Title: *Advanced Cuttings Transport Study*

Type of Report: *Quarterly*
Reporting Period Start Date: *Oct 1, 2000*
Reporting Period End Date: *December 31, 2000*

Principal Authors:
Troy Reed, Principal Investigator
Stefan Miska, Co-Principal Investigator
Nicholas Takach, Co-Principal Investigator
Kaveh Ashenayi, Co-Principal Investigator
Gerald Kane
Mark Pickell
Len Volk
Mike Volk
Barkim Demirdal
Affonso Lourenco
Evren Ozbayoglu
Paco Vieira
Lei Zhou

Date of Issue: *January 30, 2000*
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 and 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 second quarterly progress report for Year 2 of the ACTS project. It includes a review of progress made in Flow Loop development and research during the period of time between Oct 1, 2000 and December 31, 2000.

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

a) Design and development of an Advanced Cuttings Transport Facility (**Task 2**: Addition of a foam generation and breaker system),

b) Research project (**Task 6**): " Study of Cuttings Transport with Foam Under LPAT Conditions (Joint Project with TUDRP)",

c) Research project (**Task 7**): " Study of Cuttings Transport with Aerated Muds Under LPAT Conditions (Joint Project with TUDRP)",

d) Research project (**Task 8**): "Study of Flow of Synthetic Drilling Fluids Under Elevated Pressure and Temperature Conditions",

e) Research project (**Task 9**): " Study of Foam Flow Behavior Under EPET Conditions",

f) Research project (**Task 10**): "Study of Cuttings Transport with Aerated Mud Under Elevated Pressure and Temperature Conditions",

g) Research on instrumentation tasks to measure:
- Cuttings concentration and distribution in a flowing slurry (**Task 11**), and
- Foam properties while transporting cuttings. (**Task 12**),

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

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

1B. Tasks Completed During This Quarter

- Task **7**
- Task **8**

2. EXECUTIVE SUMMARY OF PROGRESS

Construction and development of the flow loop is continuing. During this quarter, the component parts for the air/foam system have been received and are currently being installed and connected to the loop. Usually severe winter weather has delayed the installation of additional electrical power for these new components. It currently appears that the new foam generation/breaker system will be operational in February. Additional discussion of this task is provided in Section 3 of this report. (**Task 2**)

<u>Study of Cuttings Transport with Foam Under LPAT Conditions</u>, (**Task 6**).
A preliminary suite of cuttings-transport experiments with foams has been conducted. These tests were conducted using different combinations of gas and liquid flow rates for a horizontal test section (90 degrees from vertical) and simulated constant rates of penetration of 30, 50 and 70 ft/h. The amount of cuttings in the test section and frictional pressure drops were recorded. Bed heights were measured directly in the test section from 10 different locations. The corresponding flow patterns were also observed for each combination of liquid and gas flow rate. These data will add to the data-base obtained during the earlier experiments. Analyses of the data are continuing.

In addition, another approach to modeling cuttings transport is being investigated. The use of a neural network model is discussed in Section 4 of this report. This type of model may supplement and even help provide ideas for improvements in the three-layer mechanistic model discussed in earlier reports.

<u>Study of Cuttings Transport with Aerated Muds Under LPAT Conditions</u>, (**Task 7**).
This research project has been completed, and an MS thesis has been written. The following summary is from the thesis by Paco Vieira.

Many studies have been conducted to determine the optimal hydraulic conditions when conventional drilling fluids are used. However, little information is available for cuttings transport when gasified fluids are used as a drilling fluid. Since deviated and horizontal-well drilling are now common practice and are frequently combined with the use of non-conventional drilling fluids such as gasified fluids or aerated muds, a better understanding of the cuttings transport phenomena is needed for these applications.

This study was conducted in order to help fill this gap and to gain more in depth understanding of cuttings transport in horizontal and highly-inclined wells when using gasified fluids. Extensive experiments were performed in a unique field-scale low-pressure flow loop (8" X 4.5", 90' long) at horizontal and an inclination angle of 80 degrees from vertical. Gravel with 3.29 mm average diameter was used to simulate drill-bit cuttings, and water and air were used as the liquid and gas phase, respectively. The three phases were injected into the test section of the flow loop with different combinations of volumetric flow rates and for the two inclination angles. Pressure drop, annular pressure, temperature and cuttings accumulation were recorded in each experiment through a data acquisition system. Gas-fluid interface distributions were visually observed and are reported for each experiment. Likewise, the solid-liquid distributions were classified into three different patterns and are reported for each experiment. The effects on cuttings transport of gas and liquid flow rates, drilling rate, inclination angle, pressure drop and flow patterns were analyzed in this study.

For the range of volumetric flow rates used during these tests, It was observed that cuttings are only transported by the liquid phase. It was also found that it is possible to define a boundary for the minimum air and water velocities required to avoid the formation of a stationary cuttings bed. These minimum requirements exist in the intermittent region for the gas and liquid interface distribution. It was observed that the minimum requirements for air and water injection rates are also a function of the solids injection rate. It is postulated that there is a minimum energy required for solids transport, and it is constant for a given solids injection rate. Insignficant differences were found for the effects of inclination angles between horizontal and 80 degrees from vertical.

The conclusions and recommendations from Vieira's thesis are included in Section 5.

<u>Study of Flow of Synthetic Drilling Fluids Under Elevated Pressure and Temperature Conditions</u>, (**Task 8**).
This research project has been completed, and an MS thesis has been written. The following summary is from the thesis by Barkim Demiral.

Synthetic oil-base drilling fluids have rheological and volumetric properties that are sensitive to downhole conditions. As a result, there is a discrepancy between calculated and measured frictional pressure losses. For this reason, the effects of pressure and temperature on the properties of paraffin-base drilling fluids were investigated during this research project.

The effects of pressure and temperature on the volumetric properties of a paraffin-base drilling fluid is investigated using a PVT cell. The associated N-paraffin base oil is also investigated in order to determine the effects of water: synthetic oil ration, emulsifiers and additives on volumetric properties of paraffin based drilling fluids.

Fann 70 High-Pressure, High-Temperature rotational viscometer tests are conducted with the fluid under investigation. Rheological parameters are determined for Bingham Plastic, Power Law and Yield Power Law fluids, and pressure losses are calculated using these parameters for each rheological model. In addition, rheological characterization of the fluid is carried out using the concept of RDR analysis.

In order to determine the accuracy of models in estimating pressure losses in pipes and annuli, experimental data from the ACTS flow loop is used. Frictional pressure drops were measured at various pressure and temperature conditions and compared with predictions from several models. These are the first flow-loop measurements for a synthetic oil-base drilling fluid at elevated pressures and temperatures.

The conclusions and recommendations from Demirdal's thesis are included in Section 6.

Study of Foam Flow Behavior Under EPET Conditions, (**Task 9**).
This report summarizes activities conducted since last October. The theoretical study about micro-properties of foams has been concluded. In addition, a brief description about advances in the ACTS loop is included. Some ideas about the final part of the PVT experiments are proposed, and a summary of the derivation of a model to calculate pressure drops in horizontal foam flow is shown. Section 7 of this report summarizes work on this research project.

Study of Cuttings Transport with Aerated Mud Under Elevated Pressure and Temperature Conditions, (**Task 10**).
The objective of ACTS Task 10 is to measure frictional pressure drops with aerated muds flowing through both pipes and an annular geometry under elevated pressure and temperature conditions. In addition, these tests will include cuttings transport. The purpose of these experiments will be to investigate the optimum gas/liquid flow rate combination that will give the best cuttings transport under elevated pressure and temperature conditions. It is also anticipated that a mathematical model and a computer program will be developed from this experimental data. A new Ph.D. student began working on this project during this quarter. The status of this research project is given in Section 8.

Research on Instrumentation to Measure Cuttings Concentration and Distribution in a Flowing Slurry, (**Task 11**).
Work is continuing on the development of an ultrasonic instrumentation package to measure cuttings concentration and distribution within an annular geometry.
A similar application of ultrasonic instrumentation has been developed at the U.S. Argonne National Laboratory. The relevant parts of their work are being utilized in the ACTS research on cuttings transport and drilling hydraulics. This task is reviewed in Section 9.

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

Design of the lab-scale flow loop for dynamic foam characterization and cuttings monitoring instrumentation tests has been completed. Construction of a closed flow loop and instrumentation to measure the properties of foam is underway. Additional components have been added during this quarter. has been received for measurements of static foam properties such as bubble size and size distribution. There is also an effort underway to identify and select computer software to assist with processing the photographic data. The status of this work is reviewed in Section 10.

Safety program for the ACTS Flow Loop; Progress on a Comprehensive Safety Review of All Flow-Loop Components and Operational Procedures, (**Task 1S**).
A "Process Hazards Review Committee" has been formed, and two meetings occurred during this quarter. Its mission is to conduct a safety review of the ACTS Flow Loop and operational procedures. A comprehensive list of all components of the loop is being compiled and an assessment will be made as to what is satisfactory and what needs to be changed and/or improved. In addition, procedures for operation of the loop will be reviewed for any changes that could enhance safety. This task was discussed at the December 5th Advisory Board Meeting, and all of the JIP sponsors were supportive and endorsed this process.

The necessary design drawings, component specifications and other documents are currently being collected, and a two-day review process is currently being planned for February. Additional discussion of this task appears in Section 11.

Activities towards Technology Transfer and Developing Contacts with Petroleum & Service Company Members, and Increasing the Number of JIP Members.
The next Advisory Board Meeting with ACTS-JIP industry members is being planned for May 22, 2001. In addition to representatives from our current 9 members of the ACTS-JIP Project, we also had seven other companies send visitors to attend the meeting. We have received positive feedback from 3 of the visiting companies that they are interested in becoming members of the ACTS team. Further discussion of these activities is given in Section 12.

TABLE OF CONTENTS

LIST OF TABLES

STUDY OF CUTTINGS TRANSPORT WITH FOAM UNDER LPAT CONDITIONS (Task 6, Sec 5)

SAFETY PROGRAM (TASK 1S, Sec.12)

LIST OF FIGURES

ACTF DESIGN AND CONSTRUCTION ACCOMPLISHMENTS (Task 2, Sec. 3)

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

STUDY OF FOAM FLOW BEHAVIOR UNDER ELEVATED PRESSURE AND ELEVATED TEMPERATURE CONDITIONS (Task 9, Sec. 7)

DEVELOPMENT OF CUTTINGS MONITORING METHODOLOGY (Task 12, Sec. 10)

3. ACTF DESIGN AND CONSTRUCTION ACCOMPLISHMENTS

3.1 Construction – Oct. 1 thru Dec 31, 2000

The primary construction objective for the second year is to add the capability for testing foams at elevated temperatures and pressures. During this quarter, all component parts for the air/foam system have been received and installed. All piping modifications necessary for the new components have been made. Key components of the new foam system are:

- A Moyno Pump which can deliver up to 500 gpm at low pressures or can deliver a pressure increase of 500 psi at low flow rates,
- A diesel powered Air Compressor that can deliver up to 400 cfm of air @ 200 psi,
- An air accumulator tank,
- Injection pumps for water, surfactant and a de-foaming agent,
- Liquid and air meters for controlling foam quality,
- Additional electrical power,
- Add new programming for controlling the Foam Breaker and processing of the additional test data.

The major components of the new foam generating system are: the air compressor; air accumulator tank; air/water separator; injection pumps for water, surfactant, and de-foamer; and liquid and air meters. These components are indicated in dashed lines on the updated schematic of the ACTS Flow Loop shown on the following page, Fig. 3.1.

This past quarter has been primarily focused on the transition from the past summer's tests with synthetic drilling mud and preparation for the upcoming experiments with two-phase flow and foam. This involved removal and clean-up of the synthetic mud and construction of the new system. In addition to this work, additional effort has been undertaken to define the requirements of the "clear sections" and optimize their design. These clear sections and Liquid Hold-up components are scheduled for construction during the spring 2001.

3.2 Plans for Next Quarter (Jan. – March, 2001)

Design and Construction efforts for the next quarter will consist of three subtasks.

- Start-up and calibration of the new air/foam system.
- Installation of the clear sections for the Annulus
- Add valves and components for Liquid hold-up measurements.

