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## Physicochemical properties of aphron drilling fluids

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### ABSTRACT

Colloidal gas aphrons (CGAs) were first reported by Sebba as micro bubbles (25-125 $\mu$ m), composed of a gaseous inner core surrounded by a thin surfactant film, which are created by intense stirring of a surfactant solution. Since then, these colloidal dispersions have been used for diverse applications, with a particular focus on separation processes. However, exploitation of CGAs in petroleum industry is only an outset, which was first used in west Texas in 1998, called Aphron drilling fluid. This fluid is characterized as having in its continuous phase, high viscosity at low shear rate and containing, as internal phase, micro air or gas bubbles, non coalescing and recirculateable. In this paper, we illuminate the physical and chemical properties of aphron drilling fluid and its processing mechanism.

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### KEYWORDS

Colloidal gas aphrons (CGAs);  
Drilling fluid;  
Properties;  
Invasion-control.

### INTRODUCTION

Drilling depleted reservoirs is fraught with a host of technical and economic problems that often make it unprofitable to further develop some mature fields. Most of the problems focus on uncontrollable losses in the large fractures that commonly characterize these reservoirs. The water-wet sands that typify many of these zones propagate seepage losses and differential sticking, both of which are extremely expensive to correct. Uncontrollable drilling fluid losses frequently are unavoidable in the large fractures characteristic of these formations. Furthermore, the typical laminated sand and shale sequences create conditions that can make drill-

ing excessively expensive and dangerous when using conventional rig equipment. Consequently, these and a host of associated problems have led some operators to abandon continued development of these promising, yet problematic reservoirs.

When drilling a well, the drilling fluid is the first material to contact the wellbore formations. The drilling fluid therefore plays a primary role in determining the type of damage and the extent to which the producing formations are impaired. Depending upon the type of fluid used, damage can be caused or can be prevented. Ideally the drilling fluid will prevent damage to the hydrocarbon bearing zones during the drilling phase and will allow for the flow of hydrocarbons during the production phase.

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Drilling fluid formations have evolved over the years to prevent formation damage<sup>[1-6]</sup>. Many previous works have dealt with the loss of production due to formation damage, impairment mechanisms and remediation of damage. Minimizing the formation damage done to a well and the efficient removal of that damage are of prime importance. In all drilling processes, for example, conventional water/oil base drilling, dry drilling, air/mist drilling and foam drilling.

The foam drilling system has been used widely, due to the ability to modify the many desirable properties of foam fluids for oil field operations<sup>[7]</sup>. foam fluid can now be tailored to have high carrying capacity, low density, low filtrate, and circulation losses, thus making it an ideal fluid for an underbalanced drilling. Foam fluids are prepared by mixing a liquid, a gas and a surfactant. The mixture is very complex and its rheological properties—shear stress, shear rate, and viscosity are strongly determined by the operating temperature, pressure, liquid phase properties, foam quality, foam stability, foam texture, foam channel wall interaction, and the type and concentration of the surfactant, changes in these parameters affect the flow properties of the foam fluid and may seriously change their hydraulic behavior. This effect in turn may affect their stored energy, viscosity and the prediction of friction losses<sup>[8,9]</sup>.

The need for development of novel methods, which minimize, and/or put an end to lost circulation, particularly containing damage-prone zones or depleted, low pressure reservoirs, while lowering the running costs of the overall process, therefore remains. For this reason, the potential of CGA as a technique for preventing formation impairment is being explored.

A new system has been developed, a water base drilling fluid called Micro-bubble-Aphron, designed to drill low-pressure mature reservoirs this fluid combines certain surfactants and polymers to create a system of aphrons encapsulated in a uniquely viscosified system. In order to produce aphrons, a gas core of the proper size and conditions, which is of pressure drop and cavitation, must exist. These conditions exist in the hydrodynamic cavitation produced as the drilling fluid exits the bit nozzles. This turbulence and pressure drop creates “microvoids” that are available to be encapsulated by the surfactant and harnessed as energized spheres able to contain the pressure under which they are cre-

ated. with this contained energy aphrons have the ability to reduce density, create downhole bridging in formation openings, and enhance the low shear rate viscosity (LSRV).

Aphron drilling fluid was first implemented in California<sup>[1]</sup>. Since then, this novel drilling system has been used in many oil fields and their performance results are available in the literature<sup>[10-14]</sup>.

