**“Enhanced Wellbore Stabilization and Reservoir Productivity with
Aphron Drilling Fluid Technology”**

QUARTERLY PROGRESS REPORT

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by

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ABSTRACT

The task areas for Phase II include Aphron Drilling Fluid Optimization, Flow Properties and Leak-Off and Formation Damage in Permeable Media. Q1 of Phase II began with studies in all three task areas. In the area of Aphron Drilling Fluid Optimization, composition studies were begun, varying the concentrations of key components of the APhRON ICSTM drilling fluid; alternative materials will begin to be investigated in Q2. The method of aphron generation was also examined. Preliminary results suggest that techniques which incorporate more air tend to create a broader bubble size distribution and larger bubbles. Although larger bubbles have been shown to withstand compression better than do smaller bubbles, they also tend to coalesce faster and separate from the body of the liquid at a more rapid rate. Studies of the microstructure of the aphron were also begun. Analysis of the surface chemistry of the fluid invasion process indicates that there are six interactions that control the fluid invasion and production processes. Three of those interactions were investigated during Q1: Bubble-Bubble, Bubble-Mineral Surface (Pore Wall) and Drilling Fluid-Produced Fluid. 2-D visualization studies confirm the hypothesis that aPhrons have little or no affinity for each other nor for silica surfaces. Yet, the APhRON ICSTM drilling fluid appears to be very compatible with oils, such as produced fluids; at least 25% by volume of a very surface active crude oil was able to be blended into the drilling fluid with minimal effect on its viscosity and bubble stability.

In the area of Flow Properties, collaboration with Dr. Peter Popov of Texas A&M university is expected to lead to a mathematical model for fluid invasion into permeable media. Preliminary results indicate that the bulk fluid itself has a fluid invasion profile not unlike that observed in the field.

Finally, in the area of Leak-Off and Formation Damage in Permeable Media, linear, static Leak-Off tests at 200 °F with 2-in cores and inlet pressure of 2,000 psig demonstrate the sealing ability of the APhRON ICSTM fluid compared with other solids-free drilling fluids. Leak-Off correlates fairly well with core permeability and is relatively independent of back-pressure. The effects of bridging materials are not as clear and require tests in a radial, long core system with dynamic flow at the face of the core; such a system will be designed and constructed in Q2.

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INTRODUCTION

Aphron drilling fluids have been applied successfully worldwide to drill depleted reservoirs and other high-permeability formations. Aphrons are specially designed air-filled bubbles that are usually incorporated into the fluid with conventional mud mixing equipment, thereby reducing costs and safety concerns associated with air or foam drilling. Because the amount of air in the fluid is very low, the density of the fluid downhole is essentially that of the base fluid. Yet, the fluid is able to seal loss zones effectively and with minimal formation damage. Consequently, aphron drilling fluids are marketed as cost-effective alternatives to underbalanced drilling.¹⁻⁴

Aphron drilling fluids possess two chief attributes that serve to minimize fluid invasion and damage to the formation. First, the base fluid is very shear-thinning and exhibits an extraordinarily high LSRV (Low-Shear-Rate Viscosity); this high viscosity is thought to reduce the flow rate of the fluid dramatically upon entering a loss zone. Second, very tough and flexible microbubbles are incorporated into the bulk fluid with conventional mud mixing equipment. These highly stabilized bubbles, or “aphrons,” are considered essential to sealing the problem area and are thought to do so by bridging within the loss zone rather than at its periphery.

Water-based aphrons consist of two essential elements: a spherical core of air and a protective outer shell.⁵ In contrast to a conventional air bubble, which is stabilized by a surfactant monolayer, the outer shell of the aphron is thought to consist of a much more robust surfactant tri-layer. This tri-layer is envisioned as consisting of an inner surfactant film enveloped by a viscous water layer, outside of which an outer bilayer of surfactants provides rigidity and low permeability to the structure while imparting some hydrophilic character to it. Under quiescent conditions, the structure is compatible with the aqueous bulk fluid, but it is speculated that the shell is non-ionic, hence has little affinity for charged mineral surfaces (pore walls) or for other aphrons.

It has been claimed that aphrons are a unique type of lost circulation material, forming a micro-environment in a pore network or fracture that appears to behave in some ways like a foam, and

in other ways like a solid, but flexible bridging material. As is the case with any bridging material, concentration and size of the aphrons are critical to the mud's ability to seal thief zones. Aphrons are created and entrained in the bulk fluid with standard mud mixing equipment, which reduces the safety concerns and costs associated with high-pressure hoses and compressors commonly utilized in air or foam drilling.⁶ Although each application is customized to the individual operator's needs, the mud system is generally designed to contain 12-15% by volume air. Aphrons are thought to be sized or polished at the drill bit to achieve a size of 15-100 μm diameter, depending on pressure, which is typical of many bridging materials.

Various aspects of the aphrons, particularly their physicochemical properties, need to be evaluated further to understand the way that they function and to enhance their performance. Greater application of aphron technology and the consequent reduction in drilling costs would be facilitated by a systematic and thorough evaluation of the structure and behavior of aphron drilling fluids under downhole conditions.

The objectives of this project are threefold: (a) develop a comprehensive understanding of how aphrons behave at elevated pressures and temperatures; (b) measure the ability of aphron drilling fluids to seal permeable and fractured formations under simulated downhole conditions; and (c) determine the role played by each component of the drilling fluid.

The Project is divided into two phases. In Phase I (Year 1) the thrust of the work has been to develop evidence for the ways in which aphrons behave differently from ordinary surfactant-stabilized bubbles, particularly how they seal permeable and micro-fractured formations during drilling operations.

One key learning of the work conducted during Phase I is that the base fluid is very highly shear-thinning and possesses a low-shear-rate viscosity much higher than conventional reservoir drilling fluids. Furthermore, low thixotropy enables the fluid to generate high viscosity very quickly when entering a loss zone. Second, aphrons can survive substantial downhole pressures for a significant period of time. In a loss zone, this feature enables the bubbles to migrate faster than the base liquid and concentrate at the fluid front, thereby building an internal seal in the pore network of the rock. Another key learning is that aphrons have very little attraction for each

other or for mineral surfaces, as had been hypothesized. Consequently, they do not readily coalesce nor do they stick easily to the pore walls. As a result, aphrons are produced back relatively easily, leaving little permanent formation damage.