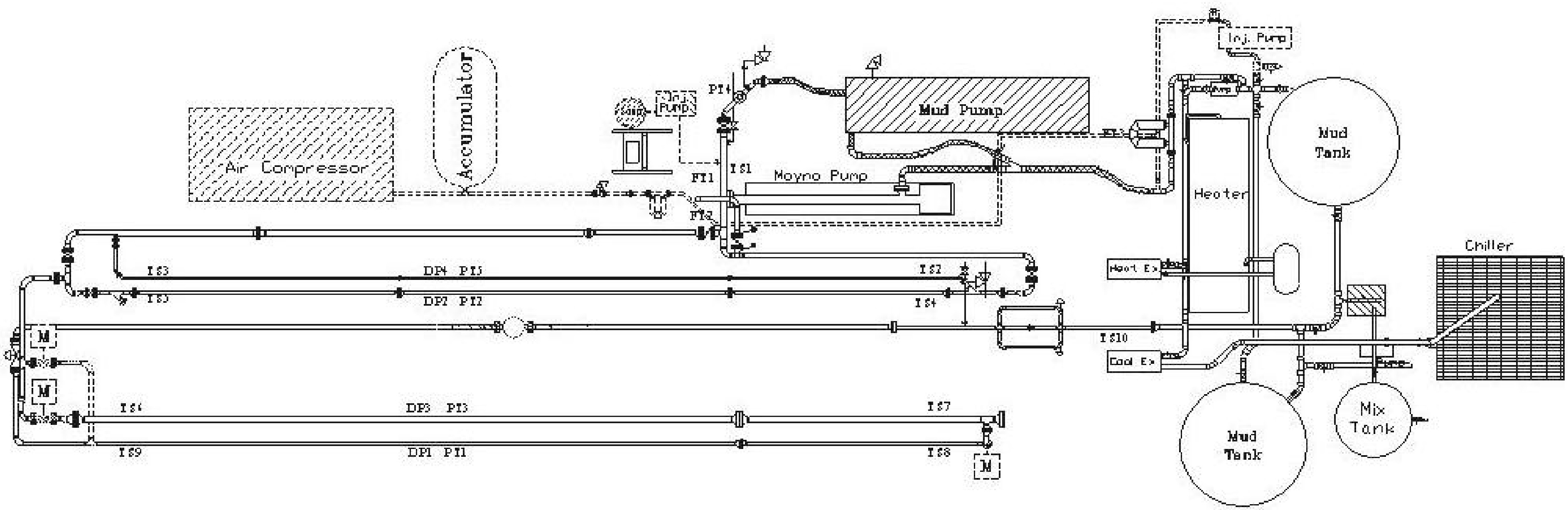

Fig. 3.1 ACTS Flow Loop with New Foam Generation Components indicated with Dashed Lines

5. 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 (numerically) 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

- A layered cuttings transport model is being developed for horizontal and inclined wellbores.
- Preliminary experiments on cuttings transport with foam are in progress.
- Development an artificial neural networks (ANN) algorithm for determination of the friction factors associated with a 3-Layer cuttings transport model is in progress.

Table 4.1 – WORK DONE

Literature Survey	Rheology of Foam	90%
	Cuttings Transport Phenomena	80%
Modification of Loop for Foam Flow	Plan	99%
	Construction	99%
Experiments Performed	Foam without Cuttings	70%
	Foam with Cuttings	10%
Model Developed	Rheology Review	90%
	Cuttings Effect	70%
Computer Simulator	Without Cuttings	90%
	With Cuttings	0%

FUTURE WORK

The literature survey on foam rheology, foam flow models and cuttings transport will continue. Experiments on cuttings transport with foam will also be continued. The experimental data will be used to help select parameters for a mechanistic model that will describe cuttings transport with foam. The results will be compared with the ANN results. A computer simulator will be based on the mechanistic model.

NEURAL NETWORKS

A neural network has a parallel-distributed architecture with a large number of nodes and connections[1, 2]. Each connection points from one node to another and is associated with a weight. A simple view of the network structure and behavior is given in Figure 1.

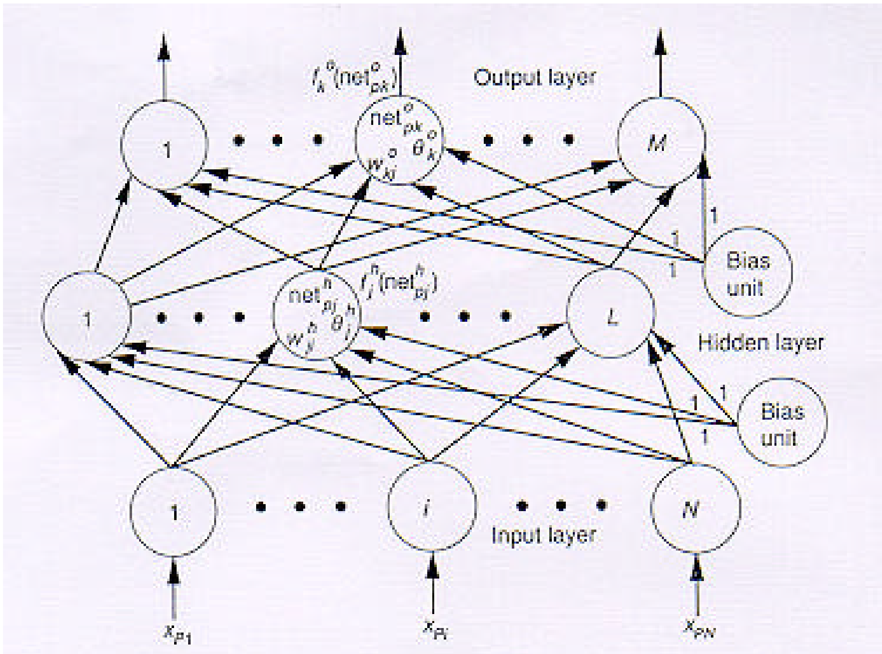

Figure 4.1 – Schematic View of a Neural Network System

Network Layers

The input layer: The nodes in it are called input units, which encode the instance presented to the network for processing. For example, each input unit may be designated by an attribute value possessed by the instance.
The hidden layer: The nodes in it are called hidden units, which are not directly observable and hence hidden. They provide nonlinearities for the network.
The output layer: The nodes in it are called output units, which encode possible concepts (or values) to be assigned to the instance under consideration.

The activation levels of nodes can be discrete (e.g., 0 and 1) or continuous across a range (e.g., [0,1]) or unrestricted. This depends on the activation (transfer) function chosen. If it is a hard-limiting function, then the activation levels are 0 (or -1) and 1. For a sigmoid function, the activation levels are limited to a continuous range of real numbers [0,1]. Figure 2 shows the sigmoid function, F(x).

$$F(x) = \frac{1}{1+e^{-x}} \qquad (1)$$

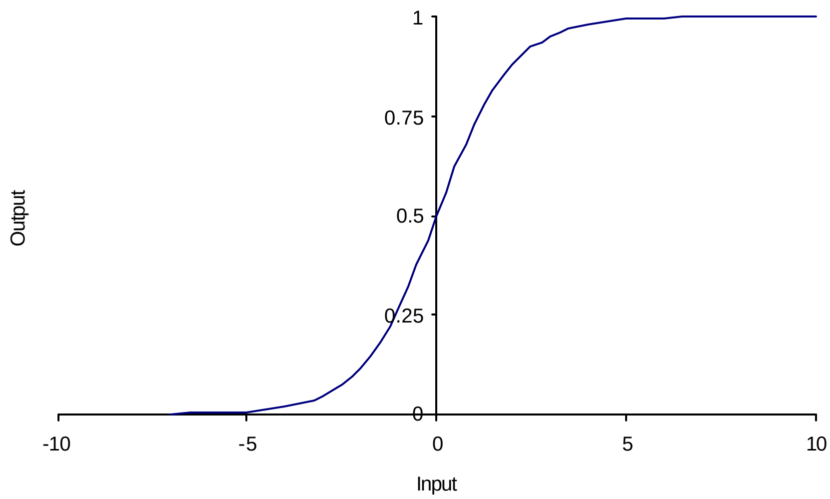

Figure 4.2 – Sigmoid Function

The neural network has also been dubbed the "connectionist". It contains a large number of simple neuron-like processing elements and a large number of weighted connections between the elements. The weights on the connections encode the knowledge of a network. It uses a highly parallel, distributed control, and can learn to adjust itself automatically.

Backpropagation

The backpropagation network is probably the most well known and widely used among the current types of neural network systems available. A backpropagation network is a multilayer feedforward network with a different transfer function in the artificial neuron and a more powerful learning rule. The learning rule is known as backpropagation, which is a kind of gradient descent technique with backward error propagation. The training instance set for the network must be presented many times in order for the interconnection weights between the neurons to settle into a state for correct classification of input patterns. While the network can recognize patterns similar to those they have learned, they do not have the ability to recognize new patterns. This is true for all supervised learning networks. In order to recognize new patterns, the network needs to be retrained with these patterns along with previously known patterns. If only new patterns are provided for retraining, then old patterns may be forgotten. In this way learning is not incremental over time. This is a major limitation for supervised learning of networks. Another limitation is that the backpropagation network is prone to local minima, just like any other gradient descent algorithm.

The backpropagation network in essence learns a mapping from a set of input patterns (e.g., extracted features) to a set of output patterns (e.g., class information). This network can be designed and trained to accomplish a wide variety of mappings. This ability comes from the nodes in the hidden layer or layers of the network, which learn to respond to features, found in the input patterns. The features recognized or extracted by the hidden units (nodes) correspond to the correlation of activity among different input units. As the network is trained with different examples, the network has the ability to generalize over similar features found in different patterns. The key issue is that the hidden units must be trained to extract a sufficient set of general features applicable to both seen and unseen instances. To achieve this goal, at first, the network must not be overtrained. Overtraining the network will make it memorize the individual input-output training pairs rather than settling in the mapping for all cases. To prevent this undesired effect, one way is to terminate training once a performance plateau has been reached. Another way is to prune the network, creating a bottleneck between the input and output layers. The bottleneck will force the network to learn in a more general manner.

The backpropagation network is capable of approximating arbitrary mappings given a set of examples. Furthermore, it can learn to estimate posterior probabilities ($P(W_i|x)$) for classification. The sigmoid function guarantees that the outputs are bounded between 0 and 1. In the multiclass case, it is not difficult to train the network so that the outputs sum up to l.

As mentioned above, the backpropagation network consists of one input layer, one output layer, and one or more hidden layers. If the input pattern is described by *n* bits or *n* values, then there should be *n* input units to accommodate it. The number of output units is likewise determined by how many bits or values are involved in the output pattern. The numbers of hidden layers and hidden units can be increased or pruned as indicated by the network performance. Typically, the network is fully connected between and only between adjacent layers.

The name "backpropagation" comes from the fact that the error (gradient) of hidden units are derived from propagating backward the errors associated with output units since the target values for the hidden units are not given. The sigmoid function is advantageous in that it can accommodate large signals without saturation while allowing the passing of small signals without excessive attenuation. Also, it is a smooth function so that gradients can be calculated, which are required for a gradient descent search.

Mathematical Expressions for Backpropagation

Here are the equations for information processing in the three-layer network shown in Figure 1. An input vector, $X_p = \left(X_{p1}, X_{p2}, ..., X_{pN}\right)^t$, is applied to the input layer of the network. The input units distribute the values to the hidden-layer units. The net input to the j^{th} hidden unit is

$$net_{pj}^h = \sum_{i=1}^{N} w_{ji}^h X_{pi} + q_j^h \qquad (2)$$

where w_{ji}^{h} is the weight on the connection from the *I* th input unit, and $\boldsymbol{q}_j^h$ is the bias term. The "*h*" superscript refers to quantities on the hidden layer. Assume that the activation of this node is equal to the net input; then, the output of this node is

$$\boldsymbol{i}_{pj} = f_j^h\left(net_{pj}^h\right) \tag{3}$$

The equations for the output nodes are

$$net_{pk}^o = \sum_{j=1}^{L} w_{kj}^o \boldsymbol{i}_{pj} + \boldsymbol{q}_k^o \tag{4}$$

$$o_{pk} = f_k^o\left(net_{pk}^o\right) \tag{5}$$

where the "*o*" superscript refers to quantities on the output layer.

