APHRON BASED DRILLING MUD

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ABSTRACT: We will be covering on how a normal drilling fluid was replaced or rather combined with a specially constituted “micro bubbles” which changed the whole history of this drilling industry. A novel drilling fluid was recently introduced which was employed successfully in various parts of the world to drill through formations which previously had experienced uncontrollable losses. The fluid contained specially designed micro bubbles called “**aphrons**”. The fluid laid with aphron seemed to appear particularly well suited for drilling through depleted zones which were facing issues like (a) formation damage due to increase in overbalance pressure (b) differential sticking and many more. Various laboratory techniques were applied to determine the physicochemical properties of aphrons. Recently, an innovation showed that, aphrons can survive compression to at least 4,000 psig, whereas conventional bubbles do not survive pressures much higher than a few hundred psig. So, we all know approximately by how many times the use of this aphron would be useful than the older simple compound. Currently, Aphron drilling fluids are being used globally to drill depleted reservoirs and other under pressured zones. Aphrons show little affinity for each other or for the mineral surfaces of the pore or fracture. Basically, these “aphrons” are nothing but a combination of some surfactants and polymers along with drilling fluid. We will be covering more about this in the latter of this script and that too in more details.

Keywords –

Drilling, Fluid, Aphrons, Bubbles, Downhole, Water, Pressure.

INTRODUCTION

The first ever aphrons were described in 1987 by Sebba as some unique microspheres with unusual properties (WRITE PLACE HERE WHERE IT WAS DISCOVERED). Their first application in drilling fluids was discovered and described by Brookey in 1998. Now, aphron-based fluids have been used successfully to drill depleted reservoirs and other low-pressure formations in a large number of wells in North and South America. There was an area in South America where six wells had been drilled using various fluids and techniques, including underbalanced drilling and many others but as there was severe depletion, lost circulation, and borehole instability, none of these wells had been drilled successfully to TD. Ramirez et al. (2002) described the application of aphron technology in this field, which resulted in no drilling-fluid losses and excellent wellbore stability even in troublesome shale sections. The process was so favorable that coring was managed with over 90% recovery on the first well itself. Extensive wire line logging was also carried out with no problems. Even cementing was highly successful, with full returns. Though this technology has been used in about 300 wells in South America, North America and the Far East over a period of several years, not all of these operations have been successful, and the cause for this is also not clear. Thus, it was considered desirable to develop a deeper understanding of the way aphron drilling fluids work and to use laboratory techniques to optimize field applications. As mentioned earlier, the initial and predominant type of aphron drilling fluid used in the field was a polymeric water-based system, though a clay water-based alternative and a non-aqueous-based aphron drilling fluid also have been developed(Growcock et al. 2003, 2004).

Some characteristics of Aphrons:-

Aphrons under ambient conditions typically have diameter ranging from 15⍰m to 100 ⍰m. A “drilling fluid aphron” is composed of a core of air that is stabilized by a polymer/surfactant shell. In contrast to a conventional bubble, which is stabilized only by a surfactant monolayer, the shell of an aphron consists of a tri-layer of surfactants. As shown in **Fig. 1**, the inner surfactant film isoverlaid with a sheath of viscosified water and a double layer of surfactants that renders the aphron hydrophilic and compatible with the continuous aqueous phase of the mud. However, the surfactants in the double layer are not strongly associated; under sufficient shear or compressive forces, the outermost surfactant layer will be shed and will leave a structure with residual hydrophobic character. The properties of the aphron shell that appear to be most important for stabilization of the bubbles include **toughness** and **permeability**. Toughness is defined here as resistance to pressurization /depressurization. Permeability is defined as the ease with which water from the shell and air from the core escape the bubble. **Thickness** and **viscosity** of the aphron shell also are important for controlling loss of air into the bulk fluid.