Drilling with aphron fluids has been shown to provide significant benefits, including:

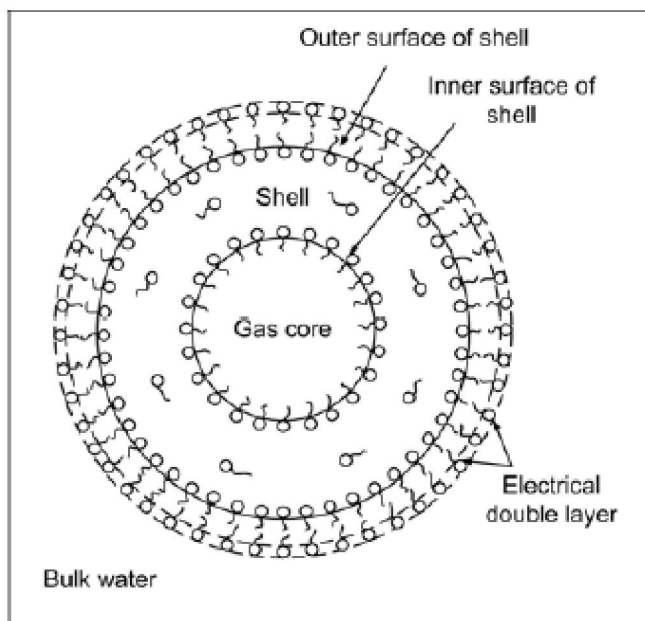
- Reduce density without injecting gasses.
- Are recirculateable.
- Provide stable fluid properties.
- Minimize well control problems
- Build bridging system downhole. Provides borehole stability.
- Provide excellent hole cleaning.
- Minimize cuttings bed formation.
- Enhance LSRV, for stability.

Although the use of the aphron drilling fluid is experiencing growth at an increasing rate, it is only an initial stage. For this reason, we will present a brief review of the physical and chemical characteristics of the aphron drilling system in order to promote its applications in more oilfields.

### Aphron structure

Colloidal gas aphrons (CGAs) are gas microbubbles (25-125 $\mu$ m) created by stirring a surfactant solution at high speed (5000-10000 rpm). The structure of CGA was first proposed by Sebba<sup>[15]</sup>. Sebba claimed that CGA are not like conventional bubbles, which are surrounded by a surfactant monolayer, but are gas bubbles surrounded by three surfactant layers (Figure 1).

Figure 1 illustrates the differences between a soap bubble and a gas aphron in the structure. According to Sebba<sup>[15]</sup>, a CGA consists of an inner gas phase surrounded by a soapy shell. The soapy shell has an inner and outer surface. The inner surface of the shell contacts the gas bubble; whereas, the outer surface of shell contacts the bulk liquid. These two surfaces have surfactant monolayers absorbed on them. Water near the two surfaces is different from the bulk water because the water near the surfaces has more hydrogen bonds than the bulk water. This water phase positions the surfactant molecules with the hydrophilic hydrocarbon



**Figure 1a : Structure of a single colloidal gas aphron (CGA) by Sebba**

head pointing inwards and the hydrophobic hydrocarbon tail pointing outwards. With this orientation, the CGAs are prevented from coalescing. An electric potential gradient is induced by the orientation of the hydrophilic hydrocarbon heads at the interface of the air bubble. CGAs created with the same surfactant will have similar surface charges and will not colloid together. The CGAs can last for minutes or for hours, if stirring is maintained, without coalescence being appreciable. The combination of these two effects results in foam that can be pumped in a pipe.

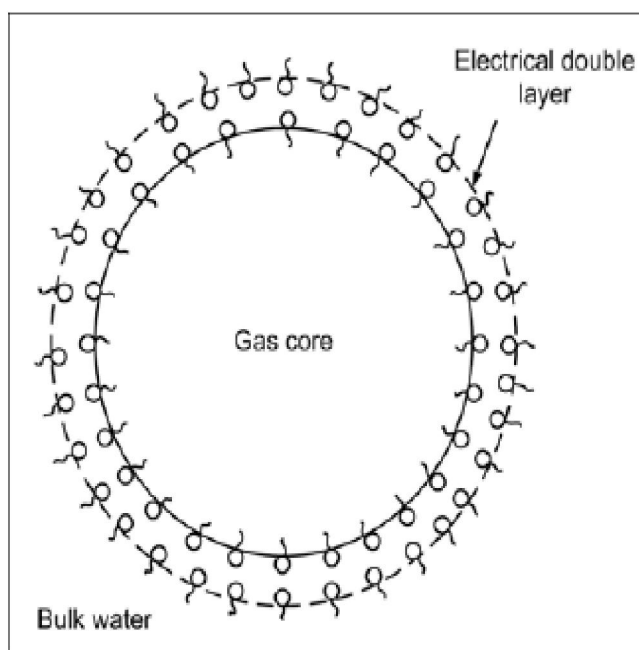
This theory was based on several experimental observations, including stability measurements. The evidence for the proposed CGA structure by Sebba (1987)<sup>[15]</sup> is inconclusive.