The error terms for the output units are defined as

$$\boldsymbol{d}_{pk}^o = \left(y_{pk} - o_{pk}\right) f_k^{o\prime}\left(net_{pk}^o\right) \tag{6}$$

The error terms for the hidden units are defined as

$$\boldsymbol{d}_{pj}^h = f_j^{h\prime}\left(net_{pj}^h\right) \sum_k \boldsymbol{d}_{pk}^o w_{kj}^o \tag{7}$$

In neural network notation, *M* stands for the number of total output nodes, *N* stands for the number of total hidden nodes, and *I* stands for the number of total input nodes present in the network. The equations presented for net input for a hidden unit (Eq. 2) and net input of an output unit (Eq. 4) are derived by using basic vector calculus.

Backpropagation Procedure

The initial set of weight values represents a first guess as to the proper weights for the problem. Actually, the technique employed here does not depend on making a good first guess. The basic procedure for training the network is embodied in the following description:

- Apply the input vector, $X_p = \left(X_{p1}, X_{p2}, ..., X_{pN}\right)^t$, to the input units.
- Calculate the net-input values to the hidden layer units (Eq. 2)
- Calculate the outputs from the hidden layer (Eq. 3)

- Move to the output layer. Calculate the net-input values to each unit (Eq. 4)
- Calculate the outputs (Eq. 5)
- Calculate the error terms for the output units (Eq. 6)
- Calculate the error terms for the hidden units (Eq. 7)

Notice that the error terms on the hidden units are calculated before the connection weights to the output-layer units have been updated.

- Update weights on the output layer:

$$w_{kj}^{o}(t+1) = w_{kj}^{o}(t) + \boldsymbol{hd}_{pk}^{o}\boldsymbol{i}_{pj} \qquad (8)$$

- Update weights on the hidden layer:

$$w_{ji}^{h}(t+1) = w_{ji}^{h}(t) + \boldsymbol{hd}_{pj}^{h}x_{i} \qquad (9)$$

The order of the weight updates on an individual layer is not important.

The error term is calculated by

$$E_{p} = \frac{1}{2}\sum_{k=1}^{M}\boldsymbol{d}_{pk}^{2} \qquad (10)$$

since this quantity is the measure of how well the network is learning. When the error is acceptably small for each of the training-vector pairs, training can be discontinued.

The Use of ANN in This Project

The layered model described in the previous DOE report uses friction factors, which define the relation between the outer environment and the fluid as well as the relation among the layers themselves. Different dimensionless groups are defined for explaining different conditions, and these groups are combined together under a roof with some equation constants. The layer thicknesses are determined by using a similar procedure. In order to define the friction factors and layer thicknesses, the equation constants should be determined. These constants will be determined by using experimental data.

Another approach for determining the friction factors and layer thicknesses is that; instead of combining the dimensionless groups with some constants, the dimensionless groups can be the input layer of the ANN. The experimentally determined results will form the output layer. Therefore, an ANN can be developed by using these data. The procedure for the ANN is given above.

The advantage of the ANN is that, the system is not limited by a pre-defined mathematical function structure. ANN defines the system by using weight functions, and the non-linearities and any fluctuations in the function are also included. The disadvantage of the ANN is that, if the required input is an extrapolated value, i.e., which is outside the range of the data used for training the ANN, the output may be far from the expected result. The reason for this characteristic is that: the ANN uses local minimums and maximums while training.

The results of the conventional function with constants and the results of the ANN will be compared after the experiments are completed.

REFERENCES

1. Freeman A., Skapura D.M., “Neural Network Algorithms, Applications and Programming Techniques”
2. Fu W., “Neural Network Programming”

5. STUDY OF CUTTINGS TRANSPORT WITH AERATED MUDS UNDER LPAT CONDITIONS (Task 7)

Investigator: Paco Vieira (MS Candidate)

Sponsors: PDVSA/TUDRP

M.S. Thesis Title: "EXPERIMENTAL DETERMINATION OF MINIMUM AIR AND WATER FLOW RATES FOR EFFECTIVE CUTTINGS TRANSPORT IN HIGH ANGLE AND HORIZONTAL WELLS", January 2001.

5.1 Objectives

1. Determine experimentally the minimum flow rates for water and air that assure hole cleaning while drilling horizontal and near horizontal sections.

2. Develop charts that help to establish minimum requirements of air and water injection rates to plan drilling of high angle and horizontal sections of a well, using air-water systems as the drilling fluid.

5.2 CONCLUSIONS)

An experimental study of cuttings transport with two-phase (water-air) flow in annular geometries for drilling operations was carried out. The effects of: 1) gas and liquid flow rates, 2) drilling rate, 3) flow patterns, 3) inclination angle and 4) frictional pressure drop on the transport of drillbit cuttings with two-phase flow were analyzed. The experimental results for the effects of these variables are as follows.

- The cuttings flow patterns in the annular section are dependent on the total flow rate of each phase and may be classified as three types "stationary cuttings bed", "moving beds" or "mostly dispersed".

- Based on the concept of critical transport velocity, it is possible to create an approximate boundary for the minimum air and water requirements in order to avoid the formation of a stationary cuttings bed.

- The minimum requirements for gas and liquid injection for a horizontal wellbore configuration were always in the intermittent region for two-phase flow (water-air).

- As the rate of penetration increases for a given total flow rate of gas and liquid, the accumulation of cuttings in the horizontal section also increases.

- As the gas/liquid ratio increases for a constant total flow rate, the cuttings accumulation in the annular test increases. However, average frictional pressure drop decreases.

- There is a minimum frictional pressure gradient or minimum energy required for continuous movement of cuttings in an upward direction and avoidance of the formation of a stationary cuttings bed.

- The minimum frictional pressure drop required to transport the cuttings in the annular section is a function of the drilling rate or cuttings injection rate.

- Ignoring the presence of solids in pressure-drop calculations for drilling operations will lead in an under prediction of the frictional pressure drop, since the presence of solids increase the resistance to flow.

- The effect of the inclination angle is negligible in the range of 80 degrees from vertical to horizontal (90 degrees from vertical).

5.3 RECOMMENDATIONS

The present study is one step forward in the analysis of the complex subject of multiphase flow in annular geometries. Additional experimental and theoretical work need to be done in order to gain a better understanding of the hydraulics of multiphase flow in annular geometries. Based on the results from this study, the recommendations for future research are as follows.

1. There is a need to extend the experimental study to inclinations angles between 80 degrees and vertical position. The experiments should be focused more on the range between 55 and 70 degrees, which are inclination angles that have been reported in the literature as the most difficult for cuttings transport.

2. This project was conducted using water as the liquid phase. That is not the most common practice for drilling operations, but it is believed that is a good starting and reference point for further studies. It is recommended that an analysis be conducted for the effects of liquid viscosity in cuttings transport with two-phase flow in annular geometries.

3. The relevant literature shows that cuttings size and density have an effect on the carrying capacity of conventional drilling fluids. Additional research is still needed on the effects of cuttings size on hole cleaning when gasified fluids are used as a drilling fluid.

4. Drill pipe rotation is a common practice used in drilling field operations to improved or enhance hole cleaning in horizontal and inclined wellbore configurations. This work could be extended to study the effect of drill pipe rotation using two-phase flow.

5. Previous studies have shown that drill pipe eccentricity has an effect on cuttings transport with single-phase flow at high angles of inclination. The effect of drill pipe eccentricity on cuttings transport with two-phase flow needs additional research.

6. The hydraulic behavior of two-phase flow (gas-liquid) in pipes and annular geometries have been studied in the last decades. Mechanistic models have been developed for two-phase flow that considers the slippage between the phases and the different flow patterns that occur. However, to the best of our knowledge, no satisfactory hydraulic model has yet been developed for three-phase flow in annular geometries that consider all of these factors. Therefore, development of a new hydraulics model for three-phase flow (gas-liquid-solid) in annular geometries at any inclination angles would be an important new tool for improving drilling operations.

6. STUDY OF FLOW OF SYNTHETIC DRILLING FLUIDS UNDER ELEVATED PRESSURE AND TEPERATURE (EPET) CONDITIONS (Task 8)

Investigator: Barkim Demirdal (MS Candidate)

M.S. Thesis Title: "THE STUDY OF FLOW OF PARAFFIN BASED DRILLING FLUIDS AT ELEVATED PRESSURE AND ELEVATED TEMPERATURE (EPET) CONDITIONS", January 2001.

6.2 Summary

Tests with a synthetic oil-base drilling fluid were completed during this quarter. The MS thesis based on this work will be submitted to the DOE as a separate report. Pipe and annular flow experiments were conducted under different pressure and temperature conditions to determine the effects of down-hole conditions on rheological properties. Shear-rate history experiments showed that, 8.6 ppg Petrobras synthetic based fluid is a thixotropic fluid. An experimental procedure was developed to determine pressure losses while minimizing the effects of thixotropy. It has been also been observed that thixotropy primarily effects laminar flows and has little effect on turbulent flows.

The flow-loop tests show the effects of pressure on rheological properties, in the range of 0 psig to 1000 psig, is negligible. More scatter in the data is observed in larger pipes and lower flow rates. This may be caused by a temperature hysteresis effect. Like thixotropy, temperature hysteresis appears to occur primarily when the flow is laminar.

In order to determine the effect of pressure and temperature on volumetric properties of the 8.6 ppg Petrobras synthetic drilling fluid, a mercury free PVT cell was used. The experimental results indicate this fluid can be classified as an "Incompressible" fluid although its compressibility is 1.5 - 2.0 times higher than that of water. It was also learned that the effects of temperature on density of this fluid is more dominant than the effect of pressure.

Comparison of experimental data with that of the base oil, water, and oil based drilling fluids and water-based drilling fluids showed that the rate of change in density of synthetic based drilling fluid with change in pressure is less than that of oil-based drilling fluids and higher than that of water-based drilling fluids and water. It was also learned that the rate of change in density of the synthetic based drilling fluid and the base oil is very close to each other. As the temperature is increased, they even become equal. It is concluded that the effects of emulsifiers, solids and water on changes in density with changes in pressure is negligible.

In addition, an empirical model was developed that defines density as a function of pressure and temperature. The empirical equation correlates the experimental

data very precisely. This correlation can be used in calculations of the friction factor to account for changes in density as a function of pressure and temperature.

6.3 CONCLUSIONS

1. The effects of pressure on density of n-paraffin base oil and 8.6 ppg Petrobras paraffin based drilling fluid under isothermal conditions can be shown using incompressible fluid relations. However, it should be stated that, n-paraffin base oil is slightly more compressible than 8.6 ppg Petrobras paraffin-base drilling fluid at all temperatures and pressures.

2. The effect of temperature is more dominant on density of the 8.6 ppg Petrobras paraffin-base drilling fluid compared to the effect of pressure. Highest change in density is observed at low pressure-high temperature conditions and high pressure-low temperature conditions.

3. Rate of change of density of 8.6 ppg paraffin Petrobras drilling fluid with change in pressure and rate of change of density of n-paraffin base oil with change in pressure are very close to each other. Agreement between them increases as temperature increases. In other words, rate of change of density of paraffin based drilling fluids with change in pressure under isothermal conditions are independent of water:synthetic oil ratio, solid content and emulsifiers present in the drilling fluid system.

4. Change in density of 8.6 ppg Petrobras paraffin-base drilling fluid with pressure is smaller than that of the less toxic mineral oil-base drilling fluids and water-base drilling fluids at lower temperatures (i.e. 80 ^{o}F). As the temperature is increased, changes in density with respect to changes in pressure increase for 8.6 ppg Petrobras paraffin-base drilling fluid. At high temperatures (i.e. 160 ^{o}F), changes in density of this drilling fluid are higher than that of water-base drilling fluids but lower than that of the less toxic mineral oil-base drilling fluids.

