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COMPARATIVE STUDIES OF USING APHRON DRILLING MUD VERSUS SPUD MUD

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ABSTRACT

The complexity involved while drilling troublesome formation where problems like stuck pipe, thief zones and wellbore collapsing exists requires special remedial actions to continue drilling operations. These issues associated with depleted reservoirs can be reduced by either going for underbalanced drilling or by using some special type of drilling fluids which can mitigate the problem of lost circulation zones and differential sticking. Now if we go for underbalanced drilling which requires special equipments that are costly in nature, can make the project economically unviable and hence we have to use some special kind of mud which can extenuate the above mentioned problems. One such type of remedial drilling fluid that can be used in these troublesome formations is Aphron drilling fluid that has inherited properties of high shear-thinning by containing stabilized air-filled bubbles known as aphrons.

This type of drilling fluid provides the property of invasion control specially in highly permeable formation that include permeable and fractured sandstone and limestone formations apart from this it also provides stability in unstable shaly/clay formation. This property of invasion-control drilling is because of the stability of aphrons even at high pressure environment and their tendency to non-coalescing and hence the micro bubbles (aphrons) will move faster as compared to the surrounding liquid phase and will instantly form a layer of bubbles at the fluid front thus slowing down the entry of drilling fluid into the permeable formation and thus helps in building an interface that acts as an internal seal to seal the pore network of the wellbore. If we look at the fundamental level the barrier formed by the micro bubbles and the radial-flow pattern of the fluid will slow it down and causes the LSRV (low-shear-rate viscosity) to increase exponentially, now as the LSRV increases which is assisted by low thixotropy due to micro gel network of the fluid causes the fluid to generate high viscosity rapidly thus protecting the fluid to penetrate in the formation. Apart from this the low adhesive and cohesive nature of aphrons will prevent their sticking to the well bore and thus assist the displacement of produced fluids.

***Keywords:* Depleted reservoirs, Differential sticking, Underbalanced drilling, Aphron drilling fluid, shear-thinning, LSRV (low-shear-rate viscosity).**

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1. INTRODUCTION

Drilling fluid is one of the most important elements of drilling process as it provides various actions that are of utmost importance during drilling a well. Some of the functions of drilling mud are:

- It controls the high formation pressure that is contained within the hole: this action of drilling fluid is achieved by hydrostatic pressure of mud. In order to prevent the well from kicking the mud pressure level should be greater than the formation pressure (This type of drilling is known as over balance drilling) for this an overbalance of 100-200 psi is used.[1]
- It carries the drill cutting to the surface: In order to have a hole inside the surface of earth, the material drilled should be removed from the subsurface. For this the annular velocity, plastic viscosity and yield point of mud is used.
- It stabilizes the well bore: The differential pressure between mud and formation keeps the well bore stable apart from this formation of a good mud cake also helps in stabilization of a wellbore.
- It helps in cooling of bit and its teeth: The energy that is used for drilling a well is provided in the form of weight on bit, rotation and hydraulic energy and large part of this energy is dissipated in the form of heat and if this heat is not removed than it can cause various drilling problems. This heat energy is removed by mud which absorbs the heat by convection process.
- It helps in evaluation well logs: The telemetry system which is used to transfer the information from MWD system (Measuring while drilling) and LWD system (Logging while drilling) also used mud as a medium to transfer pressure pulses and hence mud helps in creation of well logs.[2]

Function	Physical/Chemical properties
Transport cuttings from the well bore.	Yield point, Apparent Viscosity, Velocity, Gel strength.
Prevent formation fluids from flowing into the well bore.	Density
Maintain Wellbore stability.	Density, Reactivity with clay.
Cool and Lubricate the bit.	Density, velocity.
Transmit hydraulic horsepower to bit.	Velocity, Density, Viscosity.

Table 1: Drilling fluids function and the properties responsible for those functions.

Water-based mud: The base fluid of the water base mud is dependent on the type of well conditions that exists and also on the various formations of the well being drilled and therefore the water base mud can use fresh water, seawater, brine, saturated brine for its base fluid. The solids (clays) react with the water and chemicals in the mud and are called active solids. The activity of these solids must be controlled in order to allow the mud to function properly. The solids which do not react within the mud are called inactive or inert solids (e.g. Barite). The other inactive solids are generated by the drilling process. The main disadvantage of using water based muds is that the water in these muds causes instability in shales. Shale is composed primarily of clays and instability is largely caused by hydration of the clays by mud containing water. Shales are the most common rock types encountered while drilling for oil and gas and give rise to more problems per meter drilled than any other type of formation. The interaction of mud-shale resulted in the introduction of a WBM that combines potassium chloride (KCl) with a polymer called partially-hydrolyzed polyacrylamide – KCI PHPA mud. PHPA helps stabilize shale by coating it with a protective layer of polymer.

