

Controls losses in Depleted Reservoirs and high-permeability formations using Nanomaterial as a new mud product.

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Abstract: Losses of whole mud to subsurface formations is called lost circulation or lost returns. Lost circulation has historically been one of the primary contributors to high mud costs. Other hole problems such as wellbore instability, stuck pipe and even blowouts have been the result of lost circulation. Besides the obvious benefits of maintaining circulation, preventing or curing mud losses is important to other drilling objectives such as obtaining good quality formation evaluation and achieving an effective primary cement bond on casing. The severity of losses ranges from minor seepage to complete losses with no returns regardless of the technique utilized to cure the problem. Under-balanced drilling¹ with aerated fluids, foams or density-reducing beads has been successful in many areas. Injection of compressed air or nitrogen is usually necessary to accomplish the density reduction needed to achieve under-balanced conditions. Besides minimizing or preventing lost circulation, these techniques are also used to provide enhanced penetration rates and reduce formation damage due to invasion of drilling fluids or filtrate. In this study, novel fluids as Aphron drilling Nano-fluid have three chief attributes that serve to minimize fluid invasion and damage of producing formations. First, the base fluid is very shear thinning and not very thixotropic, exhibiting an extraordinarily high low-shear-rate viscosity (LSRV) and flat gels; the unique viscosity profile is thought to reduce the flow rate of the fluid dramatically upon entering a loss zone. Second, various components in the mud interact to produce micro-gels that help to reduce spurt loss. Finally, very tough and flexible micro-bubbles, called "Aphrons," create a soft seal within the permeable or fractured formation to reduce losses further. Aphron drilling fluids, which are highly shear-thinning water-based fluids containing stabilized air-filled bubbles (Aphrons), have been applied successfully worldwide to drill depleted reservoirs and other high-permeability formations as well as fracture Granite formations. Based on laboratory determinations, the smallest size for a gas-core Aphron is 25 μm . The bubbles smaller than this size are not able to maintain the surfactant-based boundary separating them from the bulk water and thus get dispersed in the continuous water phase. From field study, Aphron ICS mud was used to drill KHA 403 and 404 wells (Yamen) compared to previous wells drilled with a polymer mud. The total volume of Aphron drilling fluid built to drill the reservoir interval was 696m³, and losses incurred totaled 265 m³ into formation fractures. A subsequent well, KHA 404, was drilled in the same area with the APHRON ICS mud, and it experienced no losses of the APHRON ICS mud and even greater production. Hydraulics relative to offset wells drilled with simple water-based polymer muds, it is reported that hole cleaning was substantially improved, even during periods when pump rate had to be reduced in an effort to mitigate downhole losses, indicating minimal invasion of drilled solids into the fractures drilled.

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Introduction:

Properties of Aphron

Aphron were first described by Sebba² as unique microspheres with unusual properties. Aphrons are comprised of a spherical core of air and a protective outer shell. 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.⁴ This tri-layer is envisioned as consisting of an inner surfactant film enveloped by a viscous water layer; overlaying this is a bi-layer of surfactants that provides rigidity and low permeability to the structure while imparting some

hydrophilic character to it. Although this water-wet nature of the shell makes it compatible with the aqueous bulk fluid, Aphron appear to have little affinity for each other or for the mineral surfaces in the pores of permeable rocks.

Aphron can act as a unique bridging material, forming a micro-environment in a pore network or fracture that behaves in some ways like foam and in other ways like a solid, yet flexible, bridging material. As is the case with any bridging material, concentration and size of the Aphron are critical to the ability of the drilling fluid to seal thief zones. Drilling fluid Aphron are constructed by entraining air in the bulk fluid with standard

drilling fluid mixing equipment, thus reducing the safety concerns and costs associated with high-pressure hoses and compressors commonly utilized in underbalanced air or foam drilling.⁶ Although each application is customized to the individual operator's needs, the drilling fluid system generally is designed to contain between 12 volume % and 15 volume % air at ambient temperature and pressure.

In contrast to conventional bubbles, which do not survive long past a few hundred psi, Aphrons can survive compression to at least 27 MPa (4,000 psig) for significant periods. When bubbles are subjected to a sudden increase in pressure above a few hundred psi, they initially shrink as predicted by Boyle's Law³. Aphron are no exception. However, conventional bubbles begin to lose air rapidly via diffusion through the bubble membrane, and the air dissolves in the surrounding aqueous medium. Aphrons also lose air, but they do so much more slowly, shrinking at a rate that depends on fluid composition, bubble size, and rate of pressurization and depressurization.