5. Fann 70 experiments show the Petrobras drilling fluid is subject to some changes during tests in the ACTS flow loop. During these tests, the fluid loses water and paraffin base oil, particularly at high temperatures. Samples of condensate, taken from the mud holding tank, indicated approximately 90% water and 10% paraffins. Hence, 9 times more water was being loss through evaporation compared to the paraffins. As a result, it became more viscous compared to the original drilling fluid that was received from Petrobras.

6. Rubber bladder choke control valves are not compatible with paraffin based drilling fluids. They are subject to rupture during flow of paraffin based drilling fluids at high temperatures, high pressures and high pressure drop conditions.

7. Experiments showed that fluid has both shear rate hysteresis and temperature hysteresis. In order to get repeatable data, a new experimental procedure was developed to minimize hysteresis effects on the fluid. It was observed that hysteresis effects are more prevalent under laminar flow conditions and diminish under turbulent flow conditions.

8. ACTS flow loop experiments show that effect of pressure on frictional pressure losses in the range of 0 psig to 1000 psig is negligible. This observation is consistent with the first set of Fann 70 rotational viscometer experiments that were conducted with samples of the Petrobras fluid taken directly from the shipping drums. However, after the flow-loop tests had been underway for sometime, a later set of Fann 70 data for this fluid show rheological parameters increasing significantly between 0 psig and 500 psig, and only small increases with pressures above 500 psig. This kind of behavior is not normally observed in conventional drilling fluids and is unexpected. (The Fann 70 data was obtained from Baroid and involved sending them samples and then waiting for them to fit the work into their schedule. This led to the conclusion that the ACTS Project needs to have it's own Fann 70 rheometer.)

9. Comparison of pressure-loss calculations with different models using different rheology models show, in cases of low yield stresses and high flow behavior indexes ($n > 0.7$), predictions of all three different rheology models are close to each other in pipe flow. Since viscous effects become less important in turbulent flow, models estimations are even closer at turbulent flow conditions.

10. Significant differences occur between pressure-loss predictions from the models for annular flow. This is partly caused by the use of different geometrical definitions to define a diameter for the annulus. In the case of low viscosity and yield stress fluids with higher flow behavior indexes, Power-Law model pressure-loss predictions for the annulus is the lowest since 100 RPM and 3 RPM readings are used to determine rheological parameters of the fluid.

11. Comparison of pressure-loss calculations of different models which use different rheology models show that, for high yield stress, high viscosity fluids with high non-Newtonian properties, there is a large discrepancy between estimations in pipe flow especially under laminar flow conditions. AGIP model predictions becomes close to that of API 13-D Power Law predictions. Bingham plastic model's estimations are highest among four of the models. Predictions of pressure losses in turbulent flow are closer for all of the models since viscous effects on the fluid diminish in turbulent flow conditions.

12. Comparison of the data at 75°F show that, rheological behavior of the fluid at lower temperatures should be modeled carefully in order to estimate pressure losses accurately, especially in the case of laminar flow. Small decreases in temperature result in relatively large increases in viscosity.

13. Attempts to develop equations to correlate six speed dial readings suggest that this is not sufficient data to determine the effects of pressure and temperature on rheological parameters for a Yield-Power-Law model.

14. Experimental data and model's estimations show that for highly non-Newtonian systems ($n < 0.3$), the effect of flow rate on pressure losses is very low, and pressure losses increase only slightly with increasing flow rate when the flow is laminar.

6.4 RECOMMENDATIONS

This is the initial study of a drilling fluid with the ACTS flow loop. Many interesting observations on the volumetric and rheological behavior of paraffin-based drilling fluids under elevated pressure and temperature conditions. Based on the results of these tests, several recommendations are made for future work on this area.

Paraffin based drilling fluids are only one of the many invert emulsions used in drilling industry for years. Extensive analysis of the effects of pressure and temperature on volumetric and rheological properties of other invert emulsions such as ether based, ester based, linear-alpha-olefin based, poly-alpha-olefin based drilling fluids should be carried out and compared with the results of this work.

Since rheological properties affect the cuttings transport capability of a fluid, and these parameters are subject to change with down-hole pressures and temperatures, cuttings transport tests, at elevated pressures and temperatures, need to be conducted using the synthetic fluids and other kinds of fluids as well.

Annular flow in a concentric annulus with no pipe rotation is included in this study. In order to simulate drilling conditions, these tests need to be extended to include the effects of eccentricity and drill pipe rotation on different kinds of drilling fluids systems. The more shear thinning the fluid is the more important these additional effects become. Owning to the high viscosity of the Petrobras fluid under investigation, turbulent flow conditions could not be achieved in the annular region. For applications to field drilling operations, it is important to also study turbulent flow of invert emulsions in an annulus.

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

Investigator: Affonso Marcelo Fernandes Lourenço (MS Candidate)

7.1 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 under a given gas-liquid ratio, temperature and pressure conditions.

7.2 Summary of Activities

The following major tasks have been undertaken since October 2000:

- Theoretical Study of Micro-properties of Foam
- ACTS improvement
- PVT analysis for foams
- Development of theoretical model to predict pressure losses during foam flow at elevated pressures and temperatures.

7.2.1 Study of Micro-Properties of Foam

The most important phenomena, at cell level, related to stability and flow of foams were covered in this study. Having the surface and interface science as the center of the study, the effects of surfactants, surface tension, elasticity, foam structure, additives, etc, on generation, stability, flowing properties and destabilization of foams.

This study, characterized by a literature review of the subject, represents important tool in the selection of the foam system for the imminent experiments as well as base for future interpretation of results.

7.2.2 ACTS Flow Loop Modifications for Foam Flow

Important steps were taken during this period in order to provide the ACTS flow loop the ability to generate and flow foam in a safe and controlled way. Cleaning and maintenance operations were the first actions on the flow loop after the conclusion of the tests with the paraffin based drilling fluid. All piping connections regarding the air and liquid injections are completed. In addition, final installation work is an ongoing task in the most important equipment like the Moyno tri-phase pump, the air compressor, injection pumps and the defoaming tower. Among them we can cite the power supply for Moyno pump and implementation of control system, instrumentation and acquisition system.

The test procedure for the foam experiments has been updated and a check list regarding safety and specific operational issues to be considered before each test will be included on it.

7.2.3 PVT Analysis for Foam

A final set of tests at an extended range of pressure is under study. This would gather more data for the validation and implementation of the developed empirical model. In addition, the installation of a viewing window in the front cap of the cell for test's visualization is also under study.

7.2.4 Theoretical Model to Predict Frictional Pressure Losses during Foam at Elevated Pressures and Temperatures

This section shows the actual stage of an effort to define the theoretical approach for pressure losses predictions when foam flows under elevated temperatures and elevated pressures. Several models are available in literature, but none of them were validated with data bank from a large-scale horizontal flow loop including annular flow, and such pressure and temperature's ranges. Few works present field validation, but discrepancies among the results because of particularities in each operation or rheological characterization demonstrate the necessity for further investigation in this area. Based on this, one of the proposed thesis's directions is verification and implementation of known models for horizontal annular flow, elevated temperature and pressure conditions

One possible model to be verified and implemented is the proposed by Valko and Economides[1]. By introducing the volume equalized principle they developed constitutive equations for compressible non-Newtonian flow. In foam flow the expansion ratio (ratio between liquid and foam density) was used to construct a master rheogram curve for different pressure, qualities and pipe diameters for isothermal flow. Then using the so called mechanical energy balance and a "constant" volume equalized friction factor they could predict pressure drop in isotheral pipe flow:

$$\left(\frac{dP}{dL}\right) = \left(\frac{dP}{dL}\right)_{FRICTION} + \left(\frac{dP}{dL}\right)_{ACCELERATION} \qquad (1)$$

or

$$\left(\frac{dP}{dL}\right) = \left(\frac{f\rho v^2}{2}\right)\frac{\pi d}{Aflow} + \rho v\left(\frac{dv}{dL}\right) \qquad (2)$$

Rearranging the previous equation:

$$\left(\frac{dP}{\rho}\right) - v(dv) = \left(\frac{fv^2}{2}\right)\frac{\pi d}{Aflow}dL \qquad (3)$$

where:

$$f = \frac{2\tau_w}{\rho v^2} \qquad (4)$$

The follow expression can also be derived:

$$\rho v_z = \frac{4(\mathrm{Mg} + \mathrm{Ml})}{\pi D^2} \qquad (5)$$

A volume equalized constitutive equation is used to compute wall shear stress, for example Power-Law:

$$\tau_w = (k\varepsilon_S^{1-n}(\gamma)^{n-1})\gamma \qquad (6)$$

where

$$\varepsilon = \frac{\rho_l}{\rho} \qquad (7)$$

Any Reynolds number defined based on the previous equation will be invariant due to velocity changes caused by density changes, leading to a constant friction factor for a given mass flow rate in isothermal conditions.

This approach showed good results in pipe flow experiments with temperatures up to 105°F, pressure up to 300 psi and qualities from 0.2 to 0.8. The ACTS flow loop offers capabilities of 700 psi in pressure, 200°F of temperature in a wider range of qualities.

The strategy of data treatment can be summarized as follows:

- Collect pressure drop data in horizontal pipe and annular flow for different pressures, temperatures and gas-liquid ratio.
- Construct experimental rheogram (τ_w/ε vs γ/ε)
- Observe and correct data for slip at pipe wall
- Choose appropriate rheological model and apply volume equalized principle
- Correlate, if necessary, the rheological parameters with temperature, pressure, foam structure, etc.
- Compute pressure drop from Equation 7 by integration from inlet to outlet conditions.

Besides the previous discussed approach a model derived from the equations of change is also introduced. Some assumptions considered in the model are:

- Horizontal flow
- Steady state shear flow
- Pipe and annular flow
- Non-Newtonian behavior by using the definition of a non-Newtonian viscosity
- Elastic behavior is not considered
- Gaseous phase behaves according to real gas law and foam density is evaluated based on a modified equation of state
- Empirical approach to treat slip effect and behavior of rheological properties with pressure, temperature and gas ratio
- Axial velocity is a function of axial and radial position
- Radial and angular velocities are nil

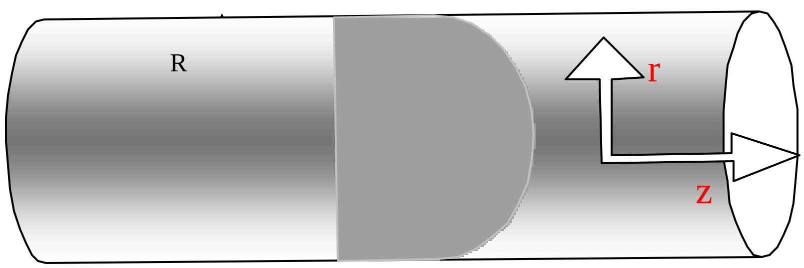

Figure 7.1 – Horizontal Pipe Flow.

- **Elastic Effects**

One of the assumptions to derive the model is that elastic effects can be ignored. We know that foam presents viscoelastic characteristics, i.e., its stress-strain behavior is between a Hookean solid and a classic viscous fluid depending upon the type and flow conditions. Elastic effects generally become important during transient flows. One way to evaluate the level of importance of this elastic behavior is through the estimation of the fluid relaxation time. This characteristic time constant of a fluid is related with the fluid structure and can be explained as the largest time constant describing the slowest molecular motions. This time is compared with some reference time constant for the flow that characterizes the experiment. When the characteristic time constant of the fluid or relaxation time is much greater than the time constant of the flow, the elastic effects become important. It is because the molecules that are (usually polymer molecules or bubbles in foams) distorted by the flow will not have time to relax during the time scale of the process. Therefore the fluid will act like a Hookean solid and more complex constitutive equation should be applied. The De number is a dimensionless group defined by the ratio of the relaxation time and the characteristic time for the flow:

$$De = \frac{l}{t_{Flow}} \tag{8}$$

The characteristic time for the flow is arbitrary and is often taken as the time period of the particular experiment. Large values of De number represents strong influence of elastic properties.