Oil Based mud: Oil-based muds are similar in composition to water-based except that the continuous phase is oil in these type of drilling fluids. OBM's do not contain free water that can react with the clays in the shale. OBM not only provides excellent wellbore stability but also provide good lubrication, temperature stability, a reduced risk of differential sticking and low formation damage potential. Oil-based muds therefore result in fewer drilling problems and will cause less formation damage than WBM's and they are therefore very popular in certain areas. Oil muds are however more expensive and require more careful handling (pollution control) than WBM's. Full-oil muds have a very low water content (<5%) whereas invert oil emulsion muds (IOEM's) may have anywhere between 5% and 50% water content. In invert oil emulsion mud (IOEM) water may make up a large percentage of the volume, but oil is still the continuous phase. (The water is dispersed throughout the system as droplets). In recent years the base oil in OBMs has been replaced by synthetic fluids such as esters and ethers. Oil based fluids do contain some amount of water but this water is in a discontinuous form and is distributed as discrete entities throughout the continuous phase.

If we talk about WBMs then we'll find that till now the waste WBMs doesn't require any special treatment and hence it could be directly discharged directly into the environment. But with more and more strictness applied by various organizations around the world and due to the toxic nature of some components that are used in WBMs makes them to become more and more restricted or prohibited around the world. For example the use of various components containing Chrome, like chrome lignosulfonates which is prohibited in many places by various environmental organizations. Apart from this, now there are many restrictions which are being imposed in many areas on various chemicals like chloride, nitrate, and potassium salts. In various regions like the North Sea,[3] use of polymers like polyacrylamide polymers, especially partially hydrolyzed polyacrylamide (PHPA) is also restricted. But if we compare the status of OBMs then we'll find that they are more restricted as compared to WBMs specially in offshore, and in some other places they can only be used only if the drilling operator is having a zero discharge strategy (this type of operation is sometimes known as a closed loop system).

2. LITERATURE REVIEW

The problem of formation damage which exists due to the tendency of invasion by drilling fluids is a well known problem especially for the depleted zones.[4] Apart from this there are many zones or formations that contain clays which have a tendency of hydrate when they come in contact with water that is present in the drilling fluids. This hydrated clay will then the producing zones which are primarily sands and this process will prevent the hydrocarbon from coming out of the borehole and therefore cannot be produced. Also the solids of the formation fluids will block the opening further thus will make the condition more severe. This whole process will also degrade the formation as the drilling fluids and filtrate will dislodge and will make the solids of the formation to migrate and thus will reduce the stability of the well bore and will eventually produce some solids which will further block the movement of produced hydrocarbons.

Invasion of reservoir rock by drilling fluid filtrate is known to be one of the major causes of productivity reduction. [4]

The issues of lost circulation and differential sticking in the depleted wells which are normally encountered during the conventional form of drilling are because of the presence of the overbalance condition. Depending on the severity of the overbalance, invasion may be in the form of filtrate, seepage of fluid and solids, or complete loss of circulation. All of these damages the production zone while seepage and lost circulation require remediation before drilling can continue. This type of remediation usually involves adding solids as seepage control or bridging agents, thereby creating additional, and sometimes permanent, damage. The various equipment that are required while using aerated muds or in other case drilling underbalanced is often very expensive and even after getting those equipments, it is not easy to meet the meeting safety requirements that are related with those muds. Apart from this it is not always possible to provide the hydrostatic pressure by the mud which is necessary maintain pressured formations that are present above the reservoir formations.