Phase II (Year 2) focuses on optimization of the structure of aphrons and composition of aphron drilling fluids, quantifying the flow properties of the fluids (radial vs linear flow, shear and extensional viscosity effects and bubbly flow phenomena), and understanding formation sealing and damage under simulated downhole conditions (including scale-up tests), so as to furnish irrefutable evidence for this technology and provide field-usable data.

The current schedule of tasks is provided in Figure 1.

Figure 1. Schedule of Tasks in Aphron Drilling Fluid Project

Task	2003	2004				2005		
	4th Q	1st Q	2nd Q	3rd Q	4th Q	1st Q	2nd Q	3rd Q
1. Aphron Compressibility								
1.1 Aphron Visualization	X	X	X					
1.2 Fluid Density	X	X	X					
1.3 Aphron Air Diffusivity	X	X	X	X				
2. Sealing Mechanism								
2.1 In Situ Visualization			X	X				
2.2 Pressure Transmissibility	X	X	X					
2.3 Aphron Shell Hydrophobicity			X	X				
3. Leak-Off/Formation Damage - Initial Tests								
3.1 Sealing of Permeable Media			X	X				
3.2 Sealing of Fractured Media			X	X				
4. Aphron Drilling Fluid Optimization								
4.1 Microstructure								
4.2 Performance								
5. Flow Properties								
5.1 Geometry of Medium								
5.2 Fluid Rheology								
5.3 Multi-Phase Flow Effects								
6. Leak-Off/Formation Damage Perm Media								
6.1 Lab Tests Leak-Off/Return Perm								
6.2 Field-Sim Tests Leak-Off/Return Perm								

Phase I ran from Oct. 1, 2003 through Sept. 30, 2004 and consisted of Task Areas 1-3. All of these have been completed, as scheduled, and are indicated by an X. In Phase II, the main task areas are as follows:

Task Area 4. Aphron Drilling Fluid Optimization - The composition of the polymeric water-based aphron drilling fluid and the method of generating aphrons will be varied to optimize the pressure/temperature stability of the fluid, its ability to reduce leak-off and its ability to be re-

moved with minimal damage to producing formations.

Task Area 5. Flow Properties – The effects of radial geometry of the borehole; aphron concentration; cavitation and extension as well as shear; and multi-phase aspect of the polymeric water-based aphron drilling fluid on its flow behavior in permeable formations will be explored. A fluid invasion model will be developed that takes into account bubbly flow and can be used to predict rate and extent of invasion of aphron drilling fluids.

Task Area 6. Leak-Off and Formation Damage in Permeable Media – Using results from Task Area 5, Core Leak-Off and Return Permeability measurements will be carried out with both linear and radial flow, static and dynamic flow of the fluid in the “wellbore”, and short to very long cores and sand packs. Effects of fore pressure, back pressure, temperature, rate of fluid compression and chemical composition of aphron drilling fluids will also be varied to characterize the Leak-Off behavior of the fluids.

EXECUTIVE SUMMARY

Phase II was initiated with work in three task areas: (a) Aphron Drilling Fluid Optimization - the composition of the polymeric water-based aphron drilling fluid and the method of generating aphrons are varied to optimize the ability of the fluid to reduce leak-off at elevated pressures and temperatures with minimal formation damage; (b) Flow Properties – A fluid invasion model is being developed that incorporates the effects of radial geometry of the borehole, aphron concentration, fluid cavitation and extension as well as shear, and multi-phase flow; (c) Leak-Off and Formation Damage in Permeable Media –Core Leak-Off and Return Permeability measurements are being carried out at various pressures and temperatures and varying fluid composition using both linear and radial flow, static and dynamic flow of the fluid at the face of the permeable zone, short and long permeable samples and a broad permeability range.

During this First Quarter of Phase II, initial tests were conducted in all three task areas. Aphron Drilling Fluid Optimization focused on the following tasks: Chemical Composition and Morphology, Aphron Generation Methodology, Oil-Wetting/Water-Wetting Nature of Aphron Drilling Fluids, and a modified Capillary Suction Time Test. Chemical Composition & Morphology dealt with a brief investigation of Anti-Bubbles and the effects of variation of the concentrations of key components in the APhRON ICSTM formulation on bubble stability and bulk mud properties.

Aphron Generation Methodology focused on the effects of type of mixer/pump used to generate the aphrons on bubble size distribution (BSD). The Silverson and Prince Castle mixers entrained a moderate amount of air and produced a BSD with average bubble size below 100 μm ; a kitchen blender entrained much more air, but the average BSD was several times higher and the bubbles were generally less stable at ambient conditions.

The work this past Quarter on the Oil-Wetting/Water-Wetting Nature of Aphron Drilling Fluids dealt with three of the six key interactions involved in drilling fluid invasion and production: Bubble-Bubble, Bubble-Mineral Surface (Pore Wall) and Drilling Fluid-Produced Fluid. Studies of flow and manual manipulation of the bubbles under ambient conditions confirm previous conclusions that aphrons have no apparent affinity for each other nor for silica surfaces. In addition, the APhRON ICSTM drilling fluid appears to be very compatible with oils, such as produced fluids; at least 25% by volume of even a very surface active, viscous crude oil was able to be blended into the drilling fluid with minimal effect on its bulk properties. Some independent, parallel studies of the physical chemistry of aphrons are also being carried out with our support by a Ph.D. student under the tutelage of Prof. Ergun Kuru at the University of Alberta, Canada.

Finally, a modified Capillary Suction Time (CST) test was developed as a fluid invasion potential screening tool for low-filtration-rate fluids. In addition to various APhRON ICSTM fluids, the DRILPLEXTM and FLOPRO NTTM systems (both from M-I SWACO) were subjected to modified CST and Core Leak-Off tests. For any given fluid system, the modified CST value was found to correlate very well with Core Leak-Off. However, no general correlation was found; the spurt loss data suggest that, whereas spurt loss on the paper used in CST tests is very similar for different kinds of fluids, spurt loss on cores varies considerably. Thus, the value of CST measure-

ments is expected to lie in monitoring of fluid invasion trends for a given drilling fluid and evaluation of potential additive treatments.

The Flow Properties task area was initiated with theoretical development of multi-phase flow in porous media: Dr. Peter Popov of Texas A&M University derived mathematical algorithms for flow of base fluid and bubbly flow in conduits (annulus and fractures) and permeable rock. The results of that work will be presented in the next Quarterly Progress Report. Arrangements have also been made with Ross Davis of Kelco Rotary in San Diego, CA to carry out some extensional viscosity measurements of the SuperEnhanced APHRON ICSTM drilling fluid and potential modifications of that drilling fluid to determine whether extensional viscosity might play a role in fluid invasion into permeable formations.