One other factor results in a slight reduction in size of the Aphrons shortly after they are created. Several components in the drilling fluid scavenge dissolved oxygen and oxygen within the bubbles, leaving each of them with a core that is mainly nitrogen. This reduces Aphron diameter by about 7%, but eliminates any concern about corrosion of tubulars and other hardware.

Fluid Dynamics

The base fluid in Aphron drilling fluids yields a significantly larger pressure loss (or lower flow rate for a fixed pressure drop) in long conduits than any conventional high viscosity drilling fluid. Similarly, if flow is restricted or stopped, Aphron drilling fluids generate significantly lower downstream pressures than other drilling fluids. In permeable sands, the same phenomena are evident. Furthermore, at low to moderate pressures, Aphrons themselves slow the rate of fluid invasion and increase the pressure drop across the sands. Lastly, and most importantly, Aphrons move more rapidly through the sands than the base fluid. When an Aphron drilling fluid is exposed to a pressure gradient, a phenomenon called "bubbly flow" causes the aphrons to move more rapidly than the base fluid. Just as high-density particles like barite or drilled cuttings

In a loss zone, Aphron that survive the trip down hole can migrate faster than the base liquid and concentrate at the fluid front, thereby building an internal seal in the pore network of the rock. A micro-el network formed by particulates

in the drilling fluid aids the Aphron in slowing the rate of invasion, as does, of course, the radial flow pattern of the invasion. As the fluid slows, the very high LSRV (low-shear-rate viscosity) of the base fluid becomes increasingly important; this high LSRV, coupled with low thixotropy, enables the fluid to generate high viscosity rapidly. Bridging and formation of a low-permeability external filter cake also occur during the latter part of this period, ultimately reducing the rate of invasion to that of ordinary fluid loss.

Another key finding is that Aphrons have very little attraction for each other or for mineral surfaces. Consequently, they do not readily coalesce nor do they stick easily to the pore walls, resulting in easy displacement by the produced fluids. In addition, the drilling fluid itself is very compatible with produced fluids and generates low capillary forces, thereby facilitating back-flow of produced fluids.

The combination of these two effects is expected to result in low formation damage and minimal requirements for cleanup.

Aphron Drilling Fluids technique

The most dominant characteristics of Aphron drilling fluids are their rheology and the presence of bubbles. The base fluid is highly shear-thinning and exhibits an extra ordinarily high LSRV (Low-Shear-Rate Viscosity) with low thixotropy (flat- gels). The bubbles of air that are dispersed in the base fluid are a dramatic departure from conventional fluids, because concerns over corrosion and well control have traditionally led to attempts to minimize air entrainment. Indeed, the air in Aphron drilling fluids is purposely incorporated into the bulk fluid, but at a very low concentration. This occurs naturally during the course of product addition using conventional drilling fluid mixing equipment, and there is no need for high pressure hoses and compressors such as those utilized in underbalanced air or foam drilling.

The surfactants in the fluid convert the entrained air into highly stabilized bubbles, or "Aphrons." However, in contrast to a conventional air bubble, which is stabilized by a surfactant monolayer, the outer shell of an Aphron is thought to consist of a much more robust surfactant tri-layer.⁵ This tri-layer is envisioned as consisting of an inner surfactant film enveloped by a viscous water layer; overlaying this is a bilayer of surfactants that provides rigidity and low permeability to the structure while imparting some hydrophilic character.

It has been claimed that Aphron form a micro-environment in a pore network or fracture

that behaves like a solid, yet flexible, bridging material. As is the case with any bridging material, concentration and size of the Aphron are critical to the drilling fluid's ability to seal thief zones. Although each application is customized to the individual operator's needs, the drilling fluid system is generally designed to contain 12-15 volume % air under ambient conditions, and the Aphrons so generated are thought to be sized or polished at the drill bit to achieve a diameter of less than 200 μ m, which is typical of many bridging materials.

Much of the scenario described above about the role of Aphron in reducing fluid losses down hole is conjecture that has not been confirmed under stringent laboratory conditions. Furthermore, the manner in which Aphron drilling fluids reduce losses down hole is still not well understood.

Aphron-fluid losses relation

The system has a natural fluid loss depending on the system makeup. When additional fluid loss reduction is desired, additional Activator I is used. This is a polymer with synergistic characteristics to support the LSRV and Aphron stability.

Other filtrate-control materials are not recommended since they are generally detrimental to the system rheology. Natural filtrate values are adequate for this system and extra additions of Activator I are not recommended in most cases. The API filtrate test measures the ability of a fluid to control invasion due to the plugging capability of the wall cake. The Aphron ICS system does not use a wall cake to control invasion, but rather uses the down hole bridging capability of the Aphrons and the resistance to movement for invasion control. The filter press does not measure these features, but actual filtrate in a properly maintained system is generally less than 5.0 ml.