Understanding the influence of formation behavior is necessary before new mud systems can be developed to predict borehole response (failure or no failure) as a function of a given drilling fluid (i.e., including both mud weight and drilling-fluid constituents). In this thesis, we focus on the physical and chemical factors and how they influence the borehole stress state and formation properties. The objective of this study is to couple the mechanics and chemistry of drilling-fluid and its interaction with the well bore's formation.[5-6] With oil and gas reservoirs becoming increasingly depleted of hydrocarbons, and thus making drilling more costlier. Apart from this the formations lying near to the producing formations usually tend to have very high formation pore pressure and thus will require greater mud density so that to maintain the overbalance and to prevent kick. And now if the same mud is being used for a depleted zone then this high-density drilling mud can cause formation damage by forming thief zone where high amount of drilling fluid can be lost. The high density of the drilling fluid can cause the additional problem of differential sticking. On top of this the presence of depleted sand zones that are interbedded with shales also need simultaneous stabilization.[7]

Aphron drilling fluid has the ability to reduce fluid loss in fractured and depleted formations as they are compressed during their pumping due to which, energy is stored in these aphrons and when they interact with the fractured or depleted formation their energy is released and these aphron tends to expands until it establish an equilibrium with surrounding formation pressure.[8-9] On the other hand, the base fluid has a very high Low Shear-Rate Viscosity (LSRV). Therefore when fluid enters the formation (a low-shear-rate region), the viscosity builds rapidly. The expansion of aphrons and the increase in viscosity, both result in creation of a solid-free bridge.[10] The solid-free bridge prevents further invasion of drilling fluid into the formation. Experience has shown that this bridge is easily removed by back flowing the reservoir fluid, and there is no need for work-over operations at the end of drilling.[11] Besides, unlike aerated muds, aphron fluids do not corrode drill string and other drilling equipment, because most of air in the system is trapped in aphron shell.

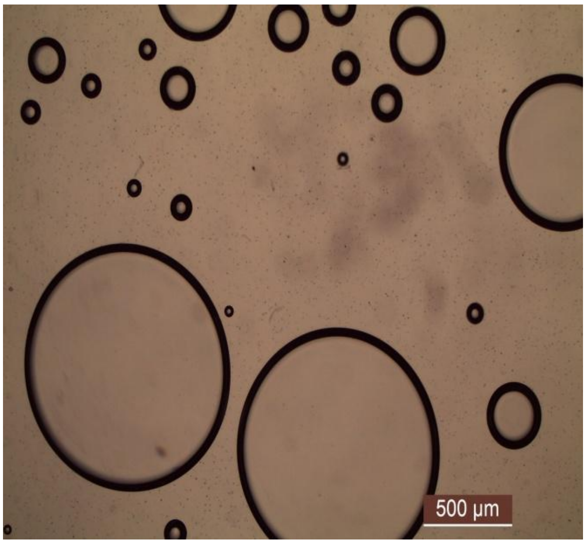

Figure 1: Aphron mud at room temperature (4X magnification).

3. METHODOLOGY

The experimental procedures of this work were followed according to the below steps:

a) **Preparation of base fluid.**
b) **Preparation of aphronized fluid.**
c) **Picturization of aphron drilling fluid under microscope.**
d) **Characterization of rheological properties.**
e) **Observing the stability of generated aphrons.**

3.1 Preparation of base fluid:

- Take 340.90 gms Tap Water in a mixing jar and start mixing on Hamilton Beach Mixer at high speed.
- Add 0.02 gm Soda Ash mix for 1 min.
- Add 22.75 gms, mix for 14 min.
- Static Age the mud for 16 hrs at room temperature (750 F).
- After aging stir mud on Hamilton Beach Mixer at high speed for 15 min.

Function of Product	**Product Name**	**Specific gravity**	**MIXING ORDER**	**MIXING TIME (Mins)**	**PRODUCT CONCENTRATION (Gms)**
BASE FLUID	Water	1	0	0	340.90
ALKALINITY	Soda Ash	2.53	1	1	0.02
VISCOSIFIER	Bentonite	2.5	2	14	22.75

3.2 Preparation of aphronized fluid:

- The first step was adding hardness control agent (Soda Ash) to the fresh water to remove possible hardening ions.
- In the next step caustic soda was added to the base fluid to increase pH to 9.5.
- Aphron generator polymer and polymer blend were added to the base fluid and mixed for 20 minutes using Hamilton beach mixer at high speed to avoid formation of local viscous agglomerates.
- After this step, Aphron Stabilizer Surfactant, which is a non-ionic surfactant was added to the system to enhance aphron bubble stability. The solution was stirred for 2 minutes for good surfactant dispersion.
- Finally, the mixture was mixed at high speed using Hamilton beach mixer for 5 minutes.