Work in the Leak-Off and Formation Damage in Permeable Media task area consisted primarily of static, linear core Leak-Off tests of SuperEnhanced APHRON ICSTM and FLOPRO NTTM (M-I SWACO) drilling fluids. The latter is a conventional reservoir drilling fluid. The tests were all conducted with 2-in long Aloxite cores at 200 °F using a core inlet pressure of 2,000 psig. Back pressure was varied, along with core permeability, and each drilling fluid was run “solids free”, as well as with CaCO₃. The results indicate that, in the absence of CaCO₃, Leak-Off with the APHRON ICSTM fluid correlates fairly well with core permeability (2 to 10 darcy), whereas the FLOPRO NTTM system does not seal even the 2-darcy core. No detectable change in Leak-Off was observed with change in back pressure from 500 to 1500 psig. When the muds were treated with 30 lb/bbl of 40-μm CaCO₃, Leak-Off in all cases was significantly reduced, a result attributable to the ability of CaCO₃ to bridge at the face of a core and enable formation of an external filter cake; indeed, Leak-Off for the FLOPRO NTTM system was even lower than for the APHRON ICSTM system. This is attributed to the interaction of CaCO₃ with various components of the APHRON ICSTM system, which can coat the CaCO₃ and make it less effective as an external bridging material. Aphron drilling fluids are thought to function by forming an internal seal, which may be demonstrated properly in an apparatus designed to incorporate a deep permeable zone, radial flow into the zone and dynamic flow at the face of the permeable zone (this tends to erode external filter cakes and would provide a higher population of aphrons at the core face). Such a device is being designed and will be built and tested during the second Quarter.

Several opportunities presented themselves to share the latest aphron drilling fluid technology with potential clients and collaborate on the Project. These included the following:

- Exhibit Booth Duty at SPE/IADC Underbalanced Drilling Meeting, The Woodlands, Texas, Oct. 11 & 12.
- Overview of DOE Aphron Drilling Fluid project to M-I SWACO Technical Service, M-I Corporate Center, Houston, Texas, Oct. 14.
- Briefing of M. Kilchrist of ActiSystems, Inc. on aphron drilling fluid test procedures, MASI Technologies LLC laboratory, Oct. 18.
- Workshop for HiTech (Canada) personnel and associates on aphron drilling fluid test procedures, MASI Technologies LLC Laboratory, Oct. 20 & 21.
- Update of collaborative work with Celanese Corp on Aphronizer B alternatives, MASI Technologies LLC Laboratory, Oct. 28.
- Decision by MASI and Dr. Peter Popov of Texas A&M University (College Station, TX), to collaborate on modeling of the mechanics of bubbly flow.

- Decision by MASI and Prof. Ergun Kuru of the University of Alberta, Canada to share APHRON ICSTM sample products, mixing procedures, and results of surface chemistry studies of aphron drilling fluids.
- Submission of paper entitled, “Drilling Fluid Selection to Minimize Formation Invasion - A New Test Method,” for presentation at the AADE 2005 National Technical Conference and Exhibition, Houston, Texas, April 5-7, 2005.
- Submission of Abstracts to SPE Annual Technology Conference and Exhibition (Dallas, TX: Oct. 9-12, 2005) and V INGE PET (Lima, Peru: Nov. 8-11, 2005).
- Submission and acceptance of article entitled, “Aphron Grant in Year 2” to *Momentum* M-I SWACO newsletter for publication in 4th Q 2004 issue.

EXPERIMENTAL APPROACH

The various approaches and tools used for the three task areas of Phase II are detailed below:

4.0 Aphron Drilling Fluid Optimization

- 4.1. Microstructure
 - 4.1.1. Chemical Composition and Morphology
 - 4.1.2. Oil-Wetting/Water-Wetting Nature
- 4.2. Performance
 - 4.2.1. Compression resistance
 - 4.2.2. Elasticity
 - 4.2.3. Leak-Off / Return Permeability
 - 4.2.4. Capillary Suction Kinetics

The compositions of the three generations of APHRON ICSTM drilling fluids are shown in Table 1.

Table 1. Compositions of APHRON ICSTM Drilling Fluids

		Quantity per Lab Equivalent Barrel		
Component	Unit	Standard	Enhanced	SuperEnhanced
Water	mL	338	337	337
Soda Ash	g	3	3	3
X-CIDE	mL	0.1	0.1	0.1
GO-DEVIL II	g	5	5	5
ACTIVATOR I	g	5	5	5
ACTIVATOR II	g	2	2	2
BLUE STREAK	mL	0.91	0.91	0.91
APHRONIZER A	mL		0.5	0.5
APHRONIZER B	g		0.5	0.5
PLASTICIZER	mL			0.3

The most current of these formulations, dubbed SuperEnhanced APHRON ICSTM, contains three aphron-stabilizing components: Aphronizer A and B and Plastisizer (sic) or Plasticizer. However, neither the composition of this system nor the method of incorporating air into it have been optimized. In this task area, the composition of the SuperEnhanced APHRON ICSTM system and the method of generating aphrons are being varied to optimize (a) the stability of aphrons at elevated pressures and temperatures, (b) their ability to reduce leak-off, and (c) their ability to be removed from producing reservoirs. Both the microstructure of the aphron and its behavior in

drilling environments are being examined as functions of fluid composition and method of generating the aphron.

Aphron Microstructure and Morphology

The microstructural work will entail deciphering the chemical composition and morphology of the layers that presumably constitute the aphron structure. Techniques such as Reflectance IR Spectroscopy may come into play for this purpose, but emphasis will be placed on use of various photomicrographic techniques, such as tagging (with chromophores), fluorescence, phase contrast, Nomarski and Environmental SEM.

Additional surface chemistry work, particularly measurements of interfacial tension and capillary pressure between aphron drilling fluids and produced fluids, is being negotiated with the University of Alberta.

Method of Generating Aphrons

To investigate the effect of the method of generating aphrons on their stability, various mixers – including single spindle, high-shear and bottom-blade mixers – will be examined, along with a Gaulin pump and a reciprocating pump. The latter is part of the new HTHP Circulating System, completed last Quarter, which is designed to safely sustain a target pressure of 20.7 MPa (3000 psia) and temperature of 121 °C (250 °F). A by-pass containing a Viewing Cell was added, as shown in Figure 2, to enable optical imaging of the fluid, and the entire flow system is heated.