Preparation of Nano fluid (Aphron) at Lab

Based on laboratory determinations, the smallest size for a gas-core Aphron is 25 μ m. The bubbles smaller than this size are not able to maintain the surfactant-based boundary separating them from the bulk water and thus get dispersed in the continuous water phase.

To obtain a lower density, a combination of LSRV, shear, and pressure drop are required. In the lab, this can usually be achieved with a Hamilton Beach mixer. Some problems have been seen with the ability of the mixers to agitate the mud sufficiently. Therefore, shear is provided, but vigorous agitation is required to produce a pressure drop in the mixer. Better results are seen after hot rolling overnight @ 180°F. The temperature and

shear create a simulated down hole condition. After hot rolling, treat with Blue Streak, agitate, and measure the density. Air can also be introduced by blowing through a tube inserted into the mud sample while it is mixing.

In the lab a positive displacement pump, (Gaulin homogenizer), is used to simulate down hole conditions such as high shear, pressure drop, and temperature. A microscope and camera with a TV screen are attached so that Aphrons can be measured on a grid. After being circulated through the Galen with a 1,000 psi pressure drop, samples have remained stable two weeks or more. In field applications, stable Aphron are created with mud pumps, pressure drop, shear, and temperature.

The high properties are not necessarily excessive. The high properties are only for desirable low-shear-rate ranges, while 600 & 300 rpm values are comparatively low. One sample, for instance, had a 69 (600 rpm), 60 (300 rpm) with a 32 (6 rpm) and 28 (3 rpm). This produces a very flat viscosity profile and indicates a highly shear-thinning fluid. Since the system is pseudo-plastic, it pumps very easily. These rheological properties seem high compared to conventional muds which exhibit different characteristics. Viscosifiers are made of long-chain, branched polymers, which exhibit excellent hole cleaning and suspension properties. These viscosifiers are also friction reducers with low "n" values and are easily pumped. The mud at rest has suspension due to the random entanglement of the polymer chains, but since the electrostatic forces are repulsive, the gel structures do not increase. This is true of a pseudo-plastic fluid, which has no true yield point, but moves readily upon the application of force. The high rheological and gel strength readings are descriptive of the high stress as the mud is sheared with an instrument. The important thing to realize is that this shear is not required to start or push the mud. The mud moves as a mass before enough shear is applied to be exerted against the formation. In other words, shearing the mud requires catching up with it.

To reduce the density, and to increase and stabilize the Aphron concentration requires additional Blue Streak and air. Stabilizing the Aphrons requires adequate LSRV (50,000+ cP). To increase density, it is possible to destroy the Aphrons using a specific defoamer to reduce or eliminate the concentration of Aphrons in the system. This will restore the system to its native density where it can be increased using conventional weighting techniques if required. It is also possible, however, to increase the density with the Aphron in place. This is helpful in cases where high-pressured and low-pressured zones coexist. Because the Aphron are a stable phase, increased density can be achieved by the addition of salts or

conventional weighting materials such as CaCO₃, barite, or hematite.

Compatibility Testing

Compatibility testing should be designed based on the region of interest. For instance, the author runs lab tests to evaluate an Aphron ICS fluid formulation prior to recommending it for use in the field:

Hot rolling for 16 hours at expected formation temperature PPT, which target local field permeability's. Return perm analysis on core samples at expected formation temperature/pressure

Table 1: Product Selection and Description System Components.

Product	Purpose
Go Devil II	Viscosifier
Activator I	Filtration Control
Activator II	pH Buffer
Acti-Guard	Shale Inhibitor
Blue Streak	Surfactant

Go Devil II: a blend of non-ionic polymers that provide low-shear-rate viscosity (LSRV) in the APHRON ICS system. The LSRV created by Go Devil II promotes hole cleaning, solids suspension, formation invasion control and lost circulation prevention. The recommended initial concentration for optimum performance is 4.0 lb/bbl.

Activator I: a filtrate reducer and thermal stabilizer for the Aphron ICS system as well as other low shear-rate viscosity fluids. Activator I can be added as a dry powder through a mud hopper or through a chemical barrel by dissolving in fresh water. Thermal stabilization is measured by determining the low shear-rate viscosity at less than one rpm after hot rolling at a given temperature. The recommended initial concentration for optimum performance is 5.0 lb/bbl.

Activator II: a pH buffer and thermal stabilizer for the APHRON ICS system. Activator II is more effective if dissolved in fresh water and added through a chemical barrel. Thermal stabilization can be evaluated by determining the low-shear-rate viscosity after hot rolling at a specific temperature. Typical concentrations are 1.0 to 3.0 lb/bbl but it has been used in the field at concentrations up to 6.0 lb/bbl.

