Plan
- A list of the Findings grouped by type and the line number of each applicable Finding
- Grided drawings of the ACTF.
- Component locator chart
- Action sheets for each group of findings.

The Action Plan is now 65 pages long and has generated several documents as it is being implemented. A status sheet has been created to better track the progress.
It is shown in Table 9.1

9.4 Planned Activities

- Continue implementation of the Action Plan
- Prepare for review of latest modifications to the ACTF

TABLE 9.1

CLASS AND RANKING OF HAZARDS REVIEW FINDINGS

FINDING	OCCURRENCE	CLASS	RANK	STATUS	LEAD
No monitoring of “no flow” condition of pump while operating	1, 2, 3, 8, 9, 12, 15, 31, 37, 41, 98, 118, 119	Equipment	1	10	ST
No design documentation for piping or fittings	7, 23, 24, 29	Documentation	3	20	LV
No design documentation for relief valves	32, 96, 102	Documentation	6	20	LV
No inspection documentation for relief valves	33, 97, 103	Safety	5	20	LV
Insufficient splash protection	39, 40, 48, 49, 110, 111	Safety	7	70	MP
Improper hose for application	42	Safety	7	100	MP
No design documentation for hose	43, 46, 55, 65, 121, 127	Documentation	3	10	LV
No inspection procedure & documentation for hoses	44, 47, 56, 66, 122, 128	Safety	5	10	LV
Incorrect relief valve pressure setting	45, 95, 101	Safety	7	0	MP
No pressure bleed valve	58	Safety	8	100	ST
Air hose not secured	59	Safety	5	0	MP
No reverse flow protection	60	Equipment	3	0	ST
No relief protection	61	Safety	8	0	ST
Incomplete design documentation of components (valves, etc.)	67	Documentation	4	90	LV
No written operating procedure	74, 76, 82, 84, 86, 88, 89, 91, 107, 109	Training	3	0	MP
Improper direction of released fluid	85, 92	Safety	6	50	ST
Inadequate protection against high-volume gas release	113, 115	Safety	6	0	MP
Flammable material too close to ignition source	123	Safety	7	0	MP
No secondary spill containment	124	Safety	5	0	ST
No placarding or labeling of containers or equipment storing flammable or hazardous material	125, 134	Safety	4	50	MP
Tubing incompatible with contents	126	Safety	7	100	ST
No protection against mechanical breakage – diesel site tube	129	Safety	8	0	ST
No automatic shut-off of fuel supply	130	Safety	6	0	ST
Inadequate number/location of fire extinguishers	131	Safety	7		MP
No site-specific emergency action plan	132	Training & Documentation	5	10	LV
No specific lock-out, tag-out procedure	133	Training & Documentation	3	10	LV
No specific lock-out, tag-out procedure	133	Training & Document	3	10	LV

FINDING	OCCURRENCE	CLASS	RANK	STATUS	LEAD
No corrosion inspection procedure & documentation for corrosion	135	Safety & documentation	3	10	LV
No written operating procedure	137	Documentation	5	0	MP
No documented training procedure for operating personnel	138	Training & documentation	4	0	MP
No documented safety training program	139, 145-147	Training & documentation	6	10	LV
No protecting barrier around facility	140	Safety	2	0	ST
No hazard communication training	141	Training & documentation	6	20	LV
No training or documentation on cleaning up small spills	142	Training & documentation	3	10	LV
No MSD sheets available on site	143	Documentation	4	20	LV

OCCURRENCE: Refers to the line number in the "What If" table in the Hazards Review Report
CLASS: Categorizes the findings into Safety>Training=Documentation>Equipment. The order gives the general ranking.
RANK: Ranges from 1 (lowest priority) to 10 (highest priority)
STATUS: Ranges from 0% to 100% of completion
LEAD: Indicates who is taking the lead roll in addressing the Finding

MP – Mark Pickell
ST – Steve Turpin
LV – Len Volk

10. TECHNOLOGY TRANSFER

Meetings with Petroleum and Service Companies

MI Drilling Fluids has informed us that it has decided to delay joining the ACTS Project until they see a better business climate.

We have been informed by a representative of Intevep, the research division of the national petroleum company of Venezuela PDVSA, that they will probably continue their association with TU Drilling Projects.

We have also received a response from ConocoPhillips that they will send someone to attend the May 20th Advisory Board Meeting. This is especially welcome news since they are now the third largest petroleum company in the US.

Additional invitations are being sent to other petroleum 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 20, 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.