Despite the lack of understanding of the structure and stabilizing mechanisms of CGA dispersions, observations<sup>[15-17]</sup> indicate that:

- CGA have large interfacial area per unit volume; a result of their small size and high gas hold-up (typically 50%).
- CGA exhibit relatively high stability.
- Flow properties of these dispersions are similar to those of water. So these fluids can be pumped easily, without collapse from one location to another.

### Density ranges

One of the interesting properties of a CGA is that it



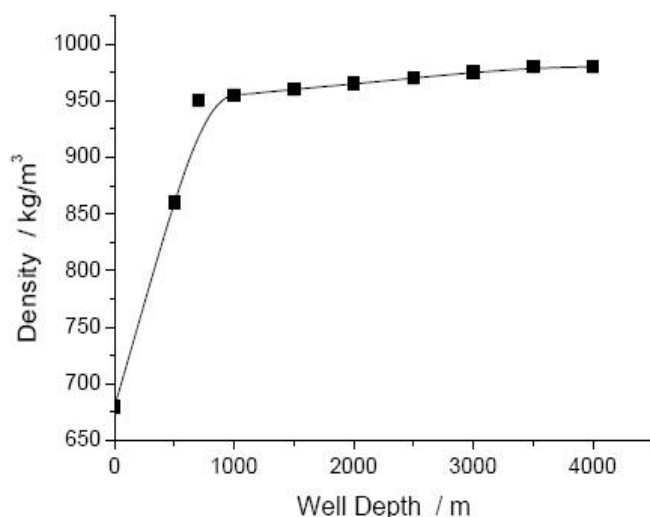
**Figure 1b : Structure of a single foam**

provides one of the lightest liquids at ordinary temperatures and pressures. Incorporation of stable air/gas particles into a drilling fluid will obviously lower the density of the fluid. The reduction in drilling fluid density is directly related to the concentration of surfactant contained in the fluid. In laboratory conditions it is possible to obtain stable drilling fluid densities, under no pressure, as low as 700kg/m<sup>3</sup>. Field applications have taken the system to as low as 800kg/m<sup>3</sup> density, although it is more common to run the densities in the range of 900-950kg/m<sup>3</sup>. Drilling fluids with mud weights under 800kg/m<sup>3</sup> tend to jack the mud pumps severely.

Because of the larger content of gas, the density changes greatly with the change of temperature and pressure. According to analysis in laboratory and data derived from applications on the site<sup>[10,14]</sup>, with the pressure rising, the change rate of aphron drilling fluids becomes small until approach zero in the end; the affection of temperature to gas molecules is very big. With the temperature rising, the kinetic energy of gas molecules will rise, and the gas is hard to be compressed.

Air/Gas is a compressible material when subjected to pressure. Measurement of aphron fluid density on surface will be less than the actual downhole density due to compression of the air or gas within the fluid. While exact depth vs. density curves have not been established, an actual downhole pressure device used on a well showed that a 900 kg/m<sup>3</sup> density surface mud

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**Figure 2a : Aphron fluid density vs well depth**

weighed  $950\text{kg/m}^3$  at a 700 meter depth.

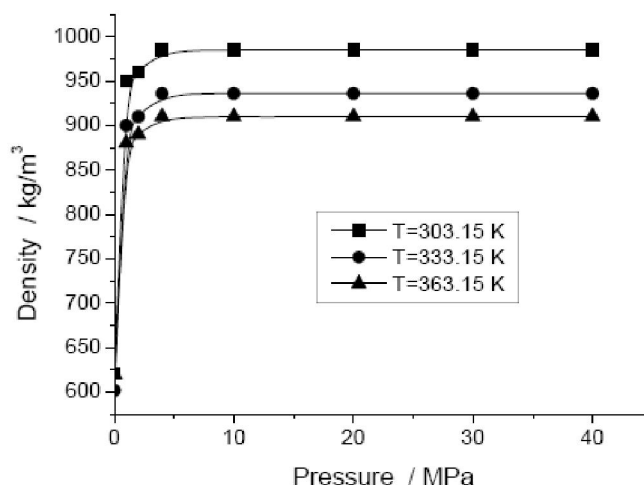
The fluid density need not be restricted to densities less than  $1000\text{kg/m}^3$ . The air/gas particles may be entrained in weighted fluids containing common weighting agents such as barite, calcium carbonate, hematite, etc. Therefore, the aphron fluid is applicable for use in higher-pressure wells. Such fluids may be utilized in underbalanced drilling, overbalanced drilling, or even at-balanced drilling operations.