Acti-Guard: a blend of surfactants and vegetable oils that inhibit water absorption and swelling of reactive clays. Typical concentrations for optimum performance are 0.1% to 0.5% by volume. Acti-Guard is usually not added unless shale control

problems are expected. It can be added on an as-needed basis.

Blue Streak: a blend of anionic and nonionic surfactants and co-surfactants in an aqueous solution. Blue Streak encapsulates air in drilling fluids creating micro-bubbles that significantly enhance the low-shear-rate viscosity (LSRV) of the system. The elevated LSRV and the bridging effect of the micro bubbles significantly reduce or eliminate formation losses. The initial application is usually 0.75 lb/bbl. Daily maintenance treatments are typically 0.1 to 0.25 lb/bbl. Blue Streak can be added through the hopper. Blue Streak should be added last in the mixing order and not before a stable LSRV of 50,000 cP is obtained.

Passivator I: a water-base mud anti-foamer specifically formulated for use in Aphron containing water-base fluids. Passivator I can be used to treat surface foams without removing the Aphrons from the system. However, surface foam is an indication that the system's LSRV may not be sufficient to prevent foam. Before adding Passivator I, refer to the next section, "Building the Aphron ICS System", for remediation guidelines.

Building the Aphron ICS system Preparation and Mixing Order

Prior to mixing, add 0.25 to 0.50-lb/bbl soda ash to the make-up water. Soda ash provides a synergistic benefit to the Activator II pH buffer as well as aiding in the stability of the LSRV. The system should always be maintained with a pH around 10.0 for optimum performance.

Make all additions of the initial bactericide concentration to the make-up water. This will ensure an even blend of the material and minimize the chance of an isolated pocket of bacteria developing within the system. Go Devil II polymer can be mixed very rapidly without worry of "fish-eyes" developing or polymer loss across the shaker screens. One to two minutes per 25-lb bucket through a standard rig hopper is possible without problems.

Activator I filtrate reducer and thermal stabilizer should be mixed through a standard rig hopper at four to five minutes per 50-lb sack. Activator I does not exhibit any tendencies to plug the hopper nor is material lost via the solids-control equipment.

Activator II pH buffer and thermal stabilizer should be mixed slowly enough to ensure even blending and consistent pH and can be pre-solubilized with water in a chemical barrel.

Acti-Guard shale stabilizer can be mixed anytime in the process but preferably after the completion of the Go Devil II additions. It should be mixed slowly enough to ensure even blending.

Blue Streak surfactant is designed to assist in

the development and stabilization of the Aphron. The preferred method of mixing Blue Streak is through the mud hopper. However, it can be mixed by pouring it directly into the mud pits over the agitators. It should be mixed slowly enough to ensure even blending throughout the system. Under no circumstances should the blue streak surfactant be mixed until a system LSRV of 50,000 cP is obtained. If an LSRV of 50,000 has not been reached, pilot test with Go devil II to find the optimum treatment level and add to the system.

As the mud nears this viscosity threshold, foaming will decrease and the entrained air bubbles will get smaller. If foaming does persist, small additions of Passivator I may be added to control surface foam. Drilling with the Aphron ICS System (Testing & Monitoring)

Rheological Parameters

In addition to stabilizing the Aphron, the drilling fluid must produce hole cleaning, cuttings suspension, and invasion control necessary for optimum performance while drilling high-angle or horizontal boreholes. The ability of high-LSRV systems to produce this performance has been well documented. LSRV should be measured by viscometers such as the Brookfield and maintained in the system at no less than 50,000 cP. A #2L (cylindrical) spindle at 0.3 rpm is normally used for ranges up to 100,000 cP.

If a Brookfield viscometer is not available, a relaxation method (RM) can be used to evaluate the critical polymer concentration (CPC). The most effective way to determine LSRV rheology with a Fann 35A is to evaluate the 6- and 3-rpm readings and gel strengths. The 6- and 3-rpm readings should be elevated and almost identical. The initial gel should be elevated, with the 10-minute gel no more than 1 1/2 times the initial gel. The 30-minute gel should approximate the 10-minute gel reading. Using this method the 3-rpm and initial gel should be no less than 20 (based on field experience) and the RM after 3 minutes should be at least 1/3 of the initial gel.

Note: However, in field applications, the 6-speed Fan readings and gels have been relatively stable, while the LSRV can vary widely, especially when solids are introduced. Because of this, a Brookfield should be mandatory. Do not rely entirely on a 6-speed rheometer.