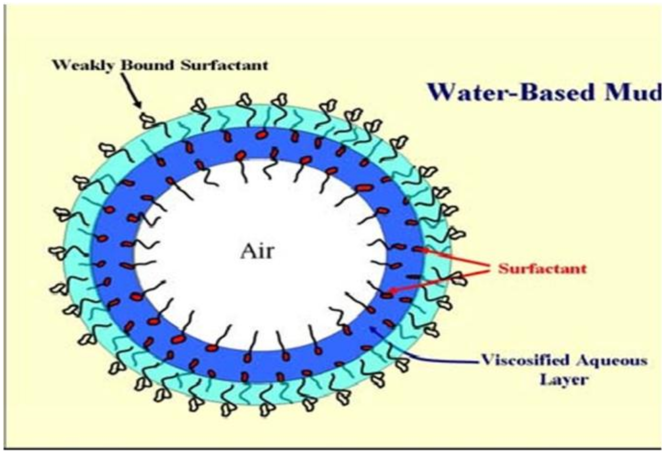

Fig. 1. Schematic of an Aphron

LITERATURE SURVEY

A representation of an aphron is shown in **Fig. 2**. This schematic illustrates Sebba's (1987) concept of a gaseous core (air, in the case of aphron drilling fluids) that is enveloped by a surfactant tri-layer surrounding a semisolid aqueous layer. The surfactants that make up the outermost surfactant layer are anionic. Because this outer layer is polar (hydrophilic), the aphron structure is compatible with the surrounding water-based fluid. Aphrons possess a strong, impermeable shell that helps to prevent leakage of air from the core and enables the aphrons to survive down hole pressures.

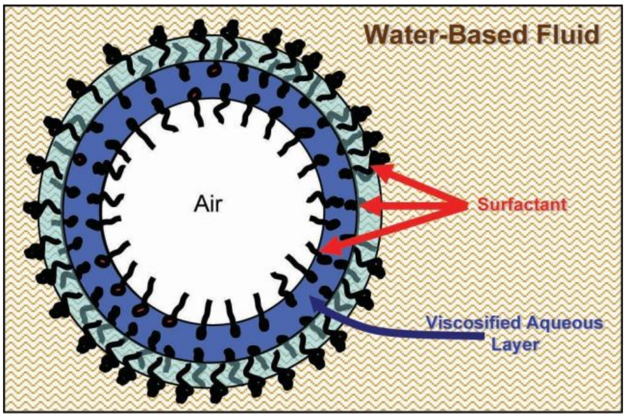

Fig. 2—Schematic of an aphron [after Sebba (1987)]

The nature of the shell also identifies how long the internal bubble barrier in a permeable formation can be made to stay in place. Recently, the polymer- based aphron drilling fluid was modified to provide even greater stability for the aphrons. This was accomplished, as shown in **Table 1,** through the addition of a blend of polymer and surfactants called "aphron stabilizer".

Table 1

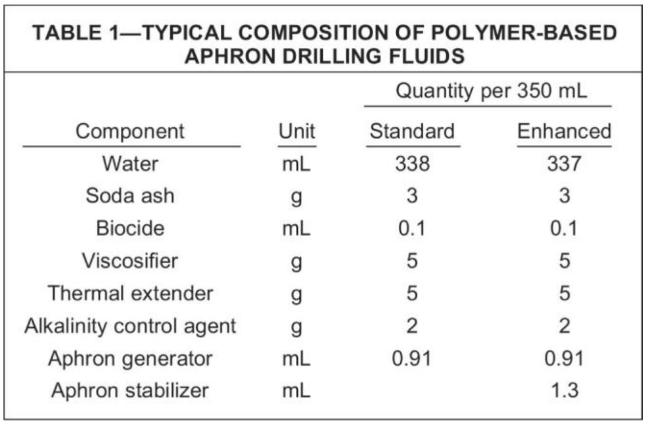

TABLE 1—TYPICAL COMPOSITION OF POLYMER-BASED APHRON DRILLING FLUIDS

		Quantity per 350 mL	
Component	Unit	Standard	Enhanced
Water	mL	338	337
Soda ash	g	3	3
Biocide	mL	0.1	0.1
Viscosifier	g	5	5
Thermal extender	g	5	5
Alkalinity control agent	g	2	2
Aphron generator	mL	0.91	0.91
Aphron stabilizer	mL		1.3