The HTHP Circulating System will be utilized not only to study and optimize the way aphrons are generated, but also to determine the effects of elevated temperature, pressure and flow.

The apparatus requires a fluid volume of about ½ gal. For some tests, a transparent fluid system will be used. The fluid that was developed for this purpose, dubbed the Transparent APHRON ICSTM drilling fluid, is similar in composition to the APHRON ICSTM system, but it does not contain any of the opaque components. This fluid system possesses key properties, such as rheology and bubble stability, that are similar to the APHRON ICSTM system.

Figure 2. HTHP Circulating System

Oil-Wetting/Water-Wetting Nature of Aphron Drilling Fluids

During drilling fluid invasion and subsequent production of oil or gas, base drilling fluid, aphrons, pore walls and produced fluid interact in various ways to determine the extent of invasion and formation damage. We have identified six such interactions:

(1) Bubble-Bubble

- Building on work carried out during Phase I, optical imaging and electrophoretic techniques will be used to obtain a semi-quantitative description of the interaction between bubbles.

(2) Bubble-Mineral Surface (Pore Wall)

- Some qualitative information will be gained from optical imaging about the stickiness of bubbles to simulated pore walls.
- Experiments are being carried out in a Hele-Shaw cell (see Figure 3) and in commercial ant farms to determine how the bubbles move through beds of beads and sand. These thin, flat cells should enable 2-D visualization and analysis.
- Contact Angle Goniometry (Sessile-Drop API Recommended Practice 42) and Emulsification Potential

- (3) Drilling Fluid-Produced Fluid (where Produced Fluid is connate water, oil or gas)
 - Emulsion compatibility tests, which have been started in collaboration with HiTech, will yield some information about the interaction of Crude Oil with APHRON ICSTM muds.
 - Contact Angle Goniometry (Sessile-Drop API Recommended Practice 42).
- (4) Bubble-Drilling Fluid (where Drilling Fluid is defined here as the aqueous phase surrounding the aphrons)
 - Contact Angle Goniometry (Sessile-Drop API Recommended Practice 42).
 - Surface Tension measurements, with a duNouy Tensiometer (ring method).
- (5) Drilling Fluid-Mineral Surface
 - Contact Angle Goniometry (Sessile-Drop API Recommended Practice 42) and Emulsification Potential.
- (6) Produced Fluid-Mineral Surface
 - Contact Angle Goniometry (Sessile-Drop API Recommended Practice 42) and Emulsification Potential.

Initially, the study will focus on interactions (1) – (3), which involve 2-D Visualization, Contact Angle Goniometry and Emulsion Compatibility tests.

A Hele-Shaw cell⁷ was constructed to observe how bubbles move through beds of glass beads and sand. Initially the cell was packed with 5-mm glass beads and filled with water. Whole SuperEnhanced APHRON ICSTM Mud was run in this cell, and close-up pictures were taken of the mud as it passed through the bed of beads. Some photos of the cell with mud are shown in Figure 3.

At the conclusion of these studies, we expect to have a fairly comprehensive picture of the physical chemistry involved in drilling fluid invasion and reservoir fluid production. Some of these data will also be used for the Bubbly Flow modeling that will be conducted at Texas A&M University.

Figure 3. APHRON ICS™ Drilling Fluid in Hele-Shaw Cell Packed with 5-mm Glass Beads

Performance Tests

Complementing the microstructural investigation is a parallel investigation of the performance of the aphron as a function of composition and aphron generation methodology. The performance tests include some microscopic techniques developed in Phase I, such as Bubble Compression Resistance (kinetics of bubble shrinkage at elevated pressure) and Elasticity (transient response of bubble size to rapid pressure changes). This will be carried out in the Variable Reservoir Depth Viewing Cell developed in Phase I and shown in Figure 4 below.

A high-pressure/high-temperature version of this cell is being considered that utilizes sapphire windows and high-strength bolts.

Figure 4. Variable-Reservoir-Depth Polycarbonate Viewing Cell

Macroscopic tests include Leak-Off, Return Permeability and Capillary Suction Time. The Tri-axial Core Leak-Off Tester was modified in preparation for this by moving the mud reservoir outside of the oven, adding back-pressure regulators to control the back-pressure and adding some additional plumbing to avoid shocking the system with large pressure changes at the beginning of a test. A schematic of the modified Leak-Off Tester is shown in Figure 5. This apparatus is of a fairly conventional design for testing of typical filter-cake-producing drilling fluids. The core is a short (2 in) solid cylinder; flow into the core is linear, from face to face and there is no dynamic flow across the face of the core. The system will be converted to measure Return Permeability, as well as Leak-Off. Later, a system will be developed and constructed to measure dynamic, radial flow of aphron drilling fluids through long cores.

Figure 5. Schematic of Modified Triaxial Core Leak-Off Tester

The Capillary Suction Time tester measures the speed of filtration of drilling fluid on a piece of filter paper continuously wetted by the fluid. Figure 6 shows the hollow sample cylinder, which is placed on the paper and filled with fluid. Filtrate moves out along the paper; ring electrodes under the paper measure the rate of travel of the filtrate from the inner ring to the outer ring.

Figure 6. Capillary Suction Time Test Apparatus

5.0 Flow Properties

5.1. Fluid Flow Pattern

5.1.1. Core Geometry

5.1.2. Dynamic vs Static Fluid Flow

5.2. Fluid Rheology

5.3. Multi-Phase Flow Effects

The flow behavior of aphron drilling fluids that was documented in Phase I demonstrated that these fluids are uniquely qualified to produce low fluid invasion rates in high-permeability formations. This low invasion rate appears to be related to the very high LSRV of the drilling fluid and to acceleration of the pressure-stable aphrons ahead of the liquid front.⁸ However, we have much to learn yet about how the fluid behaves under downhole conditions. First, all of the tests thus far have been carried out with a fixed fluid reservoir using linear flow. During Phase II, the effects of a continuous source of aphrons at constant concentration and radial flow (as occurs in a wellbore) on the flow properties of aphron drilling fluids will be examined, including flow through sandpacks in a specially designed radial flow simulator.