Experience with running PWD and RFT tools has shown that the equivalent density in the hole is about equal to the base mud weight without Aphron. Virtual Hydraulics can be run to evaluate rheological conditions down hole as long as the density input is measured with a pressurized balance.

Fluid Loss Control

Filtrate control in the Aphron ICS system is

a combination of LSRV, the Aphron bridging mechanism, and the filtration control thermal stabilizer, Activator I. Typical API fluid losses will usually run <10.0 mL with no problems.

Aphron Concentration

Aphron concentration in the system is dependent on the LSRV properties of the fluid and the surfactant concentration. Maintaining the LSRV at a minimum of 50,000 cP is critical as this helps to stabilize the Aphron.

A field method to gauge Aphron concentration would be to record the weight differences between a pressurized mud balance and a conventional mud balance. Typical density differences run at least 0.5 lb/gal less on a conventional balance than a pressurized balance when the system is functioning properly. This equates to approximately a 6.0% reduction in weight as measured at the surface (ambient pressure). Depending on the application and objectives, density reductions of 8.0-12.0% are normally sufficient. Anything less usually indicates a need to increase the Aphron concentration to maintain optimum system performance. The logical procedure would then be to evaluate the system's LSRV, surfactant (Blue Streak) concentration, and air introduction at the surface, pilot test and correct as needed. Mixing hoppers, solids control equipment, and air pumps have been used to introduce more air into the system.

Note: Percent density reductions (air/gas) range from 6.0 to 15.0%. Above 15.0% at the suction, pump problems may be encountered and down hole tool signal telemetry may be affected.

Equipment needed for the test:

Pressurized mud balance
Conventional 20 cm³ oven-type retort
Analytical balance accurate to 0.01 gm.

Measurements:

Mud density with pressurized balance
Weight of retort including steel wool and empty cup
Weight of retort with whole mud before retorting
Weight of retort with dry mud solids after retorting.

Calculations:

SG mud = mud weight (lb/gal) / 8.34
Grams of mud in retort = Value c – Value b
Grams or cm³ water distilled = Value c – Value d
% Solids v/v = (c-b) – [SG mud x (c-d) x 100 c-b

Lost Circulation Control Measures

If losses occur while circulating and drilling with a stable volume, micro-fractures have probably been encountered and a drop in the pit volume may be observed. Most of the time this will be temporary and will stop as the losses are controlled by establishing the micro-environment bridge provided that the fractures are fairly small (size & volume). When whole mud losses are observed, mud engineer

suggests that the drill string be temporarily pulled above the loss zone and circulation stopped. Allowing the annular fluid column to find its balance point respective to pressure differentials between the hydrostatic head and the formation pressures will allow the mechanical establishment of the micro-environment bridge in freshly exposed micro-fractures. Care should be taken to keep the top of the annular fluid visible by topping off. After allowing the microenvironment bridge to set up (observed by a stable annular fluid level) gradually increase the circulating rate to the drilling rate and rotate to bottom, resuming the drilling process. This procedure has proven very effective in previous experiences of similar parameters.

If lost circulation is experienced while drilling highly porous sands, sandstones, and micro fractures, it is recommended to increasing the Aphron percentage in the circulating system after making sure that the present APHRON ICS system has sufficient

LSRV thus ensuring Aphron stability. A sufficient quantity of stabilized Aphron relative to the instantaneous penetration rate and the volume of porous or micro-fractured formation being drilled will stop the losses. If the LSRV is not adequate, Aphron are not effective, so the LSRV must be re-established as previously discussed.

Note: Always be careful not to pump away the APHRON ICS fluid since it can be very costly. Instances will occur where conventional lost-circulation materials will have to be added to the system to create additional bridging. Most of these materials are compatible with the system but caution should be exercised when adding these materials in or near a production zone. Only calcium carbonate and other acid-soluble materials should be used for additional plugging in a pay zone (refer to the M-I "Prevention & Control of Lost Circulation" manual. Contingency plans should be built into the mud program for reference.

Table 2: Lost Circulation Decision Tree

Rate of Loss	Action
Losses < 10 bbl/hr	Ensure high LSRV, then increase Aphron concentration to 12-14 % by volume.
Losses 10-50 bbl/hr	Cause is probably exposed large fractures Pull above fractures, stop circulation and observe as above If unsuccessful proceed to next step
Losses 50-100 bbl/hr	Cause is probably exposed large fractures of minimal tortuosity Pull above fractures, stop circulation and pump high LSRV Go Devil II/Blue Streak/CaCO ₃ 50-bbl pill. If unsuccessful proceed to next step
Losses > 100 bbl/hrs	Pump a high LSRV Go Devil II 50-bbl pill containing: 15 lb/bbl M-I-X II Fine 30 lb/bbl CaCO ₃ (50 micron) 20 lb/bbl CaCO ₃ (150 micron) 5.0 lb/bbl Blue Streak If unsuccessful proceed to next step
	Set a FORM-A-SET AK bridge

When the most serious losses of up to 40 m³/hr after were encountered after drilling at 3198 m, the Aphron system successfully addressed these losses. Dynamic loss rate was reduced to 0.4 – 0.5 m³/hr and static losses became zero.