As illustrated in **Fig. 3,** these aphrons can survive exposure to elevated pressures much better compared to conventional bubbles, and enhanced aphrons have greater longevity than standard aphrons. For this comparison, a conventional bubble and bubbles from standard and enhanced aphron drilling fluids were selected, each measuring about 250 μm in diameter when first prepared at atmospheric pressure. When compressed to 500 psig and maintained at that pressure, all three bubbles immediately shrank to about 150 μm. Within 2 minutes, the conventional bubble had disappeared, whereas the standard aphron disappeared in less than 10 minutes and the enhanced aphron survived more than 30 minutes. Aphrons constitute a major phase usually 10 to 15% volume of the drilling fluid at atmospheric pressure.

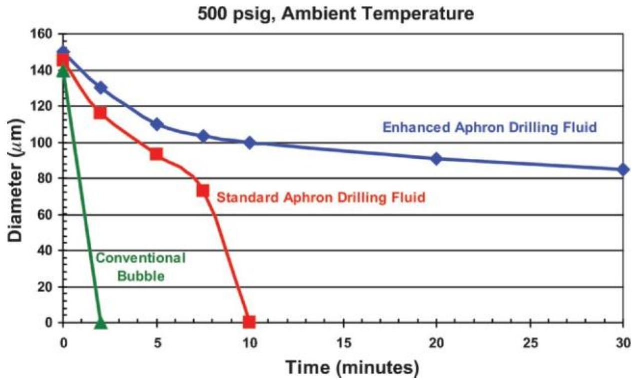

Fig. 3—Aphrons withstand elevated pressures much better than do conventional bubbles.

Aphrons are formed spontaneously when air is naturally incorporated into the fluid during the course of product addition. Conventional drilling- fluid mixing equipment is used for these additions, and there is no need for high-pressure hoses and compressors, such as those used in underbalanced air or foam drilling. At downhole pressures, aphrons occupy an almost insignificant volume (e.g., a mud sample containing 12 volume % nitrogen at atmospheric pressure will contain less than 0.06 volume % nitrogen at

3,000 psig). Thus, the aphrons have little effect on mud density downhole. Indeed, the almost insignificant volume that aphrons occupy under downhole conditions allows the fluid to maintain a stable and predictable hydrostatic and circulating pressure for wellbore control and stability. When the drilling fluid enters a formation, the aphrons expand to a small extent and, more importantly, move forward rapidly by means of "bubbly flow" to concentrate at the fluid front and create a "microenvironment" that separates the borehole from the formation pressures. This effectively puts the borehole and formation "in balance." More details on this phenomenon are provided in the Bubbly Flow section.

The solubility of gases in liquids is described by

Henry's law and the **Lewis-Randall rule**, which state that the solubility of a gas is roughly proportional to the pressure (Perry and Green 1984). When a fluid containing 15 vol% entrained air (or ▯12 vol% nitrogen) at ambient pressure is compressed to just 250 psig, essentially all the gas becomes soluble. If the stabilizing membrane surrounding a bubble is permeable, the gas diffuses out of the bubble and goes into solution. This is what happens with ordinary bubbles, and it occurs within a matter of seconds after compression. Aphrons possess a much less permeable membrane, so they do not lose their air or nitrogen as readily. Indeed, when subjected to a pressure of 250 psig, aphrons will quickly shrink to the size predicted by Boyle's law, but they will retain their gas for hours. The rate of diffusion of nitrogen from conventional bubbles under pressure is expected to be proportional to the bubble size (radius or diameter), which is given by the product of the driving force (the excess pressure between the bubble and the medium, which is inversely proportional to size) and the leakage rate (proportional to surface area) (Hiemenz and Rajagopalan 1997). However, for aphrons, the diffusion rate was found to be proportional to the surface area. Thus, as an aphron decreases with size (because of increased pressure, the passage of time, or both), the rate of nitrogen loss slows to a greater extent than for conventional bubbles (Belkin et al. 2005).