In order to evaluate the order of relaxation time for foams, experiments were performed in a plate-plate Haake rheometer inside Petrobras research center. The relaxation time was estimated by calculating the non-Newtonian viscosity over a large range of shear rates. Traditionally the relaxation time is estimated as the inverse of the shear rate at the interception of the curves that approximates the Newtonian plateau and the “power-law” region in a log-log plot. The technique is illustrated at Figure 2.

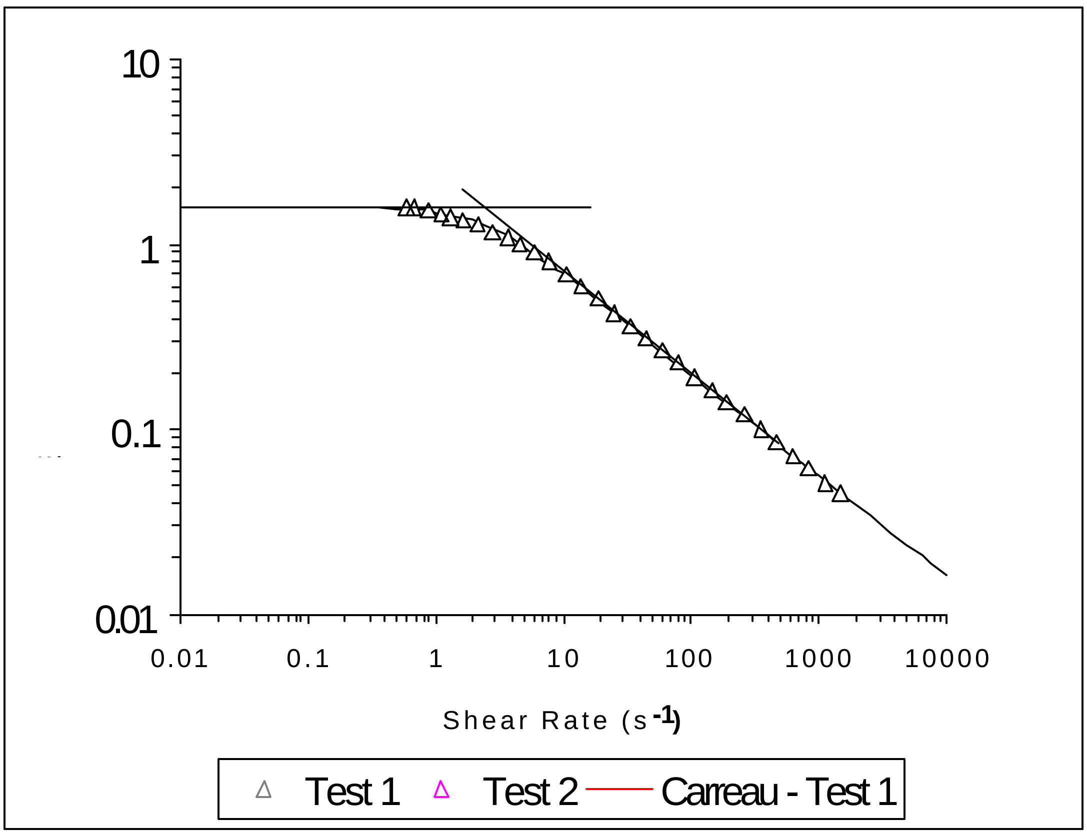

Figure 7.2 – Relaxation time λ evaluation - Plate-Plate Haake Rheometer Results

According to the results of the tests, the relaxation time is about 0.4 sec. The tests were performed at a fixed foam quality around 90% where the elastic effects are expected to be greater and atmospheric conditions. Although the tests will be performed at elevated pressures and temperatures, the results suggests a quite low relaxation time when compared with experiment time. This suggests small <u>De</u> numbers, and that the assumption of no elastic effects is valid.

Then we can use the equations of change as follows to derive the model.

Equation of Continuity for Compressible Flow in Cylindrical Coordinates:

$$\frac{\partial \rho}{\partial t}+\frac{1}{r}\frac{\partial(\rho r v_r)}{\partial r}+\frac{1}{r}\frac{\partial(\rho v_\theta)}{\partial \theta}+\frac{\partial(\rho v_z)}{\partial z}=0 \tag{9}$$

When v_r and v_θ are zero and steady state condition considered:

$$\frac{\partial(\rho v_z)}{\partial z}=0 \tag{10}$$

Equation of Motion

Z component:

$$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right)=-\frac{\partial P}{\partial z}-\frac{1}{r}\frac{\partial(r\tau_{rz})}{r}+\frac{1}{r}\frac{\partial(\tau_{\theta z})}{\partial \theta}+\frac{\partial(\tau_{zz})}{\partial z}+\rho g_z \tag{11}$$

When v_r and v_θ are zero and steady state condition considered:

$$\rho v_z\frac{\partial v_z}{\partial z}=-\frac{\partial P}{\partial z}-\frac{1}{r}\frac{\partial(r\tau_{rz})}{r}+\frac{\partial(\tau_{zz})}{\partial z} \tag{12}$$

Introducing the Non-Newtonian Behavior:

$$\overset{\rightarrow}{\overset{\rightarrow}{\tau}}=-\eta\overset{\rightarrow}{\overset{\rightarrow}{\Delta}} \tag{13}$$

with $\eta = f(\overset{\rightarrow}{\overset{\rightarrow}{\Delta}}, T, P, FluidStructure, GasRatio, ...)$ (14)

and Δ is the rate of deformation tensor defined as:

$$\overset{\rightarrow}{\overset{\rightarrow}{\Delta}}=\nabla v+(\nabla v)^T \quad . \tag{15}$$

In this particular example the constitutive equation will be assumed as a Power Law.

It is common to assume that h can be taken as some function of (Δ:Δ). This then allows the scalar h to be a scalar function of the tensor Δ.

$$\vec{\vec{t}} = -K\left(\frac{1}{2}\sqrt{\vec{\vec{\Delta}} : \vec{\vec{\Delta}}}\right)^{n-1} \vec{\vec{\Delta}} \tag{16}$$

In the problem under consideration, the appropriate form of (Δ:Δ) is:

$$\Delta : \Delta = \frac{8}{3}\left(\frac{\partial v_z}{\partial z}\right)^2 + \left(\frac{\partial v_z}{\partial r}\right)^2 \quad . \tag{17}$$

Substituting this into Equation 19:

$$\vec{\vec{t}} = -K\left(\frac{1}{2}\sqrt{\frac{8}{3}\left(\frac{\partial v_z}{\partial z}\right)^2 + \left(\frac{\partial v_z}{\partial r}\right)^2}\right)^{n-1} \vec{\vec{\Delta}} \quad ,$$

(18)

where h is:

$$h = K\left(\frac{1}{2}\sqrt{\frac{8}{3}\left(\frac{\partial v_z}{\partial z}\right)^2 + \left(\frac{\partial v_z}{\partial r}\right)^2}\right)^{n-1} \quad . \tag{19}$$

Then we can write the equations for the shear stress and normal stress in the z direction.

$$t_{rz} = -h\frac{\partial v_z}{\partial r} \tag{20}$$

$$t_{zz} = -h\left(2\frac{\partial v_z}{\partial z} - \frac{2}{3}\frac{\partial v_z}{\partial z}\right) \tag{21}$$

Returning to the equation of motion.

$$\frac{\partial P}{\partial z} = -\left(\frac{1}{r} \frac{\partial \left(r \left(-h \frac{\partial v_z}{\partial r} \right) \right)}{r} + \frac{\partial \left(-h \left(\frac{4}{3} \frac{\partial v_z}{\partial z} \right) \right)}{\partial z} \right) - r v_z \frac{\partial v_z}{\partial z} \tag{22}$$

If we consider that the variation of h is small compared with other terms in the equation, the final form of the previous equation becomes:

$$\frac{\partial P}{\partial z} = h \left(\frac{1}{r} \left(\frac{\partial v_z}{\partial r} \right) + \left(\frac{\partial^2 v_z}{\partial r^2} \right) + \frac{4}{3} \left(\frac{\partial^2 v_z}{\partial z^2} \right) \right) - r v_z \frac{\partial v_z}{\partial z} \quad . \tag{23}$$

Boundary conditions for the problem can be:

Pipe

$v_z = 0$ at r = R; if slip occurs: $v_z = v_{slip}$ at r = R

$dv_z/dr = 0$ at r = 0

Annulus

$v_z = 0$ at r = Ri; if slip occurs: $v_z = v_{slip}$ at r = Ri

$v_z = 0$ at r = Ro; if slip occurs: $v_z = v_{slip}$ at r = Ro

$dv_z/dr = 0$ at r = (Ri - Ro)/2

It is clear that the final equation has no trivial analytical solution. The best numerical approach to solve this problem is still under investigation.

Nomeclature:

P -pressure
ρ -fluid density
r -radial direction in cylindrical coordinates
z - axial direction in cylindrical coordinates
q - angular direction in cylindrical coordinates
v_r - fluid velocity in radial direction
v_q - fluid velocity in angular direction
v_z - fluid velocity in axial direction
t - time
h - non-Newtonian viscosity
Δ - rate of deformation tensor
τ_{rz} - shear stress on r face in z-direction
$\tau_{\theta z}$ - shear stress on q face in z-direction
τ_{zz} - normal stress in z-direction
R – inner radius of the pipe
R_i – outer radius of an internal pipe in annulus
R_o – inner radius of outer pipe in annulus

7.3 Future Work

- Finalize tests in the PVT cell

- Follow modifications in the ACTS loop and run preliminary tests.

- Complete and check theoretical model for pressure losses predictions during foam flow under elevated pressure and temperature.

7.4 References

1. Valko P., Economides M.J., "Volume Equalized Constitutive Equations for Foamed Polymer Solutions", Journal of Rheology, August 1992.
2. Bird R. B., Armstrong R. C., Hassager O., " Dynamics of Polymeric Liquids", vol.1, Wiley-Interscience,1987.
3. Goldstein R.J., "Fluid Mechanics Measurements", edited by Richard J. Goldstein, 1996, chapter 8.

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

Investigator: Lei Zhou (Ph.D. Candidate, replaced Heru Danardatu starting Jan, 2001)

8.1 Objectives (Preliminary)

This study has the following objectives:

1. Develop flow pattern maps for aerated fluids (two phase flow) under elevated pressure and temperature conditions inside an annulus in 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.

8.2 Introduction

As part of the advanced cuttings transport study at the University of Tulsa, this study will provide an experimental data base for cuttings transport with aerated fluids. An experimental analysis of aerated-fluids flow behavior in both pipes and an annular test section will be conducted. The basic purpose is to investigate the characteristics of aerated fluids when flowing through these geometries under elevated pressure and temperature conditions. Differences in flow patterns will be noted between pipe flow and annular flow. The experimental study will also include cuttings transport with aerated fluids. Here the focus will be on flow through the annular test section. The objective is to investigate the optimum gas/liquid flow rate combinations that will provide efficient cuttings transport under elevated pressure and temperature conditions. Both of the above experimental studies will be conducted using the Advance Cuttings Transport Facility (ACTF). The test data will then be used to assist in development of a mathematical model and a computer program.

Aerated mud drilling has been recognized as having advantages compared to operations using only a single-phase drilling mud. Some of the advantages are increased drilling rate, less formation damage, minimum lost circulation, reduction or elimination of differential sticking of the drill string, and earlier and higher production rates. The use of aerated mud to drill has been rapidly increasing worldwide. Recently, the application of the technology has even reached offshore operations. Based on field drilling experience, there is a genuine need for a better understanding of the multiphase flow hydraulics associated with aerated drilling muds.

In 1997, Azar and Sanchez reported factors that have an impact on hole cleaning while drilling directional wells. These factors are: velocity of drilling fluid in the annulus between drillstring and wellbore, hole inclination angle, drill string rotation, annulus eccentricity, rate of penetration, drilling fluid properties and characteristics of drilled cuttings. They concluded that proper planning and simultaneous considerations of all of these variables are mandatory. It is a complex problem and requires a concerted effort by the industry. Also there are still many key issues in the research methodology that need to be addressed before a universal solution to hole cleaning problems can be achieved.

The Tulsa University Drilling Research Project (TUDRP) has produced and continues to produce test data and applied research to help answer this need. Furthermore, a new step has been taken by taking into account the effects of elevated pressure and elevated temperature conditions. This step will take the research closer to the needs of field drilling operations.