3. Results of Field Operations

The initial and predominant type of Aphron drilling fluid used in the field has been a polymeric water-based system, though a clay water-based alternative and a nonaqueous-based Aphron drilling fluid have also been developed⁴. A solids -free Aphron drilling fluid was used to drill successfully into the oil-bearing, fractured granite basement of the KHA 403 well for TOTAL in central Yemen. KHA 403 is the third of several planned development wells into the fractured basement. This well, which reached TD on Jan 17, 2005, tested at 6, 088 BOPD with negligible clean up. The production interval was successfully drilled through fractured basement rock at an initial inclination of 36° and increasing to 55° at total depth. The well was conventionally logged on wire-line

without problems prior to running open hole completion

The Kharir basement reservoir structure essentially is a hydrocarbon-bearing fractured granitic gneiss formation⁵, with reservoir pressure equivalent to approximately 0.90 sg. Historically, an 8½-in. hole was drilled into the reservoir rock with a simple water-based polymer drilling fluid, which typically resulted in substantial mud losses into the fractures until TD is reached.

This type of reservoir only produces through the fracture network; therefore, occurrence of mud losses is systemic, and the extent of the losses is indicative of the future production capability of the well.

Since the reservoir rock has good integrity, simple open hole completions have been the obvious

choice. However, after displacing out the polymer drilling fluid, long clean up has been required before achieving acceptable productivity. Any stimulation work like acid washes was shown to be detrimental to productivity.

Logistically, heavy loss of drilling fluid posed problems with supply and mixing of new mud chemicals, along with providing sufficient make-up water to keep up with the loss rates.

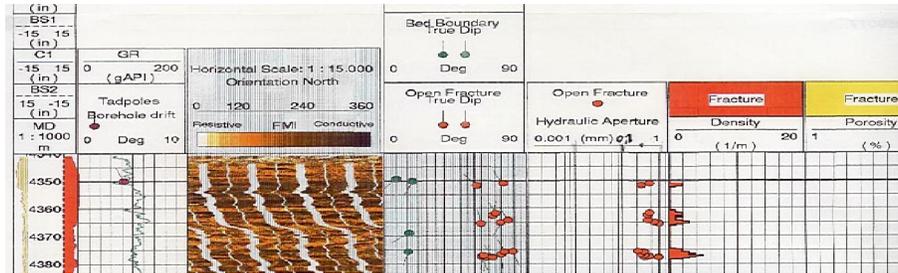


Figure. 1 Caliper, Dipmeter and Density log showing sand fracture formation for KHA 403 well, Yamen.

The logistical benefits of using a fluid system that does not require supplying a large replacement volume under high dynamic loss rates are simple to appreciate.

More significant, however, are the reduction in time and the elimination of equipment and personnel involved in conventional clean-up procedures to facilitate full production.

The final and most rewarding aspect of this application of Aphron drilling fluid technology was a substantial improvement in productivity.

Table 1 shows the reduced mud losses and enhanced production experienced with the Aphron ICS mud on the KHA 403 well, compared

to previous wells drilled with a polymer mud. The total volume of Aphron drilling fluid built to drill the reservoir interval was 696m³, and losses incurred totaled 265 m³ into formation fractures. A subsequent well, KHA 404, was drilled in the same area with the Aphron ICS mud, and it experienced no losses of the Aphron ICS mud and even greater production.

Hydraulics relative to offset wells drilled with simple water-based polymer muds, it is reported that hole cleaning was substantially improved, even during periods when pump rate had to be reduced in an effort to mitigate down hole losses, indicating minimal invasion of drilled solids into the fractures drilled.