Second, unconventional rheology of aphron drilling fluids, such as extensional viscosity, will also be examined, to determine what role – if any – such properties may play in the flow of aphron drilling fluids through porous media. Finally, based on the results of the Pressure Transmissibility study conducted in Phase I, the manner in which individual phases (aphrons, liquid, solids) flow through sands and consolidated porous media will be quantified and incorporated into a flow model for multi-phase fluids. This modelling is expected to be carried out at Texas A&M University.⁹

6.0 Formation Invasion and Damage Potential

6.1. Laboratory Tests of Core Leak-Off and Return Permeability

6.2. Field Simulation Tests

Much was learned in Phase I concerning the effects of various fluid and core properties on invasion of aphron drilling fluids. High fluid viscosity slows the rate of invasion, as does stabilization of aphrons and incorporation of bridging materials. This year, invasion into permeable and fractured formations and potential formation damage will be examined in detail with lab bench Leak-Off and Return Permeability tests -- primarily with Aloxite and outcrop cores -- followed

by scale-up tests in a full-size rig with large cores.

Initially, linear static Leak-Off tests will be carried out on 2-in long cores covering a range of permeabilities and pore structure while varying back-pressure and temperature. A new high pressure diaphragm-type back pressure regulator was installed on the Triaxial Core Leak-Off Tester, as shown in Figure 5.

Shell Oil has shown considerable interest and requested these tests at 200 F with varying back-pressure and pressure drop; a constant fore pressure of 2,000 psi will be applied. While the temperature and pressure specifications are reasonable and practical, the flow geometry (linear), fluid loading (static) and shortness of the cores (2 in) are suitable only for fluids that build an external filter cake. APHRON ICSTM drilling fluids, which are expected to form an internal seal in loss zones, require a design that simulates at least the dynamic loading of aphrons into the formation and longer cores; radial geometry (as in a wellbore) is also important, though perhaps not as critical, for monitoring trends. These changes would require significant and expensive modifications to the Leak-Off Apparatus. At this juncture, Core Leak-Off tests will be carried out in our conventional Core Leak-Off Apparatus. Return Permeability tests themselves will require some modifications, which are in the planning phase.

RESULTS AND DISCUSSION

4.0 Aphron Drilling Fluid Optimization

Chemical Composition and Morphology

When examining the morphology of aphrons, literature on “anti-bubbles” was found and briefly reviewed. An anti-bubble is simply the rare reverse case of a typical (bilayer) bubble. In a typical (bilayer) bubble, a ball of air is surrounded by a thin film of liquid. An anti-bubble is a ball of liquid surrounded by a thin film of air.¹⁰ The existence of such a phenomenon was confirmed in our lab. Although anti-bubbles are short lived (< 2 minutes), they can form in an environment similar to that of the APhRON ICS™ drilling fluid, as shown in Figure 7.

Figure 7. Picture of an Anti-Bubble in a Soap Solution**

**Picture from anti-bubbles.org

The bubbles above the surface of the liquid are normal bubbles. The bubble in the middle of the beaker is an anti-bubble. Because its core is liquid, an anti-bubble is characterized principally by its tendency to sink; when it becomes unstable, the surfactant layers fall away and disappear, as

the liquid core, and both the surfactant and core simply blend with the surrounding liquid. The microstructures of an aphron, a conventional bubble and an anti-bubble are illustrated in Figure 8. The aphron, with its unique arrangement of water and surfactant layers, is a much more stable structure; this arrangement is crucial to its survival at high pressures.

Figure 8. Microstructure of an Aphron, a Bubble and an Anti-Bubble

The effect of chemical composition on the microstructure of the aphron will be investigated by using performance measures, particularly stability at 500 psig: the sizes of individual bubbles, as well as a full bubble size distribution (BSD), will be determined over a period of 30 min using Vision Assistant, and these will be cross-checked with the change in fluid density over that 30-min period. A typical BSD of a SuperEnhanced APHRON ICSTM sample mixed on the Silverson L4RT-W mixer at 7000 rpm for 6 min is shown in Figure 9.

Initially the test matrix of fluids will be restricted to the current formulation, varying the level (concentration) of Go-Devil II, Aphronizer A, Aphronizer B and Plastisizer. The test matrix, shown in Table 2, was by necessity restricted to two levels of each of the four varied compo-

nents. The goal is to reduce the rate of air loss from the aphron into the surrounding fluid.

Figure 9. Bubble Size Distribution of SuperEnhanced APHRON ICS™ mud

Table 2. Test Matrix for Optimization of APHRON ICS™ Drilling Fluid Composition

Formulation	Soda Ash (ppb)	X-Cide (ppb)	Activator II (ppb)	Go-Devil (ppb)	Activator I (ppb)	Blue Streak (ppb)	Aphronizer A (ppb)	Aphronizer B (ppb)	Plasticizer (ppb)
1	3	0.1	2	3.5	5	1	0.25	0.25	0.2
2	3	0.1	2	5	5	1	0.25	0.25	0.2
3	3	0.1	2	3.5	5	1	0.25	0.25	0.4
4	3	0.1	2	5	5	1	0.25	0.25	0.4
5	3	0.1	2	3.5	5	1	0.25	0.6	0.2
6	3	0.1	2	5	5	1	0.25	0.6	0.2
7	3	0.1	2	3.5	5	1	0.25	0.6	0.4
8	3	0.1	2	5	5	1	0.25	0.6	0.4
9	3	0.1	2	3.5	5	1	0.75	0.25	0.2
10	3	0.1	2	5	5	1	0.75	0.25	0.2
11	3	0.1	2	3.5	5	1	0.75	0.25	0.4
12	3	0.1	2	5	5	1	0.75	0.25	0.4
13	3	0.1	2	3.5	5	1	0.75	0.6	0.2
14	3	0.1	2	5	5	1	0.75	0.6	0.2
15	3	0.1	2	3.5	5	1	0.75	0.6	0.4
16	3	0.1	2	5	5	1	0.75	0.6	0.4

Method of Generating Aphrons

Air was entrained in an APHRON ICS™ drilling fluid using three types of mixers. Bubble stability was measured using the standard Density Change method and Bubble Compression Resistance. The results indicate that, while there is some difference mixing the aphrons with a kitchen blender, the samples mixed with the Silverson and the Hamilton Beach style mixers produced physical properties, including aphron stability, that were very close to each other, and these aphrons were more stable than the ones produced with the kitchen blender. Although larger bubbles have been shown to withstand compression better than do smaller bubbles, they also tend to coalesce faster and separate from the body of the liquid at a more rapid rate.

The development of a procedure to observe aphrons at elevated temperature and pressure has continued with the modification of the HTHP Circulating System (Figure 2). One test has been performed at 150°F and 2,000 psig on the SuperEnhanced APHRON ICS™ Mud; qualitatively, the results appeared quite similar to those conducted previously at ambient temperature and 2000 psig, i.e. the aphrons re-appeared essentially intact after pressure reduction.