### Rheology of aphron drilling fluid

In order to be most effective, the aphrons must be stabilized in a drilling fluid, this is most effectively done by using a high yield stress, shear thinning (HYSST) polymer. This type of polymer most effectively viscosifies the "lamella" separating the aphrons and the water layer in the bubble film surrounding the aphron core. This builds the strength of the bubble film and the surrounding layer so that aphrons are self-contained. This feature allows them to resist both compression and expansion so they are effective downhole and recirculateable. According to sebba, aphrons protected

**TABLE 1 : Effect of aphron generation on low shear rate viscosity (LSRV) of various fluids**

Fluid sample No.	1	2	3	4	5	6
Low shear rate viscosity, mPa.s (Brookfield rheology @ 0.5rpm)						
Before aphron generation	880	4560	1880	11600	5280	1380
After aphron generation	4880	9200	6200	19400	11600	20600



**Figure 2b : Temperature-Pressure-Density curve of aphron fluid**

by encapsulating shells can attract one another to build up complex aggregates. These aggregates can contain tremendous energy because of Laplace pressure.

In addition to stabilizing the aphrons, the drilling fluid must produce hole cleaning, cuttings suspension, and invasion control necessary for optimum performance while drilling the high angle or horizontal borehole. Biopolymers produced by the action of bacteria, fungi, or other microorganisms on a suitable substrate, which increases the low shear rate viscosity (LSRV), are particularly useful in the drilling fluids.

A xanthan gums were found to be most effective in stabilizing the aphrons in drilling fluid. The low shear rate viscosity (LSRV) was used to produce excellent hole cleaning, cuttings suspension, and invasion control in addition to aphron ability. TABLE 1 shows the ability of aphrons to enhance LSRV<sup>[1]</sup>.

The drilling performance of the HYSST fluids in high angle and horizontal hole cleaning, and its prevention of cuttings bed formation, invasion control has been documented. This cleaner borehole reduces cuttings and debris, which can be carried into the formation or stored in the cuttings bed.

A minimum low-shear rate viscosity of the drilling fluid is also required as part of the fluid package. The drilling fluid requires good LSRV to keep the air/gas particles from escaping out the fluid on surface. In practice, an LSRV of greater than  $50000\text{mPa.s}$  on a Brookfield at  $0.5\text{rpm}$  is the minimum rheology required to keep the air/gas particles within the drilling fluid system. Ideally, a  $100000\text{mPa.s}$  Brookfield viscosity will

keep all air/gas particles entrained and will keep the drilling fluid density at a consistent and predictable value.

The drilling fluid composition is key to being able to achieve LSRV and therefore the entrainment of the air/gas particles. Brookey employed high yield stress, shear thinning polymers in order to achieve the required rheology and to ensure that the air/gas particles are self-contained.

### Bridging with air/gas particles

The vast majority of reservoir formations are water-wet. As the oil/liphophilic phase is displaced by water, which wets the rock surfaces, capillary pressure is a driving force. An insular globule of non-wetting fluid moves only by virtue of the differential pressure applied across it within a moving wetting fluid<sup>[18,19]</sup>. Before a globule can be displaced, this pressure differential must be sufficient to squeeze it through capillary restrictions, which offers resistance. The resistance offered to fluid displacement by a bubble of non-wetting fluid when squeezed from its original radius to the constriction radius, can be described by the following expression<sup>[20]</sup>:

$$\Delta p = 2\gamma \left( \frac{1}{r_1} - \frac{1}{r_2} \right)$$

where:  $\Delta p$  is capillary pressure(resistance);  
 $\gamma$  is interfacial tension;  
 $r_1$  is constriction (capillary) radius;  
 $r_2$  is original radius.