Table 3 – Comparison of KHA wells

Table 1 – Comparison of KHA wells				
Mud Type	Well #	Production (BOPD)	Drain Length (m)	Mud Losses (bbl)
Polymer	KHA 101	1003	442	1780
Polymer	KHA 201	1497	247	11400
Polymer	KHA 106	1449	634	4300
Polymer	KHA 402	822	680	1550
Polymer	KHA 401	0	1034	No losses, attributed to the absence of fracturation, dry well)
APHRON ICS	KHA 403	3632	593	1500 Polymer Mud 1200 APHRON ICS
APHRON ICS	KHA 404	5620	839	1500 Polymer Mud 0 APHRON ICS

The LSRV was initially established at a level of 70,000 – 90,000 cP, which proved to be less suitable for maintaining stability of the system than would a more elevated LSRV in the range 100,000 – 125,000 cP. A higher LSRV of 150,000 cP was attempted, in an endeavour to address increased formation losses of up to 30 m³/hr, which resulted in difficulties maintaining Aphron content, the further mixing of products, and reduced performance of solids control equipment.

Ultimately, LSRV in the range 100,000 –120,000 cP was found to be optimal for maintaining stable Aphron concentration and correct functioning of solids control equipment and rig pumps.

Typically, pump pressures were around 10 – 15 % less than would normally be reported with conventional drilling fluids. Variations in pump pressure were linked to the LSRV and Aphron content. However, a direct relationship between LSRV, Aphron content, flow rate and pump

pressure could not be established.

LSRV depletion was observed after the second day of drilling. This was recognized as a natural phenomenon, since the fluid polymers are continuously sheared, and gradual LSRV reduction is normal. Maintenance of LSRV was typically accomplished by using 0.5 lb/bbl of viscosifier per day. No product biodegradation was encountered.

When the most serious losses of up to 40 m³/hr after were encountered after drilling at 3198 m, the Aphron system successfully addressed these losses. Dynamic loss rate was reduced to 0.4 – 0.5 m³/hr and static losses became zero.

The drilling site for well # KHA 403 was located on a plateau in the mountainous region of Hadramawt in central Yemen, at a ground elevation of 941 m above sea level and 950 m to rotary table.

The objective was to drill an 8 1/2-in. hole into a fractured crystalline basement formation, with minimum invasion of drilling fluid into hydrocarbon-bearing fractures having a predicted pressure gradient equivalent to approximately 0.90 SG, and to address logistical concerns with the supply of drill water.

The interval commenced by drilling with a simple freshwater xanthan polymer fluid. The first bit run drilled out the shoe and new formation from 2790 m MD (2685 m TVD) to 2930 m MD, 2796 m TVD. At this depth the bit exhibited signs of wear and was pulled.

On the trip out of the hole, losses were reported at the shoe of 1.2 m³/hr, prompting the decision to proceed with mixing the Aphron system for displacement in the hole, and drill ahead.

During the trip, 225 m³ Aphron drilling fluid was prepared, and after reaming back to bottom with the existing polymer mud, an open hole displacement was made to the Aphron drilling fluid. During the trip into the hole, some further losses were reported with the polymer mud, but ceased immediately when the xanthan polymer fluid was displaced to the Aphron system. Adequate volume to displace the well was built during the tripping period, without any additional use of rig time.

Drilling proceeded with the Aphron system with no losses to the formation. The Aphron concentration was initially around 8 – 9 volume % with LSRV at 80,000 cP. Sodium bicarbonate was added at a concentration of 0.5

lb/bbl to reduce pH and elevate the Aphron level. The Aphrons increased to 15.5 volume %, and combined with some reactive foaming, resulted in a significant reduction in pump pressure.

Drilling proceeded with stable parameters and losses to the hole only while tripping to a depth of 3198 m. The LSRV was gradually increased to 100,000 cP and the Aphrons content maintained in the range 12 – 14%, with circulation rate of 1800 L/min while drilling and circulating. The bit trip at 3039 m resulted in losses of 7 m³ to the hole and 15.1 m³ at 3145 m.

At 3198 m a significant drilling break was experienced to 3213 m, with ROP up to 40 m/hr. A rapid loss of 19 m³ of mud was reported. Drilling continued with varying degrees of losses until 3250 m where another drilling break was experienced, and this time resulting in increased and sustained losses of 30 m³/hr to the formation, with 1800 L/min circulation rate.

Drilling continued from 3250 m to 3261 m, circulating at 1800 L/min and with formation losses of 30 m³/hr. Drilling was halted at 3261 m and circulation rates reduced to observe changes in losses. It was found that losses reduced to zero at a circulation rate of 500 L/min, with LSRV of 107,000 cP, and 12 volume % Aphrons concentration. This was the only occasion where it was necessary to control circulation rate at a reduced level of 1020 L/min to minimize losses.

From 3330 m, the mud parameters were adjusted. The LSRV was reduced to the range 110,000 – 120,000 cP, making it much easier to elevate the Aphron concentration to 15– 17 volume % without compromising pump performance. The increased Aphron concentration contributed to a reduction in down hole losses from 3 m³/hr to between 0.4– 0.5 m³/hr losses. These parameters were maintained through to interval and well TD of 3383 m.