For aphrons, the increase in driving force that normally accompanies a decrease in bubble size may be nullified by a decrease in permeability as the shell is compacted. When aphrons become smaller than about 50 µm in diameter, they become less stable, and when they reach a diameter of 25 to 35 µm, they suffer catastrophic loss of nitrogen (Belkin et al. 2005). Clearly, the mechanism for nitrogen loss changes below this critical size and does not follow the diffusion behavior described above. This agrees with Sebba's (1987) hypothesis that aphrons smaller than 25 µm in diameter may not be able to survive because of the inability of the surfactant tri-layer in the aphron shell to assume a high radius of curvature and pack properly around the gas core (Brookey 1998).

Aphrons can survive compression to at least 4,000 psig in laboratory tests. **Fig. 4** demonstrates the ability of aphrons to survive during compression and recover or regenerate during de- compression. In this case, the maximum applied pressure was 3,000 psig.

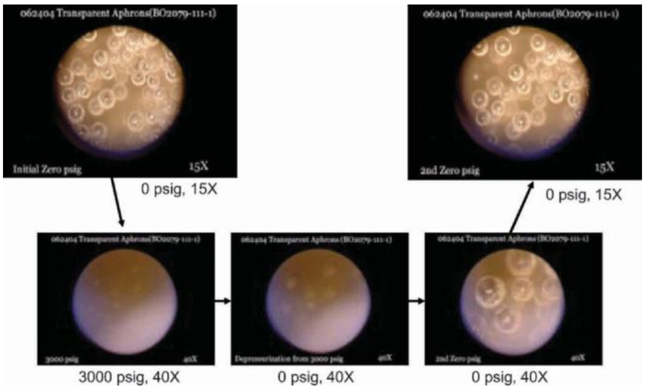

Fig. 4—Rapid pressure cycling of aphron drilling fluids leaves most aphrons intact.

Aphrons are also affected by the **rate of pressurization or depressurization**. Rapid changes in pressure appear to affect the stability of aphrons much less than slow changes in pressure (Belkin et al. 2005). Aphrons are **strongly** affected by **shear as well as by pressure**. In previously reported tests (Belkin et al. 2005), aphrons were easily comminuted by passing the drilling fluid through various types of filter media. Indeed, with increasing number of passes through a filter, the bubble size distribution became increasingly finer and narrower. However, for air concentrations less than 15 vol%, neither reducing the bubble size nor removing air from the sample affected the bulk viscosity of the fluid. On the other hand, resistance to flow through that same filter did increase, suggesting that aphrons behave as **conventional lost circulation materials** (i.e., aphrons reduce fluid invasion by physically plugging pores or fractures).

RESULT & DISCUSSION

In summary, aphrons obey Boyle's law, so that the volume of a bubble (as well as the volume of air or nitrogen in a fluid) is inversely proportional to pressure. Bubble diameter will be inversely proportional to the cube root of the pressure. Examples of the net effect of pressure on bubble diameter are shown in **Table 2.** Thus, an aphron which begins its life at the surface with a diameter of 100 µm will decrease in size to 32 µm at 1,000 ft TVD and to half that size at 8,000 ft TVD. If it is 10 times bigger at the surface (i.e., 1,000 µm), then it will be 10 times bigger downhole, so that at 1,000 ft TVD it will have shrunk to 320 µm, and so on. Because aphrons cannot survive below 25 to 35 µm in diameter in an unsaturated fluid, as described above, aphrons at the surface need to measure at least

250 μm in order to survive to depths as great as 16,000 ft TVD.