Although the  $p$  may be very small for a single bubble, the cumulative resistance of many bubbles may be large. It is highly unlikely that pressure gradients of sufficient magnitude could be applied in the field to overcome the "Jamin Effect" and force deep penetration of aphrons into the interconnected openings in permeable formations<sup>[20,21]</sup>.

An aphron is much more than a "gas bubble". The viscosified water lamella, in tandem with the surfactant layers, creates an "energized environment". When an aphron is generated inside a liquid, a new surface must be created, which increases in area in proportion with the growth of the bubble. This expansion must be balanced by an increase in the pressure within the bubble (Laplace pressure), thus explaining why the aphron is associated with an "energized environment" or "precompressed structure".

Aphron contain a gas nucleus of encapsulated air/

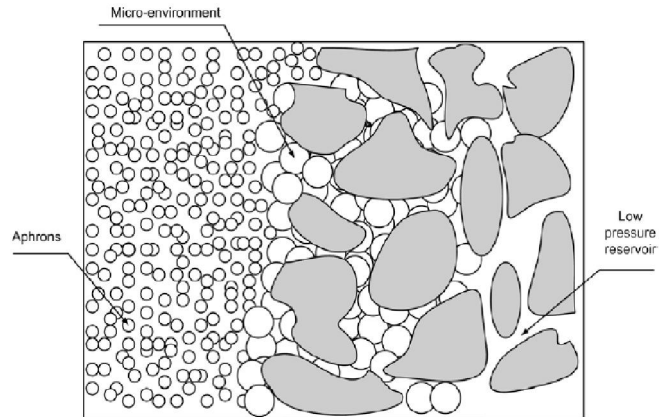


Figure 3 : Bridging mechanism

gas and compress when circulated down hole. The internal pressure of these micro-bubbles increases at a rate proportional to the external pressure being applied. The combination of increasing pressure and temperature serve to energize the individual aphrons.

Once the drilling bit exposes a depleted formation, the aphrons immediately aggregate within the openings of low-pressure zones. There, a portion of the energy stored within each aphron is released, causing it to expand. The expansion continues until the internal and external pressures on the wall of the aphron are in balance (as shown in Figure 3).

As the energized microbubbles enter formation openings, they carry energy equal to that of the annulus. As the aphrons crowded into the openings, external laplace forces increase dramatically, causing aggregation and an increase in low shear rate viscosity (LSRV). The micro-environment created by this phenomenon forms a solid-free bridge. The characteristics of the system allow it to create a low-density system in the formation openings separating the borehole and the formation. The system continues to build until an at-balance condition is achieved. It may be said that when this condition is achieved, the downhole filtrate value is zero, and that continual or sporadic filtrate does not occur.

### Impact on production

The main benefit of this drilling fluid system is in its ability to minimize lost circulation. This is beneficial to well productivity, primary cementing and provides the means to drill through low pressure formation in search of productive zones below. These wells using aphron fluid have generally exhibited faster response after ini-

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tial stimulation. The quick response to production is due to the fact that the micro-environment consists not of filtrate water or solids packed wallcake, but is a system containing mostly air/gas, with small concentrations of surfactant and polymer. Therefore, removal at well completion is not difficult. The energized aphrons usually will remove themselves as the borehole hydrostatic pressure is relieved. Any residue of surfactant and polymer is minor and is not tenacious due to novel surface wetting characteristics. This surface wetting encourages removal of the residue by dilution of the produced hydrocarbons, and fast, easy well cleanup is normal with the aphron system.

### Summary

The shell in aphron structures resists compression and loss of encapsulated air/gas, while promoting agglomeration. Aphron drilling fluids as the bridging agent are extremely effective in preventing formation impairment. The system is effective in a wide variety of formation types, especially high-permeability formations. In addition, the aphron drilling systems are not only water base fluids, but also oil base systems<sup>[22,23]</sup>. The use of aphron drilling system has proved to be a successful and cost-effective alternative to drilling underbalanced or at-balanced.

Despite the rapid development in application of aphron drilling fluids, many problems associated with field applications exist and need to be addressed scientifically. The performance of the compressible drilling fluids is rather unpredictable. This is mainly because, compared to conventional (incompressible) drilling fluids, very little is known about the hydraulic and rheological properties of compressible drilling fluids, and even less is known about their cuttings transport capabilities. Other questions remain, such as how to predict the bottom-hole pressure and how to combine different controllable variables in order to obtain optimum cutting transport performance and bit hydraulics. Finally, there is also a need to conduct research on exact depth vs. density curves.

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