8.3 Literature Review

A review of available literature on multiphase flow is being conducted. As an initial effort, the literature review is basically segmented into three linked parts which are two-phase flow behavior in pipe and annuli including mechanistic modeling efforts, cuttings transport in horizontal flow with two-phase (liquid/gas) fluids, and the effects of elevated temperatures and pressures. A list of relevant publications is attached at the end of this section. Selected papers are summarized below in one or two paragraphs.

Lage et.al. present a formulation of a mechanistic model to predict the flow behavior of two-phase mixtures in horizontal or slightly-inclined fully eccentric annuli. A new flow pattern map was generated based on the following flow regimes: stratified, intermittent, dispersed bubble and annular flow. Data were measured with a flow loop that was 150 ft long straight 4 inch ID pipe containing a 2 inch OD tube lying on the bottom. The experimental results were used to validate the model. These authors claim their model performs better than some existing empirical models. It is concluded that dispersed bubble and intermittent flow are more relevant than the other flow regimes for UBD in horizontal and near horizontal wells. Their mechanistic approach for treating two-phase flow in horizontal fully-eccentric annuli seems to be promising.

Sunthankar, Ashwin presents a modified Taitel and Dukler model for flow through an annular geometry. The modification incorporated inner pipe diameter and its eccentricity. The model assumes smooth stratified flow exists. By considering this flow, the liquid level in the annulus and other flow variables are determined for the known input parameters. The combined momentum equations have new terms for wetted perimeter of the gas and liquid as S_{Gd} and S_{Ld} , respectively. In addition, the eccentricity term, e, is defined as two times the distance between pipe centers divided by the diameter difference between the outer pipe ID and the inner pipe OD. The resulting flow pattern map shows a considerable shift in the transitions from one regime to another. The transition from stratified flow to slug flow takes place at lower liquid velocities and transition to dispersed bubble flow was predicted at higher liquid velocities. This leads to a larger region being occupied by slug flow on the flow pattern map. Ashwin noted that applying pipe flow models to flow in annuli (by incorporating hydraulic diameter concept) might not yield correct results.

Petalaz et.al. present a new mechanistic model for multiphase flow in pipe that is applicable to all pipe geometries and fluid properties. This paper thoroughly describes a procedure for flow pattern determination using a mechanistic model. The model was refined by comparisons with additional experimental data for the stratified and intermittent flow regimes. The model incorporates roughness effects as well as liquid entrainment, both of which are not accounted for by previous models. New empirical correlations are proposed for: 1) liquid/wall and liquid/gas interfacial friction in stratified flow, 2) for the liquid entrained and the interfacial friction in annular-mist flow, and 3) for a distribution coefficient used in the determination of holdup in intermittent flow. Further testing of the new model is still needed.

Gomez et.al. present a unified mechanistic model for the prediction of flow patterns, liquid hold-up and pressure drop in wellbores and pipelines. The model consists of a unified flow pattern prediction model and unified individual models for stratified, slug, bubble, annular and dispersed bubble flow which is applicable to the entire range of inclination angles from horizontal (0°) to vertical upward flow (90°). The new criteria eliminate discontinuity problems, providing smooth transitions between the different flow patterns.

Pilehvari et.al. present a review of the state-of-the-art for cuttings transport in horizontal wellbores. There are many aspects of hole cleaning that need to be carefully studied and researched. They include: non-Newtonian fluid flow simulation (what will be the right model for flow in annuli), drillpipe rotation and drillstring dynamics (the need to adequately represent drillstring movement in a wellbore), mechanistic modeling (ideally, a fluid/solids interaction model is needed to simulate the cuttings transport phenomenon), and a hole-cleaning monitoring system for field drilling operations (to provide data on cuttings transport downhole that should be related to parameters that can be monitored at the surface).

Martins et.al. presented a series of large-scale lab experiments, which focus on erosion of a cuttings bed deposited in the lower part of a horizontal annular section. A group of correlations were developed to predict bed height and critical flow rate for bed removal as a function of several independent variables. The Π theorem was used in this effort to understand cuttings transport phenomenon. Their objective was to predict the pump rates required to clear a cuttings bed. This paper shows us the needs and efforts that have been done to tackle the cuttings transport problem associated with drilling horizontal wells.

Li et.al. presents test results from a 20-ft flow loop to conduct a sensitivity analysis of hole-cleaning parameters in directional wells. The results indicate that the fraction of the drilling fluid that is liquid has a significant impact on the cuttings transport in underbalanced drilling with gasified fluids. Among the different variables, the in-situ liquid velocity is the most important variable for cuttings transport. Another result is that the time to clean the hole decreases non-linearly with increasing fluid circulation rate. The experiments were conducted for a nearly horizontal pipe with 100% eccentricity and two-phase flow of water and air mixtures.

A search for specific publications that discuss the effects of elevated pressure and temperature on two-phase flow is continuing. So far, none have been found. The relevant papers only state that laboratory or full-scale experiments have conducted at high pressures (up to 1,160 psia). But none have been found that also studied the effects of elevated temperatures.

8.4 Scope of Project

This study will have the following scope:

1. Experimental study of two-phase aerated fluids flowing under elevated pressure and temperature conditions through pipes and an annulus.
2. Experimental study of cuttings transport with aerated fluids at elevated pressure and temperature conditions.
3. Development of a three-phase air-fluids-cuttings flow model.
4. Development of a computer program to calculate pressure losses with aerated fluids flowing under elevated pressures and temperatures.

Proposed test matrix (draft):

Liquid flow rate (GPM)	Gas flow rate (SCFM)	ROP (ft/hr)	Pressure (psi)	Temperature (F)
50 – 250	0 – 400	0 – 60	0 – 700	50 - 200

8.4 Approach

In order to achieve the above objectives, the following tasks are proposed and are being planned.

1. Develop a flow-loop capable of providing high pressure and temperature conditions for tests with aerated fluids.
2. Install a cuttings injection/collection system into the flow loop.
3. Carry out experiments at different gas and liquid flow rates and at different pressures and temperatures to determine optimum gas/liquid flow rates and/or an optimum flow pattern for cuttings transport.
4. Measure liquid hold-up and pressure drops in an annulus.

5. Determine flow patterns for different two-phase and three-phase flow conditions and generate the corresponding flow pattern maps for aerated fluids under high pressures and temperatures.
6. Generate proposed cuttings-transport graphs and/or models using aerated fluids at high pressure and temperature conditions.
7. Conduct an extensive literature review of air-fluid-cuttings flow in pipes and annuli.
8. Develop a computer program to calculate pressure losses in an annulus with aerated fluids flowing at elevated pressures and temperatures.
9. Review existing models and develop, if necessary, an alternative model to simulate air-fluid-cuttings flow through an annulus.

8.5 Deliverables

The following results will be presented during and at the end of the study time.

1. Semi-annual Advisory Board Meeting (ABM) reports.
2. Flow pattern maps for aerated fluids under elevated pressure and temperature conditions.
3. Practical guidelines and/or graphs to determine the optimum gas/liquid rate to obtain efficient cuttings transport with aerated fluids under elevated pressure and temperature conditions.
4. A computational tool to calculate pressure drops inside the annulus for aerated fluids flowing under simulated down-hole conditions.

8.6 Experimental Facility

The Advanced Cutting Transport Facility loop is located on the North Campus of The University of Tulsa. The loop consists of three rheology sections with nominal diameters of 2”, 3” and 4” plus an annular test section. The annular section consists of a 6” diameter external pipe (ID = 5.761”) and a 3.5” OD inner pipe. All pipes are made of steel and tested to 3,300 psig for not less than 30 minutes and not more than 60 minutes. The 2” and 3” pipe sections provide pressure drop measurements over a length of 52.75 ft, and the 4” pipe is designed with pressure taps that are 66.5 ft apart. The annular test section has pressure taps that are 57.33 ft apart. All sections have entrance and exit lengths that are designed to exclude disturbances at the ends. The annulus has triangular supports every 20 ft to hold the inner part concentric.

To measure differential pressure drops in the sections, Rosemount Model 3015CD Differential Pressure Transmitters were installed. Their ranges of measurements are 0.5 inH_2O to 250 inH_2O with 0.075% accuracy. The static pressure in the system is measured by using liquid-filled Bourdon Tube Pressure Gauges. The range of measurement is 0 to 2,000 psig with 20 psig increments. These gauges are used to check whether the data acquisition system is working properly or not by comparing the readings on the computer with and the gauges. One of these gauges is installed in the pump discharge line to measure static pressure at the entrance to the flow loop. Another one is installed upstream of the first choke valve to observe the backpressure applied to the test sectons. The third one is installed on the downstream side of the choke to measure the pressure decrease that the choke is generating.

Static pressures are also measured by Rosemount Model 3051CA Absolute Pressure Transmitters, which measure absolute pressures from 0.167 psia to 4,4000 psia with 0.05% accuracy. These transmitters are mounted on the middle of each section and to the discharge line just after the pump discharge.

A differential pressure transducer with a capacity of 5,000 in H_2O is installed on the 2" pipe due to very high-pressure drop expected in this pipe. Turbulent flow conditions are achieved even under relatively low flow rates.

Micro Motion flow meters are used to measure the volumetric flow rate in the system. The range of measurement for drilling fluids is 0 gpm to 450 gpm.

The differential pressure transmitters, absolute pressure transmitters and flow meters are connected to a computer located in the control room near the loop. The system pressures, differential pressures and flow rates can be measured, stored and processed. LABView™ software is used for data storage and logging, real time display and on-line analysis. The selection of time averaging intervals is also controlled using the data acquisition system.

Rosemount Model 3144 Temperature Transmitters are used to measure the temperature of the circulating fluid in the system. They measure the temperature of the flowing fluid at the point where they are installed. The temperature transmitter can measure fluid temperatures in the range of 20 °F to 220 °F. Ten transmitters are used to observe temperature distribution in the system. These transmitters can operate under ambient conditions ranging between –60 °F to 185 °F. One is installed on the discharge pipe after the pump to measure fluid temperature entering the system. Another is installed on the return line to measure fluid temperature existing the system. The three pipe test sections and the annular section have two temperature transmitters installed on them. They are installed at each end of the pipes to measure the change in fluid temperature across each pipe section.

Plate Frame Heat Exchangers are installed upstream of the test sections to heat or cool the test fluid. The reasons for choosing this type of heat exchanger are due to its compact size, higher operating pressures and efficient heat transfer with drilling fluids. To reach the desired temperature, the testing fluid is circulated through the mud tank, heat exchanger and the piping system. A chiller is installed in the system to reduce temperature of the fluid as needed. It can reduce the temperature of fluids to 'wet bulb' temperature. In this way, it will is possible to obtain rheological data on the fluid under both low and high temperatures and at elevated pressure conditions.

Two mud tanks are available in the system. The capacities are 100 bbl for the storage tank and 5 bbl for the mixing tank. A jet mixer is used in the mixing tank to help homogenize the test fluid before being pumped into the larger holding tank.

In order to conduct this study, the aeration capability is currently being added to the flow loop. The first part of this study will be conducted to gain a better understanding of the flow of two-phase fluids through an annulus under elevated pressure and temperature. In the next stage of loop development, a system will be added to inject cuttings for a test and remove them near the exit. When this is achieved, the second part of this project will be conducted to study the cuttings transport characteristics of two-phase flow under elevated pressures and temperatures.

8.7 Milestones

The following summarizes several milestones during the project.

1. Mathematical modeling effort should begin January 2001.
2. Aeration/Foam system should be installed by July 2001.
3. Two-phase flow pattern analysis based on annular flow experiments should be conducted by December 2001.
4. Cuttings injection/collection system should be installed by July 2002.
5. Cuttings transport analysis based on experiments should be completed by July 2003.

8.8 Expected Completion Date

Fall, 2003.

9. DEVELOPMENT OF CUTTINGS MONITORING METHODOLOGY (Task 11)

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

9.1 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 drill pipe. There are four different techniques that could be examined. However, as it was pointed out in the previous reports only three have good potential for success. These are Ultrasound, X-Ray/ -Ray and Optical. Of these, we will concentrate on Ultrasound the primary approach for Task 11, and X-Ray/ -Ray will only be used if the first one is not successful.