Function of Product	**Product Name**	**MIXING ORDER**	**MIXING TIME (Mins)**	**PRODUCT CONCENTRATION (Gms)**
BASE FLUID	Water	0	4	330.90
ALKALINITY	Soda Ash	1	1	0.4766
pH BUFFER	Caustic Soda	2	4	0.1
APHRON GENERATOR/ APHRON STABILIZER	Xanthan Gum	3	4	1.9
FLUID LOSS CONTROLLER/ THERMAL STABILIZER/ VISCOSIFIER	Xanthan Gum + PAC-R polymer	4	6	9.51

3.3 Picturization of aphron drilling fluid under microscope:

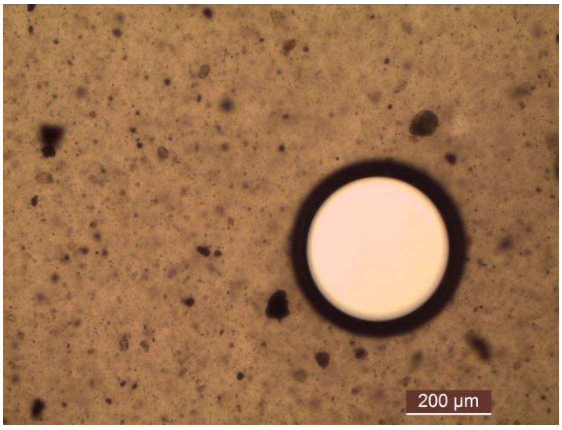

Figure 2: Spud mud at room temperature (10X magnification).

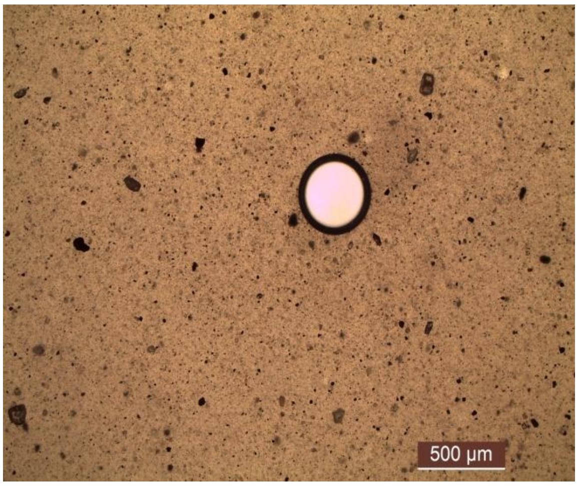

Figure 3: Spud mud at room temperature (4X magnification).

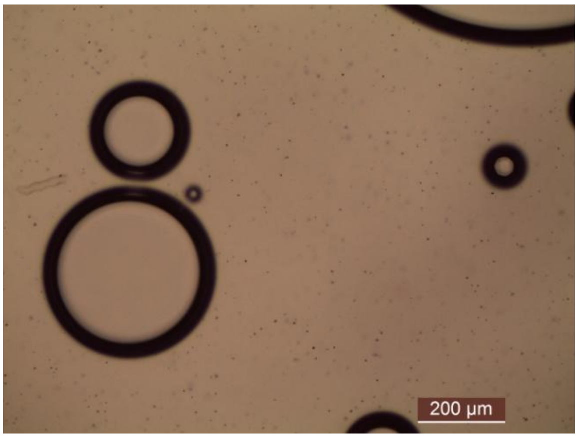

Figure 4: Aphron mud at room temperature (10X magnification).

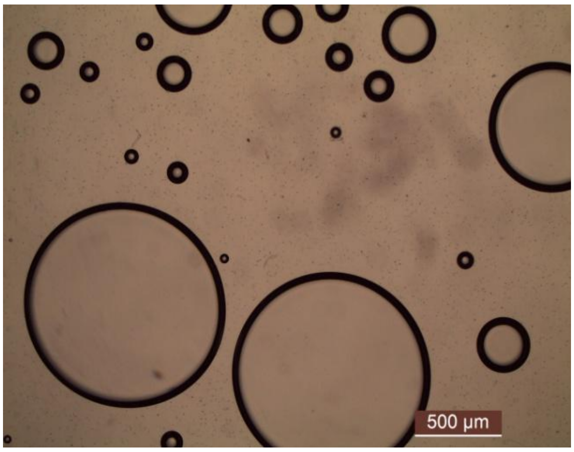

Figure 5: Aphron mud at room temperature (4X magnification).