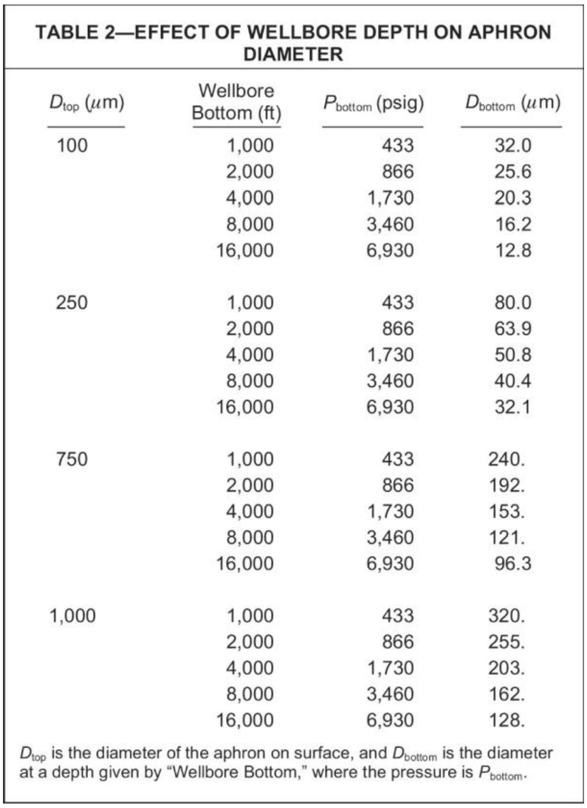

TABLE 2—EFFECT OF WELLBORE DEPTH ON APHRON DIAMETER

D_{top} (μm)	Wellbore Bottom (ft)	P_{bottom} (psig)	D_{bottom} (μm)
100	1,000	433	32.0
	2,000	866	25.6
	4,000	1,730	20.3
	8,000	3,460	16.2
	16,000	6,930	12.8
250	1,000	433	80.0
	2,000	866	63.9
	4,000	1,730	50.8
	8,000	3,460	40.4
	16,000	6,930	32.1
750	1,000	433	240.
	2,000	866	192.
	4,000	1,730	153.
	8,000	3,460	121.
	16,000	6,930	96.3
1,000	1,000	433	320.
	2,000	866	255.
	4,000	1,730	203.
	8,000	3,460	162.
	16,000	6,930	128.

D_{top} is the diameter of the aphron on surface, and D_{bottom} is the diameter at a depth given by "Wellbore Bottom," where the pressure is P_{bottom}.

Popov and Growcock (2005) describe "bubbly flow," a phenomenon in which the aphrons move at a much faster rate than the bulk fluid and form an aphron layer. Bubbly flow appears to follow conventional Navier-Stokes theory, so that the relative velocity of a rigid bubble in an infinitely wide conduit can be described by

$$V \approx 0.23\, r^2/\mu * AP/L, \text{ ....} (i)$$

where r is the radius of the bubble, μ is the viscosity of the fluid, and AP/L is the pressure gradient. Thus, for maximum effect, aphrons should be large, viscosity low, and pressure gradient high. For flow through permeable media, expression (i) is modified to incorporate Darcy flow, but it retains the basic form shown above. Thus, as demonstrated in **Fig. 5,** large aphrons move faster than smaller ones, as predicted by Navier-Stokes theory.

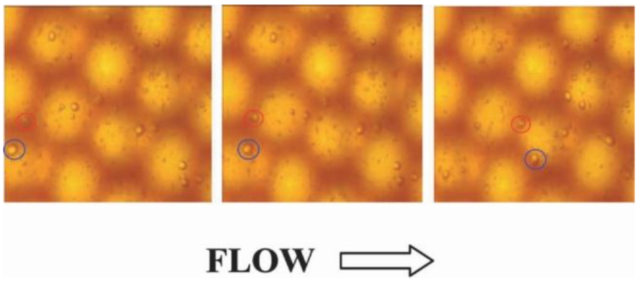

Fig. 5—Velocity of aphrons increases with increasing size. The bubble in the blue circle is about 25% larger than the one in the red circle.

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