9.2 Team Composition

The instrumentation team charged with completing Task 11 consists of Dr. Gerald R. Kane and Dr. Kaveh Ashenayi both registered professional engineers and professors of Electrical Engineering Department at the University of Tulsa. MS level graduate students are assisting them. These students have BS degrees in EE and CS. This particular combination works well because successful completion of this project requires skills from both disciplines. In order 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 data received.

9.3 Progress to Date

We have identified the sensors to order. We need 8 sensors to form two rings along a six feet long pipe. We propose to buy 8 of Massa sensor models TR 2445/210.

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

Investigator: Leonard Volk (ACTS Research Associate)

10.1 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 divided into three 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. Install the foam bubble size and distribution monitoring system on the 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.

The techniques developed under Subtask 12.2 will be applied to the drilling section of the ACTF in Subtask 12.3.

10.2 Objective

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

10.3 PROJECT STATUS

10.3.1 Static Bubble Characterization

New Techniques. In an effort to measure foam properties, new (to us) and inexpensive methods are being continually sought and developed. Below are two possibilities.

Foam quality. If light reflects off an interface, such as glass-air or glass-water, the intensity of reflected light depends on the index of refraction of the materials forming the interface (along with the angle of incidence, light polarization, wavelength, etc.). Therefore, if we pass light through a glass window into a foam, the light reflected off the second surface (glass-foam interface) will depend on the amount of air in the foam because the indices of refraction of glass and water are more similar than that of glass and air. Figure 9.1 illustrates the approximate % of light passing through and reflecting off each interface. We have discounted refraction since it doesn't substantially alter the results. This assumes that the bubbles of the foam are smaller than the light beam. Cuttings should have minimal effect on this measurement, providing we are not under the cuttings bed. Placing these devices around the circumference of the casing would provide us with a measure of segregation (air-foam-water). A fitting equipped with a small window should provide sufficient contact with the fluid, and a laser would probably be the best light source. Figure 9.2 is a schematic representation of this method. For more information, see reference 1.

Average bubble size. If light passes through foam, the transmitted light intensity is related to the average bubble size and the foam thickness.

$$\mathbf{T \approx 6\,b / L}$$

Where
T = the % transmitted light
b = the average bubble size
L = the thickness of the foam (optical path length)

We should be able to adapt this concept to inexpensively estimate the average bubble size at various places along the flow path. One option is to place a small window in a pair of fittings, use one to direct light into the foam and the other to measure the exiting light intensity. Potential light sources are light-emitting diodes and inexpensive lasers (solid state or He-Ne gas). Photodiodes would be the best detector, although they may need to be set off a short distance from the pipe with fiber optic cable due to the heat. These fittings could also be placed at various places along the circumference of the casing to monitor changes in the average bubble size (vertical segregation). Cuttings would create "noise" in the signal. In principle, we could compensate for this since the maximum signal strength would be due only to the foam (no cuttings in the optical path). Figure 9.3 provides a schematic representation. For more information, see Refs. 2 - 4.

10.3.2 Dynamic Bubble Characterization

10.3.2.1 Dynamic Imaging

Light Source. We have received some, but not all components of the Oriel xenon flash lamp system. The remainder of the order (the power supply and lamp housing) is expected within the next few weeks. Based on the 1.6 s pulse width of the flash lamp, figure 9.4 illustrates the relationship between the fluid velocity and the smallest bubble we will be able to image, assuming that 5% blur (5% bubble movement during the light pulse).

Imaging. Once we receive the pulsed xenon light source and verify its operation, we will be in the position to evaluate CCD cameras.

10.3.2.2 Dynamic Testing Facility

Figure 9.5 shows an updated schematic of the DTF. The inlet of the Moyno is gravity-fed with fluid (liquid and cuttings) from a 30 gal tank equipped with an air-powered mixer. Any excess fluid can be directed to the 55 gal waste tank. Since we will not be measuring rheology with the DTF, precision gauges (1/2% accuracy) are being used rather than more expensive pressure transducers. The pressure safety system is not specified in figure 9.5, but will include a spring-loaded relief system, a rupture disc or shear pin backup, and a flow switch to shut the power off to the Moyno pump if either safety device releases fluid. Nitrogen will be added on the high-pressure side of the Moyno pump using a pair of calibrated needle valves (not shown). A copper-constantan thermocouple monitors mechanical heating of the process fluid with time. A valve at the lowest point in the loop allows one to remove any settled material (cuttings). A static mixer will help ensure mixing and provide continual shear if foam is being pumped. The static mixer can be bypassed, or another design of mixer can be inserted into the loop for comparison. A considerable distance (> 8ft) has been set aside for the measuring of bubble size and/or cuttings tomography. Straight pipe is also available for this section if other instrumentation tests are to be conducted. A clear section will also be provided (yet to be purchased) to visually monitor the “condition” of the fluid. The visualization cell can be replaced with either straight pipe or a strainer (to remove debris from the flow line). The screening cell allows one to remove liquid (increase foam quality) if desired without removing cuttings. It is used to accurately arrive at the foam quality when initially filling the system. A pulsation dampener (yet to be purchased) is primarily used with liquids to pressurize the system and compensate for pressure variations due to minor temperature changes. Additional fluid can be supplied while conducting tests with the Sprague pump if needed. Since this is a closed system, no additional fluid should be required once we arrive at the desired operating pressure (up to 150 psi). Cuttings can be removed during a test by shunting the flow through the separator and back into the flow loop. Once testing has been completed, the fluid is routed to the separator, removing the cuttings, and onto the 55 gal waste tank. If foam is being used, a chemical breaker can be introduced just ahead of the separator. The separator has been design to hold all the cuttings (at pressure) until the testing is completed. Gas can be released from the top of the separator. Since the system is made of mostly 1-1/2” diameter steel pipe, we intend to fill the system with a corrosion inhibitor when it is not in use. The corrosion inhibitor will be stored in a separate tank while tests are being conducted. Following testing, cuttings can be withdrawn from the bottom of the separator. Any cuttings that adhere to the inside of the separator can be flushed out by inserting a wand pressurized with water into the top of the separator. This may be required if neutrally-buoyant cuttings (such as polystyrene beads) are used during a test.

10.4 References

1. D. Ronteltap and A. Prins, Food Colloids (R. D. Bee, P. Richmond and J. Minglus, eds.), Royal Society of Chemists, London, 1988
2. D. J. Durian, D. A. Weitz and D. J. Pine, *Science*, **252**: 686-688 (1991)
3. J. Durian, D. A. Weitz and D. J. Pine, *Am. Phys. Soc.* **44**(12): R7902-R7905
4. J. Durian, D. A. Weitz and D. J. Pine, *Mater. Res. Soc. Symp. Proc.* **248** (1992)

10.5 PLANNED ACTIVITIES

10.5.1 Static Bubble Characterization

- Acquire software needed for bubble analysis.
- Construct/verify methods for measuring foam quality and average bubble size

10.5.2 Dynamic Bubble Characterization

- Select and purchase a CCD camera.
- Complete construction of the Dynamic Testing Facility.