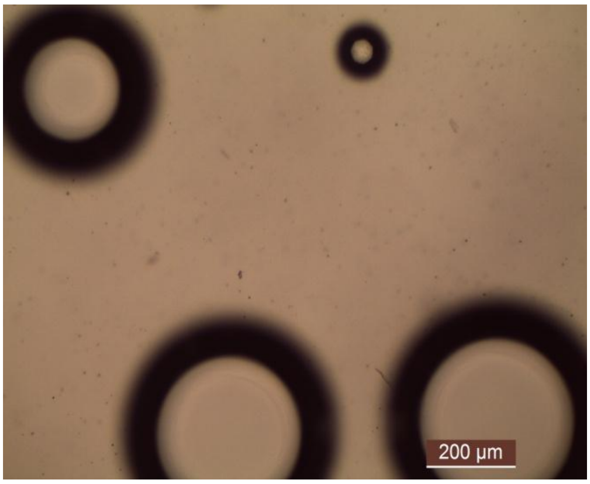

Figure 6: Aphron mud at 49^0 C (10X magnification).

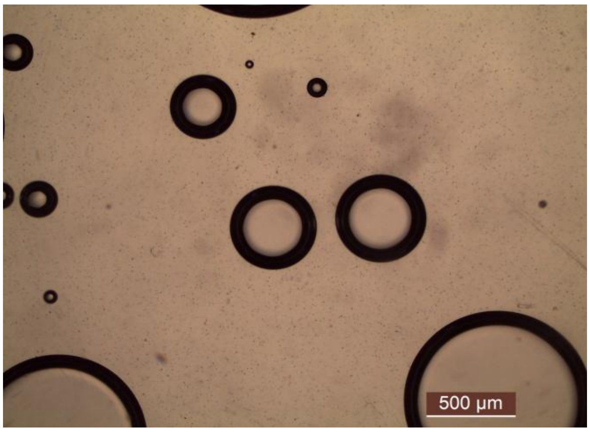

Figure 7: Aphron mud at 49^0 C (4X magnification).

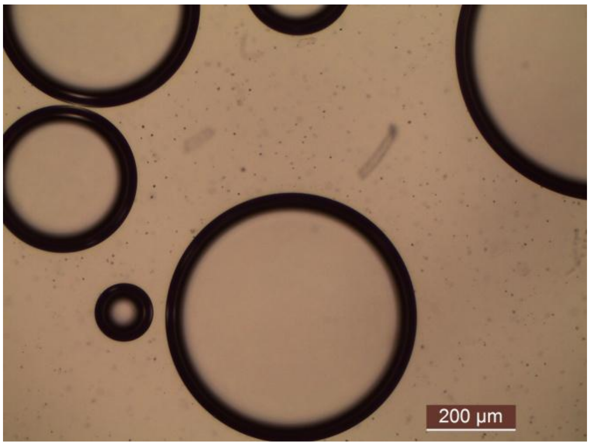

Figure 8: Aphron mud at 71^0 C (10X magnification).

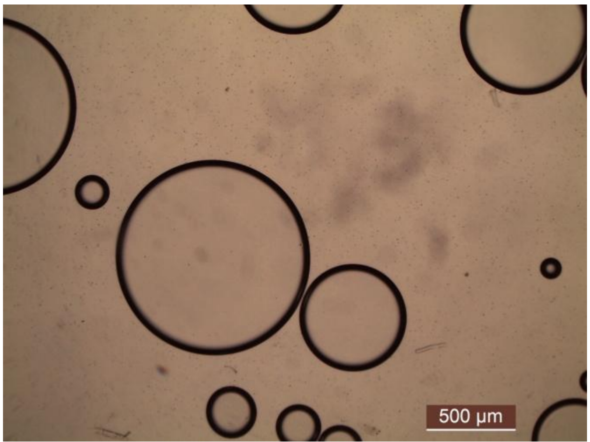

Figure 9: Aphron mud at 71^0 C (10X magnification).

Characterization of rheological properties:

Dynamic shearing force:

- First, the viscosity of the drilling fluid was tested by using multi speed viscometer.
- The sample before and after Aphron generation was poured into the cup, the dial readings were recorded at different rpms (600, 300, 200, 100, 6, 3) and temperatures and converted to shear stress and shear rate.
- The first temperature point tested was 29^{0}C (84.2^{0}F), which is the room temperature.
- The second temperature point tested was 49^{0}C (120.2^{0}F), the standard temperature to perform rheology test according to API, and a temperature commonly used in oil field test and report on drilling fluid rheological parameters.
- The third temperature, 71^{0}C (159.8^{0}F a temperature in between surface temperature and bottom hole temperature, which is taken as the temperature of drilling fluid flowing in the annulus.