Oil-Wetting/Water-Wetting Nature of Aphron Drilling Fluids

Investigation of the first three of the six interactions described in the Experimental Approach section was begun this Quarter:

- Bubble – Bubble
- Bubble – Mineral Surface (Pore Wall)
- Drilling Fluid - Produced Fluid

Bubble-Bubble Interactions:

Since interpretation of the optical imaging used to document the water-wetting/oil-wetting nature of the aphrons depends so much on the quality of the photomicrography, some RIT #6 blue dye was added to the Enhanced Transparent APHRON ICS™ mud to highlight the aphron shell (it actually colors the liquid phase). However, in some cases, the blue dye appeared to increase the affinity of the aphrons for each other and also for the needle used to generate and stir the

aphrons. A few of these pictures are shown in Figures 10a – 10c.

Figure 10a. Aphrons Formed during Air Injection

Figure 10b. Agglomerated Aphrons after Air Injection

Figure 10c. Aphrons after Swirling with Needle

This affinity, which has not been seen previously, must be caused either by the blue dye or the way that the bubbles are introduced in the mud.

To ensure that the effect was not caused by post-addition of the blue dye, some tests were run by mixing the mud in the standard fashion but using Blue Streak that had been prepared with varying concentrations of the blue dye. Other tests were run where blue dye was added directly to the mud during mixing as a last step. In none of these cases was any attraction among the bubbles evident. Thus, the blue dye itself apparently does not affect significantly the affinity of the aphrons for each other.

Attention shifted to the method of aphron generation, along with the presence of the blue dye. To this end, a simple test matrix was run in which both the blue dye and the aphron generation method were varied. The results are shown in Table 3.

We can conclude that we see some affinity of the aphrons for each other only in the presence of blue dye and when the aphrons are generated via air injection. Of course, in the field, air is entrained (and aphrons are formed) in the mud pits and hopper. Furthermore, when air injection

was used, as in the tests described above, within a short time the aphrons separated and showed no further sign of any affinity for each other.

Table 3. Effects of Blue Dye and Aphron Generation Method on Aphron Affinity

Method of Aphron Generation	Blue Dye	
	With Blue Dye	Without Blue Dye
Injection	Very little Attraction	No Attraction
Mixer	No Attraction	No Attraction

Bubble – Mineral Surface (Pore Wall):

Some work was begun to create an “aphron farm” (a modified ant farm) for the study of aphrons in the drilling fluid and their migration through a sand pack. This emphasized the phenomenon of bubbly flow discovered during Phase I of this Project. In Figure 11, fluid flow is from right to left. The oval shows a large bubble along with smaller ones. Moving clockwise from the lower left photo, it is apparent that the large bubble moves further than the smaller bubbles nearby.

Additional tests are being carried out to attempt to quantify this phenomenon for incorporation into the mathematical model of bubbly flow being developed at Texas A&M University.⁹

Another experiment was carried out with wet 20/40 raw sand, a picture of which is shown in Figure 12. In these experiments, the sand was not confined at the top, and fluid flow was sufficient to open large gaps in the sandpack. It appeared from the color of the sand at the edges of the gaps that the mud was penetrating the sand pack on both sides of the gap and sealing it. More tests will be carried out to better understand these phenomena. Other issues that will be investigated include how the bubbles move with respect to the liquid phase; are the bubbles being squeezed through the sand pores or are they being chopped as they go through; how does the

size of the filter medium affect the latter mentioned phenomena, etc.

Figure 11. Bubbly Flow in a SuperEnhanced APHRON ICS™ Mud

Figure 12. APHRON ICS™ Drilling Fluid in Hele-Shaw Cell Packed with 20/40 Sand

Drilling Fluid – Produced Fluid Interaction:

Some emulsion compatibility tests were carried out on the interaction of Crude Oil with APHRON ICSTM muds was revealed. In this work, the crude oil was homogenized with SuperEnhanced APHRON ICSTM drilling fluid to ascertain how easily the crude could make the mud oil-wet. A picture of a blend composed of 50% crude oil /50 % drilling fluid by volume is shown in Figure 13. The light filamentous structures are bands of APHRON ICSTM mud dispersed in the darker oil.

Figure 13. 50% Crude Oil / 50% APHRON ICSTM Blend

Future plans include examining other volume ratios of this blend, microscopic examination, dispersibility in water and measurements of viscosity. In addition, the blends will be treated with various surfactants and commercial emulsion breakers to improve their water-wetting nature

Additional surface chemistry studies, particularly measurements of interfacial tension and capillary pressure between aphron drilling fluids and produced fluids, have been negotiated with the University of Alberta. A proposed Confidentiality Agreement has been drawn up and is waiting approval by the University.

Capillary Suction Time Test

Several drilling fluids which are known to yield relatively low fluid loss were subjected to the conventional CST Test. All of these generated very long CST values (> 1000 sec). The values themselves were not clearly differentiable and were highly suspect, because artifacts such as evaporation of water from the blotting paper exerted substantial control over the rate of advance of the filtrate. Thus, a Modified CST test was developed that involves measuring the distance in mm traveled by the fluid at 30, 60, 90 and 120 min.

Four samples of each drilling fluid system were blended, and the concentration of viscosifier specific to each system was varied. The systems utilized were: a standard APHRON ICSTM, SuperEnhanced APHRON ICSTM, FLOPROTM (the flagship M-I SWACO reservoir drilling fluid) and DRILPLEXTM (a mixed metal fluid from M-I SWACO). These samples were run as “solids free” systems, but some tests were also run with samples containing 30 ppb of SAFECARBTM 40 (CaCO₃ with a nominal particle diameter of 40 µm). Following are the formulations of FLOPROTM and DRILPLEXTM used:

<u>FLOPROTM</u>		<u>DRILPLEXTM</u>	
<u>Additive</u>	<u>Concentration, ppb</u>	<u>Additive</u>	<u>Concentration, ppb</u>
NaCl	10%	Soda Ash	0.25
FLO-VIS PLUS	2.25/ 2.6/ 2.85/ 3.15	DRILPLEX	0.18/ 0.4/ 0.8/ 1.2
FLO-TROL	4.5	FLOPLEX	4.0
KLA-GARD	4.0	Caustic Soda	0.5

The pre-hydrated gel used for the DRILPLEXTM samples was prepared at a concentration of 30 ppb, and the pre-hydrated gel / DRILPLEXTM ratio was maintained at 8.3.