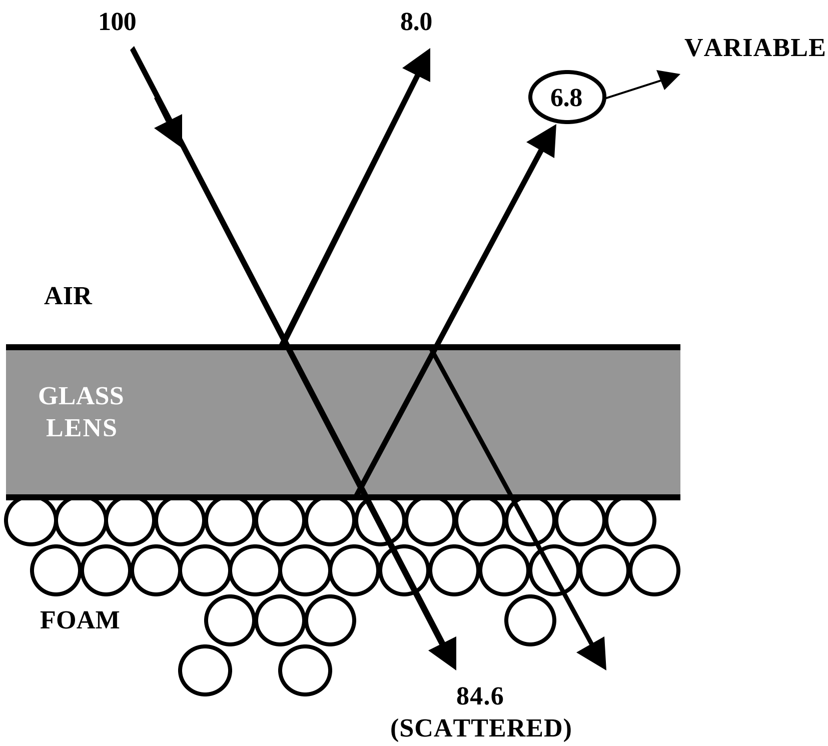

Figure 10.1. Basis for measurement of foam quality

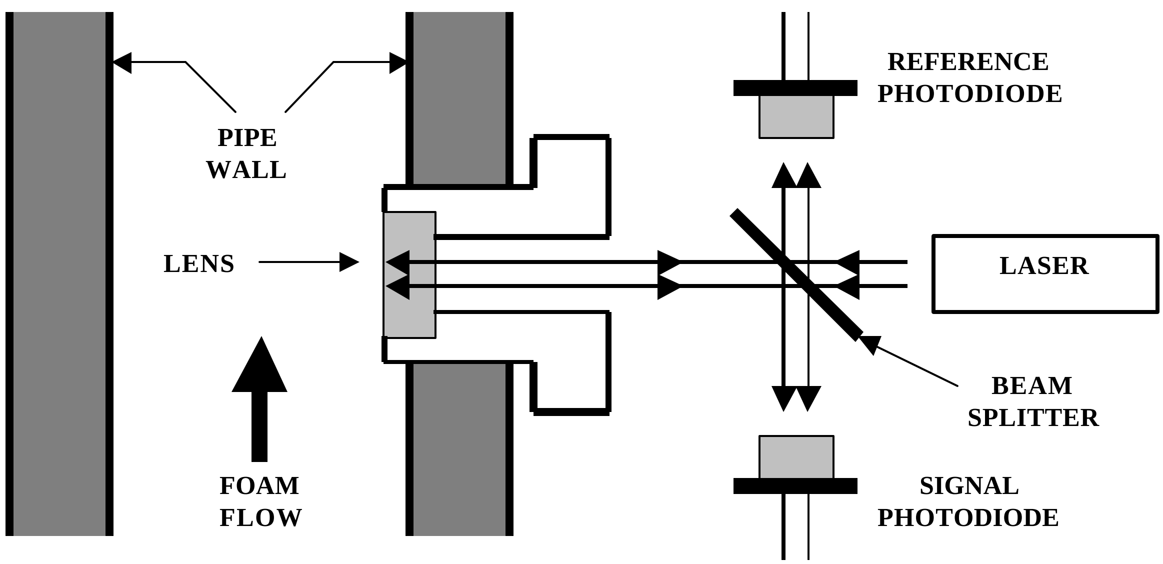

Figure 10.2 Measurement of foam quality

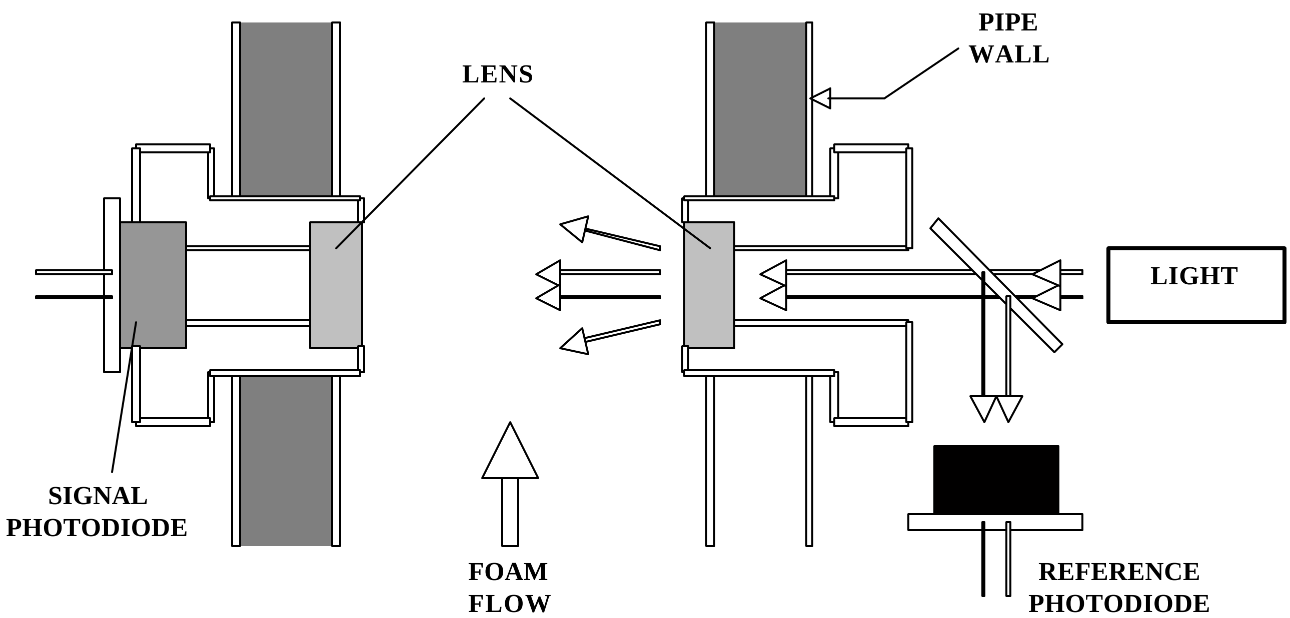

Figure 10.3 Measurement of average bubble diameter

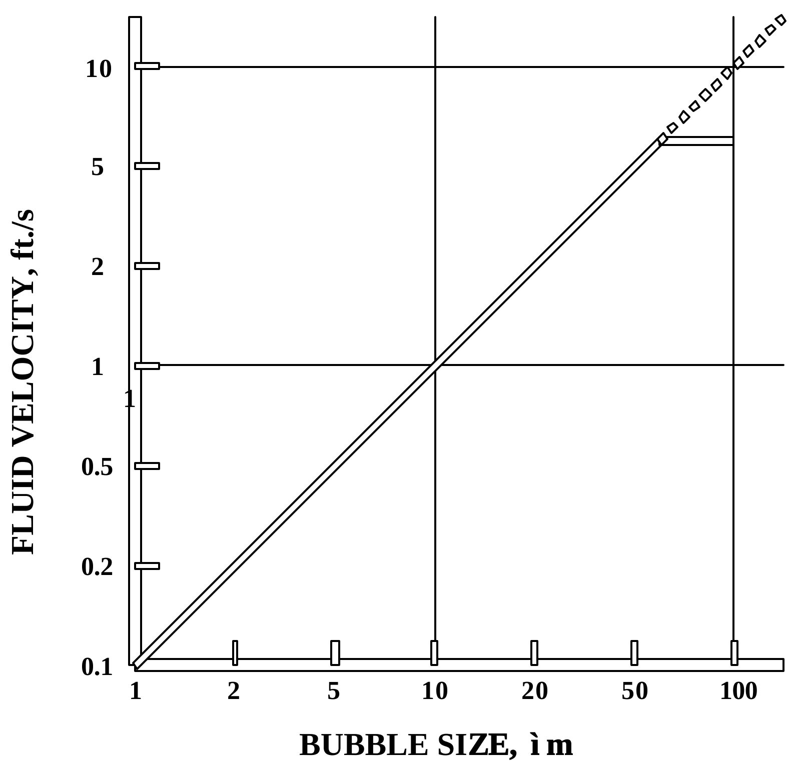

Figure 10.4. Minimum bubble size resolution versus fluid velocity for a 1.6 s pulse width lamp (maximum fluid velocity ~ 6 ft/s)

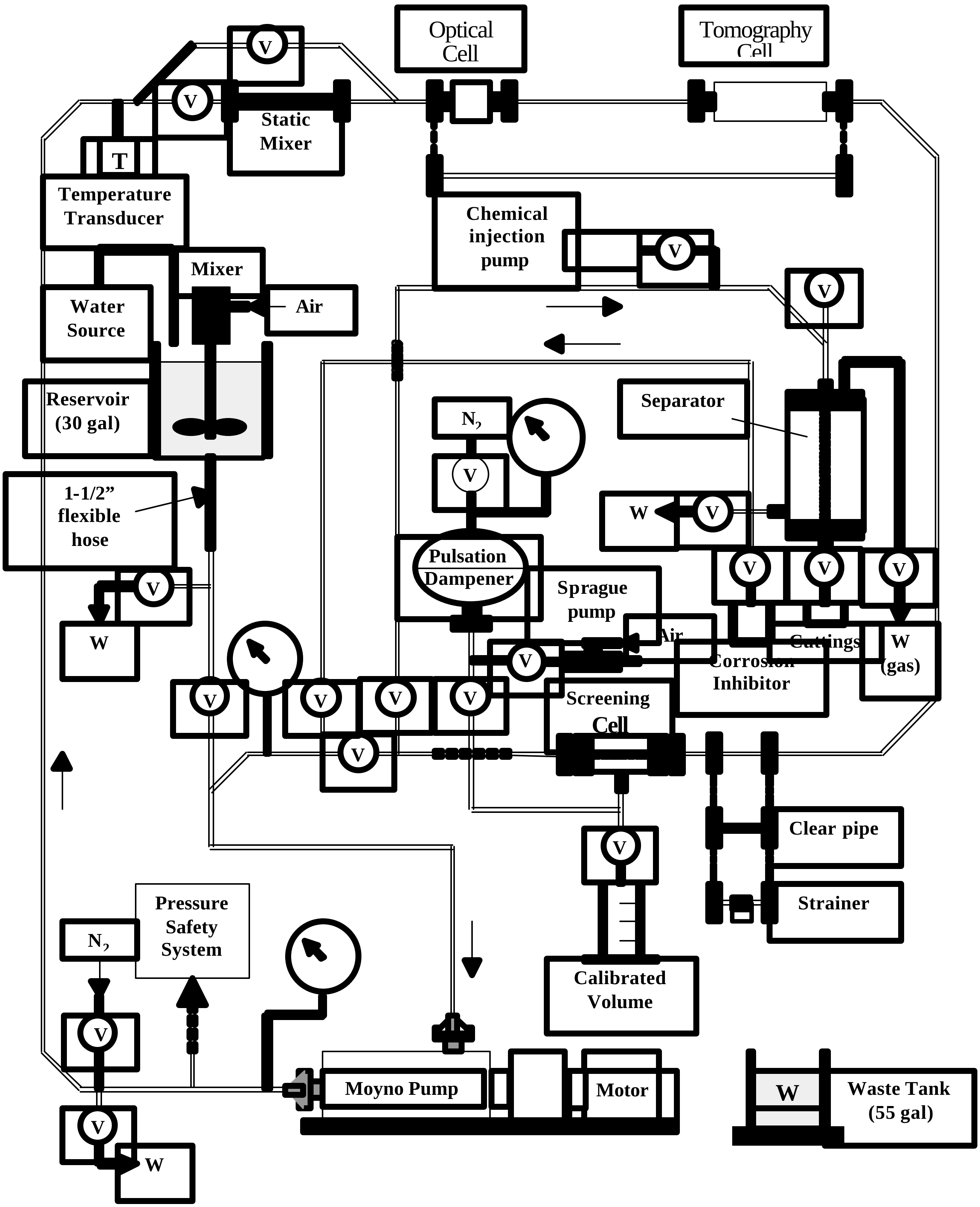

Figure 10.5. Schematic of Dynamic Testing Facility, January 2001.

12. SAFETY PROGRAM (TASK 1S)

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

12.1 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 any problems discovered during this Hazards Review. A Hazards Review is an industry accepted method used to improve the overall safety characteristics of a process and reduce the possibilities of accidents in the work place. Each individual component of the ACTF, in all possible operational modes, will be examined as to the effect and consequences on safety, health, and the environment. A Hazards Review can result in:

- Equipment modification
- Inspection and testing
- Documentation
- Personal protective equipment
- Personnel training to assure safety during daily operations
- Development of emergency response procedures

Review Process. The review process begins by selecting a method. Next a team of qualified individuals must be formed. This team should include people who are knowledgeable in the review process and are familiar with the process to be reviewed. Prior to beginning the review, all available relevant documentation needs to be gathered. This will include schematics, organized training records, results of periodic inspections and testing, 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. Ideally, 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 all recommendations from the Hazards Review. In our case, team members will participate in developing this plan.

12.2 Objectives

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

12.3 Project Status

At our initial meeting (October 26, 2000) of potential team members, we discussed the basics of a Hazards Review and decided to use the "What if" method. This method is briefly described below: We also formed a team that was later named the Review Team because these people will review the results of the Hazards Review and suggest modifications, additions and/or corrections. Members of both the Hazards Work Team and the Review Team are given in Table 1. Others may be added to this list later. Review Team members will participate in the development of the Action Plan based on recommendations from the Hazards Review.

"What if" Method

The "What if " method was chosen for these reviews because it is thorough but straight forward, and because it is widely used in industry. Each stage and each component of an apparatus or process is examined with a "What if" question as to what happens when that component is in different modes of operation. Next, the consequences of these operating modes are identified and listed. Safeguards are listed for those consequences that may result in injury, property damage or release of environmentally damaging material. If adequate safeguards do not exist, a finding is issued with a recommendation.

At a second meeting (November 20, 2000), a second team was formed that will actually conduct the Hazards Review by performing a failure/effect analysis of all aspects of the ACTF. We refer to this as the Work Team. Table 1 lists members of this team

Table I. Review Team and Work Team Members

NAME	REVIEW TEAM	WORK TEAM	AFFILIATION
Leonard Volk	X	X	Chairman (TU)
John Ford	X	X	Nat'l Petr. Tech. Office (US DOE)
David Hensley	X	X	Consultant (Tulsa Tech. Center)
Stefan Miska	X		ACTS Co-PI (TU)
Mark Pickell	X		ACTS Project Engineer (TU)
Troy Reed	X		ACTS PI (TU)
Laurie St. Clair	X	X	Dir. Environmental, Health & Safety (TU)
Nicholas Takach			ACTS Co-PI (TU)
Mike Volk	X	X	Mgr. Research & Tech. Dev. (TU)

12.4 Planned Activities

- Complete review of current documentation on ACTF
- Convene & conduct Hazards Review
- Write draft report based on findings from Hazards Review
- Present draft report to Review Team
- Modify draft report to incorporate revisions

- Develop an Action Plan based on recommendations in final Hazards Review Report
- Submit final Hazards Review Report and Action Plan to ACTF Advisory Board Members for their assessment and input.

13. TECHNOLOGY TRANSFER

a- Meetings with Oil and Service Company Members

As a result of our continuous efforts to develop more contact with oil and service companies, seven companies sent representatives to the December Advisory Board Meeting. We are still waiting for their decisions about joining the ACTS Project. There are currently 9 members of the ACTS-JIP including, BP-Amoco, Chevron, Dowell Schlumberger, Halliburton, Intevep, JNOC, Petrobras, Statoil, and the U.S. D.O.E.

b-Technical Work Groups

Work at the Argonne National Laboratory on ultrasonic sensors for slurry measurements are being utilized in the development of a monitoring system for cuttings transport in an annulus, (Task 11). During this past quarter, we obtained some additional reports and technical data from Dr. H-T Chien at ANL. They would like to see us continue the development of some of their concepts.

c- ACTS-JIP Advisory Board Meeting

An advisory board meetings with ACTS-JIP industry members was held on December 5,2000. As noted above, seven visitors attended the meeting, in addition to the nine existing sponsors