Rheological properties of spud mud:

Dial deflection at 600 RPM	40
Dial deflection at 300 RPM	35
10 second gel	18
10 minute gel	30

- Plastic Viscosity (centipoise) = D600 - D300 = 40-35 = 5 centipoise
- Yield Point (lb/100 ft^2) = D300 - Plastic Viscosity = 35-5 = 30 lb/100 ft^2
- Apparent viscosity (centipoise) = D600/2 = 40/2 = 20 centipoise
- Gel strength (10 seconds) = 18 lb/100 ft^2
- Gel strength (10 minutes) = 30 lb/100 ft^2

Rheological properties of aphron mud (at room temperature):

Dial deflection at 600 RPM	150
Dial deflection at 300 RPM	115
10 second gel	**19**
10 minute gel	30

- Plastic Viscosity (centipoise) = D600 - D300 = 150-115 = 35 centipoise
- Yield Point (lb/100 ft^2) = D300 - Plastic Viscosity = 115-35 = 80 lb/100 ft^2
- Apparent viscosity (centipoise) = D600/2 = 150/2 = 75 centipoise
- Gel strength (10 seconds) = 19 lb/100 ft^2
- Gel strength (10 minutes) = 20 lb/100 ft^2

Dial deflection at 600 RPM	135
Dial deflection at 300 RPM	100
10 second gel	**17**
10 minute gel	17

Rheological properties of aphron mud (at 49^0 C):

- Plastic Viscosity (centipoise) = D600 - D300 = 135-100 = 35 centipoise
- Yield Point (lb/100 ft^2) = D300 - Plastic Viscosity = 100-35 = 65 lb/100 ft^2
- Apparent viscosity (centipoise) = D600/2 = 135/2 = 67.5 centipoise
- Gel strength (10 seconds) = 17 lb/100 ft^2
- Gel strength (10 minutes) = 17 lb/100 ft^2

Rheological properties of aphron mud (at 71^0 C):

Dial deflection at 600 RPM	118
Dial deflection at 300 RPM	**86**
10 second gel	10
10 minute gel	**12**

- Plastic Viscosity (centipoise) = D600 - D300 = 118-86 = 32 centipoise
- Yield Point (lb/100 ft^2) = D300 - Plastic Viscosity = 86-32 = 54 lb/100 ft^2
- Apparent viscosity (centipoise) = D600/2 = 118/2 = 59 centipoise
- Gel strength (10 seconds) = 10 lb/100 ft^2
- Gel strength (10 minutes) = 12 lb/100 ft^2

4. RESULT AND DISCUSSION

- Water based aphron drilling fluids are effective at controlling losses of whole mud and filtrate in permeable zones. This property is provided by three main characters of the aphron fluid, these characters are:
  - They can survive and hence will experience a bubbly type of flow and by virtue of this phenomenon they always occupy the fluid front and this fluid front is responsible for forming a seal around the well bore and will therefore reduce the fluid invasion.
  - They have a tendency of forming the microgel network which can further reduce the fluid invasion into the well bore.
  - Due to the reduction in the process of invasion the low shear rate viscosity of base fluid will further decreases the fluid transport and since the fluid have a very low thixotropy therefore it will make it more viscous and hence will assist in forming a filter cake of very low permeability.
- The shell in aphron structures resists compression and loss of encapsulated air, while promoting agglomeration. Thus, micro-bubbles become concentrated at pore throats and perhaps at fracture tips. It is speculated that these microbubbles produce an effective seal in a loss zone primarily by developing a physical barrier via compression of the flexible micro-bubbles into a tight agglomerate, but also by dampening pressure transmission.
- The aphrons have a very low affinity for rock surfaces and between themselves and thus they don’t interact with the well bore and will be produced back very easily and hence they will not interfere with the production of hydrocarbon.
- If we compare the plastic viscosity, apparent viscosity and yield point of aphron fluid with normal water base mud then we’ll see that all these properties have higher value for aphron mud which is a contributing factor for the affectivity of aphron fluid.
- The 10 second gel is nearly same for both the fluid while the 10 minute gel value for water base fluid is higher as compared to the aphron fluid, which means that the internal stresses that will develop in aphron fluid after keeping it stagnant will be less as compared to the water base fluid.
- With increase in temperature the plastic viscosity, apparent viscosity and yield point of aphron fluid will decrease due to the slight loss in the number of the aphrons which can

also be seen in the microscopic view of the aphron fluid at different temperature.

- The gel strength (both 10 second gel and 10 minutes gel) is also following an inverse relationship with the temperature, this infers that the internals stresses will reduce with the application of heat in an aphron fluid.

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