The corresponding Low-Shear-Rate Viscosity (LSRV), Leak off, and modified CST were measured for each one of the mud samples. All of the tests were run at room temperature. LSRV was measured with a Brookfield LV-II+ Viscometer at 0.06 sec⁻¹ using a L3 spindle. The Core Leak-Off tests were run for 30 min in the Triaxial Core Leak-Off Apparatus using 1,000 psi confining

pressure, 500 psi inlet pressure and no back pressure, employing 2-in long Aloxite cores of about 5 darcy air permeability. In all cases, the modified CST values used for the correlations were those measured at 60 min (half of the total testing time). The CST vs Leak-Off correlations obtained with the 30-min CST data were similar to these, but the CST data appeared to be somewhat less precise. The correlations obtained with the 90-min and 120-min data were also similar to those obtained with the 60-min data and did not appear to provide any greater precision. Consequently, the 60-min CST values were used for all of the correlations.

The effect of low-shear-rate viscosity (LSRV) on CST is shown in Figure 14.

Figure 14. CST vs. LSRV for Solids-Free Drilling Fluids

All of the curves in Figure 14 follow power law trends fairly well, though it appears that the curves cannot be unified into a single model, i.e. each fluid system appears to follow a different power law expression. Both APhRON ICSTM systems give lower CST values than the FLOPROTM and DRILPLEXTM systems. Aerating the SuperEnhanced APhRON ICSTM system lowers the CST even more. This is likely the result of the aphrons acting as a bridging agent.

Figure 15 shows the correlation of Core Leak-Off vs. LSRV for all the set of data. As is the case for the CST correlations, Core Leak-Off appears to follow a power law trend with respect to LSRV. Again, it does not seem possible to be able to unify the curves; indeed, the curves appear to be considerably more scattered than are the CST vs LSRV curves. This is likely the result of spurt loss being more variable for core invasion than for blotter paper invasion.

Figure 15. Leak-Off vs. LSRV for Solids-Free Drilling Fluids

The discrepancy between the CST and Core Leak-Off correlations is especially evident for DRILPLEXTM, which exhibits the lowest Core Leak-Off, yet the highest CST Value. The sealing mechanism of this fluid involves a special polymer-clay network that is thought to be particularly effective at reducing spurt loss.

Figure 16 shows the correlation of Leak off vs. CST for all the systems. As expected from previous discussions and borne out by Figure 16, there is a fair correlation between CST and Core Leak-Off for individual fluid systems, but there is no unifying correlation curve for all of them. Addition of CaCO₃ to the FLOPRO and the SuperEnhanced APHRON ICSTM systems reduces both Leak-Off and CST. Addition of air to the SuperEnhanced APHRON ICSTM system has a similar effect.

Figure 16. Core Leak-Off vs. CST for Several Drilling Fluids

From the results shown in Figure 16, it appears that CST and Core Leak-Off for any given fluid system correlate well enough to approximate the value of the Leak-Off of a particular system based on its CST value. Thus, the value of CST measurements is expected to lie in monitoring of fluid invasion trends and evaluation of potential additive treatments.

5.0 Flow Properties

Multi-Phase Flow Effects

Discussions were carried out with Peter Popov and Yetzirah Urthaler of Texas A&M University to begin development of a Bubbly Flow model for aphron drilling fluids in January. MASI Technologies will gather all necessary input data, such as interfacial tension measurements, and will ultimately carry out corroborative tests. Preliminary work by Dr. Popov suggests that the liquid phase itself generates an invasion profile of modest depth not unlike that seen in the field for Aphron ICS systems.

6.0 Formation Invasion and Damage Potential

Leak-Off tests were conducted with FAO-0, FAO-5, FAO-10 and FAO-40 (nominal air permeability 2, 5, 10, 80 darcy, respectively) Aloxite cores 1-1/2 in diameter x 2 in length, using 2000 psig fore pressure, 2500 psig confining pressure and a temperature of 200 °F. The SuperEnhanced APHRON ICSTM mud contained 17 to 20% air. A reservoir drilling fluid, FLOPRO NTTM (M-I SWACO), was used as a benchmark. Both fluids were run “solids-free” and “with bridging solids;” the latter consisted of treatant with 30 lb/bbl 40 µm CaCO₃. The rheological properties of these compositions are shown in Table 4.

Table 4. Rheology of APHRON ICSTM and FLOPRO NTTM Drilling Fluids

Test	APHRON ICS	APHRON ICS + CaCO ₃	FLOPRO NT	FLOPRO NT + CaCO ₃
LSRV: Brookfield LVDV-II+, LV-3C, 0.06 sec-1, 77 F (cP)	158000	182000	111000	126000
Grace 3500, 77 F				
600 rpm	92	118	84	90
300 rpm	77	95	68	70
200 rpm	69	84	60	60
100 rpm	59	71	49	49
6 rpm	50	59	26	42
3 rpm	41	46	24	26
PV (cP)	15	23	16	20
YP (lb/100 ft ²)	62	72	52	50
10 sec	38	41	22	24
10 min	47	46	24	29
30 min	51	47	24	30
Grace 3500, 150 F				
600 rpm	73	114	62	67
300 rpm	64	89	52	54
200 rpm	59	85	46	48
100 rpm	53	76	39	40
6 rpm	45	63	21	35
3 rpm	35	47	19	23
PV (cP)	9	47	10	13
YP (lb/100 ft ²)	55	25	42	41
10 sec	33	39	18	20
10 min	42	42	21	25
30 min	44	42	21	25

The FLOPRO NTTM system is usually run with a LSRV (Low Shear Rate Viscosity) of about 40,000 cP. For these tests, it was determined to optimize the fluid viscosity of the FLOPRO NTTM system so as to compete well with the APHRON ICSTM mud; consequently, the viscosifier concentration was raised to give LSRV > 100,000 cP.

The effect of back pressure and core permeability on Leak-Off was determined. Net Leak-Off is obtained after 30 minutes by subtracting the Dead Volume of water between the mud and the face of the core at the beginning of each test. Dead Volume was approximately 33 mL in all cases. Figure 17 shows the Gross Leak-Off obtained with the APHRON ICSTM mud in FAO-5 at the three back pressures. The results are very close and suggest little effect of back pressure, at least in the range 500 to 1500 psig.

Figure 17. Effect of Back-Pressure on Leak-Off from SuperEnhanced APHRON ICSTM Mud

Most of the tests resulted in plugging of the cores and production of clear filtrate. Table 5 shows the Net Leak-Off at the three back pressures for the Solids-Free APHRON ICSTM mud samples.

For the solid-free fluids at elevated temperature (200⁰ F) and pressure (up to 2000 psig inlet

pressure) the APHRON ICSTM drilling fluid system yielded significantly lower Leak-Off than the FLOPRO NTTM system. Indeed, even with the lowest permeability core, the experiment with FLOPRO NTTM had to be stopped after 8 minutes because the fluid flowed through the core with the flow rate close to the maximum flow rate set for the pump, and the pressure drop on the core was significantly lower than 1000 psig. As demonstrated in Figure 17, back-pressure does not appear to affect these results significantly; this is to be expected for incompressible fluids or fluids with a low concentration of a compressible phase. However, permeability does affect the Leak-Off, again as expected: Leak-Off is very roughly proportional to permeability.

Table 5. Net Leak-Off of Solids-Free APHRON ICSTM and FLOPRO NTTM Drilling Fluids

Sample	Core	Nominal Gas Permeability, darcy	Mean Pore Diameter,	Axial Pressure Drop, psi	Net Leak-Off after 30 min, mL
APHRON ICS TM	FAO-00	2	10	1000	7.0
APHRON ICS TM	FAO-5	5	20	1500	10.2
APHRON ICS TM	FAO-5	5	20	1000	11.2
APHRON ICS TM	FAO-5	5	20	500	11.9
APHRON ICS TM	FAO-10	10	35	1500	36.3
APHRON ICS TM	FAO-10	10	35	1000	26.3
APHRON ICS TM	FAO-10	10	35	500	29.6
FLOPRO NT TM	FAO-00	2	10	1000	380*

* Test stopped after 8 minutes.

With addition of CaCO_3 , the Leak-Off trend between APHRON ICSTM and FLOPRO NTTM was reversed, as shown in Table 6.

Table 6. Net Leak-Off of APHRON ICSTM and FLOPRO NTTM Drilling Fluids with 30 ppb CaCO_3

Sample	Core	Nominal Gas Permeability, darcy	Mean Pore Diameter, Microns	Axial Pressure Drop, psi	Net Leak-Off after 30 min, mL
APHRON ICS TM + 30ppb CaCO_3	FAO-5	5	20	1000	8.1
APHRON ICS TM + 30ppb CaCO_3	FAO-10	10	35	1000	9.9
APHRON ICS TM + 30ppb CaCO_3	FAO-40	80	80	1000	8.0
FLOPRO NT TM + 30ppb CaCO_3	FAO-10	10	35	1000	1.7
FLOPRO NT TM + 30ppb CaCO_3	FAO-40	80	80	1000	3.3

It is clear that CaCO_3 lowered the Leak-Off of both fluids significantly, but it lowered the Leak-Off of the FLOPRO NTTM much more, producing a Net Leak-Off of the FLOPRO NTTM fluid that was consistently lower than that of the APHRON ICSTM fluid. Filter cake formed from APHRON

ICSTM + CaCO₃ at elevated temperature and pressure appears to be significantly thicker and somewhat gelatinous compared to that formed from FLOPRO NTTM + CaCO₃. Thus, it appears that there is some interaction of the APHRON ICSTM fluid with CaCO₃ which, in static Leak-Off tests, renders the CaCO₃ less than desirable as a bridging material. This is thought to be an artifact of the test apparatus.

In dynamic Leak-Off tests conducted with continuously replenished fluid at the wellbore wall and with long cores, the bridging behavior observed above is expected to be much less pronounced, and the APHRON ICSTM mud should behave in a manner more consistent with its performance in the field. APHRON ICSTM drilling fluids are thought to form an internal seal in loss zones. Thus, proper Leak-Off and Formation Damage testing of these fluids requires a design that simulates erosion of filter cake at the wellbore wall by fluid moving at high shear rate, continuous loading of aphrons into the formation and much longer cores than are used in conventional linear static Leak-Off tests; radial geometry (as in a wellbore) is also important, though it may not be critical for monitoring trends. These specifications require a different type of apparatus for proper testing of APHRON ICSTM muds. Potential designs for such an apparatus are being considered, as are tests at Terratek in a drilling simulator.

CONCLUSIONS

Phase II began with studies in all three task areas identified in the Work Plan for this year. First, in the area of Aphron Drilling Fluid Optimization, the concentrations of key components of the APHRON ICS™ drilling fluid were varied to optimize the current formulation; alternative materials will be investigated as well. The method of incorporating air to generate aphrons was also examined through the use of various mixers and pumps. Preliminary results suggest that techniques which incorporate more air tend to create a broader bubble size distribution and larger bubbles. Although larger bubbles have been shown to withstand compression better than do smaller bubbles, they also tend to coalesce faster and separate from the body of the liquid at a more rapid rate. Analysis of the surface chemistry of the fluid invasion process indicates that there are six interactions that control the fluid invasion and production processes. Three of those interactions were investigated during Q1 of Phase II: Bubble-Bubble, Bubble-Mineral Surface (Pore Wall) and Drilling Fluid-Produced Fluid. 2-D visualization studies confirm previous conclusions that aphrons have no apparent affinity for each other nor for silica surfaces. Yet, the APHRON ICS™ drilling fluid appears to be very compatible with oils, such as produced fluids; at least 25% by volume of even a very surface active, viscous crude oil was able to be blended into the drilling fluid with minimal effect on its bulk properties.

In the area of Flow Properties, a fluid invasion model began to be developed in collaboration with Dr. Peter Popov of Texas A&M University. Plans call for this model to incorporate the effects of radial geometry of the borehole, aphron concentration, fluid cavitation and extension as well as shear, and multi-phase flow; preliminary results indicate that the bulk fluid itself has a fluid invasion profile not unlike that observed in the field.

Finally, in the area of Leak-Off and Formation Damage in Permeable Media, Leak-Off tests – even linear, static tests with short cores -- demonstrate the sealing ability of the APHRON ICS™ fluid compared with other solids-free drilling fluids. Leak-Off correlates fairly well with core permeability and is relatively independent of back-pressure. The effects of bridging materials are not as clear and require tests in a radial, long core system with dynamic flow at the face of the core; such a system will be designed and constructed in Q2 of Phase II.

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LIST OF ACRONYMS AND ABBREVIATIONS

APHRON ICSTM = Polymer-Based Aphron Invasion Control System

BSD = Bubble Size Distribution

HTHP = High Temperature and High Pressure

ppb = lbm/bbl = Pounds (mass) per Barrel

psia = lbf/in² = Absolute Pressure

psig = Gauge Pressure, i.e. psig = psia + 14.7