At TD of the reservoir interval, formation losses were controlled at under 1.0 m³/hr while circulating at 1000 L/min, and zero losses were observed under static conditions. The interval was logged successfully on wireline, even with inclination increasing from 36° to 55°. The FMI log (figure.2) showed an excellent correlation of drilling breaks, associated losses and gas peaks with the presence of fractures of various size and intensity.

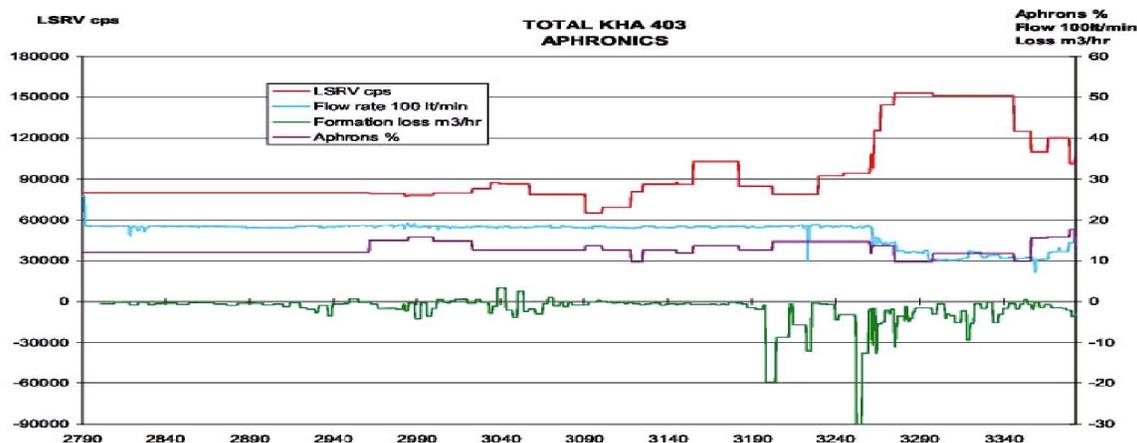


Figure.2 LSRV, Gas Shows, % Aphrons, Flow Rate and Losses at KHA 403 well.

At the well total depth, a bit was run back in the hole and circulated to condition it for logging then running the completion assembly. The unique nature of the Aphron bridging mechanism facilitates rapid and simple clean-up, enabling production to be established without additional time and costs.

Summary and Conclusion

The Aphron ICS system should not be considered a cure for all types of losses since it is not applicable in many cases. Applying the Aphron ICS system to the wrong situation when a more appropriate alternative should have been considered can be costly and ineffective. The APHRON ICS system design criteria should be evaluated thoroughly and should match the well objectives and drilling parameters of the particular well under consideration.

From field study, the Aphron system has been effective in:

High-porosity, permeable sands and micro-fractured carbonate zones where it has the capacity to conform to openings of different sizes and shapes.

Solids-free bridging with fluid weights of 8.4-10.0 lb/gal and equivalent formation pressures less than 2.0 lb/gal.

Formations where normal pressure and low-pressure zones are drilled in the same interval Wells where underbalanced drilling (UBD) creates problems with borehole stability or well control.

Conventional lost circulation materials are usually more appropriate in these types of formations with seepage losses and should be considered first. If the formation is a production zone and clean up procedures or formation damage are a concern, the Aphron ICS system may be a candidate for drilling this well and specific design parameters are made to accommodate such applications Cavernous – Vugular.

Usually low-pressure carbonate (limestone and dolomite) or volcanic formations.

Losses can be sudden and complete and dependent on the degree to which the vugs are interconnected. Mainly shallow and consist of sands or gravel, but can occur in shell beds or reef deposits. Coarse unconsolidated formations can have permeabilities of 10 to 100 Darcies. Losses are gradual but can become complete as drilling continues

Seepage losses can continue even when not circulating. These losses are usually confined to shallow wells or surface hole where the economics of employing the Aphron ICS system will need to be justified. Highly Permeable / Low-Pressure (Depleted Zones) range from seepage to severe The Aphron ICS system is a very good candidate for these zones. However, as a matter of practice, permeability testing should be performed if the formation is a production zone.

Also from the field study, Aphron ICS mud was used to drill KHA 403 well at Hadr amout area, Yamen compared to previous wells drilled with a polymer mud. The total volume of Aphron drilling fluid built to drill the reservoir interval was 696m³, and losses incurred totaled 265 m³ into formation fractures. A subsequent well, KHA 404, was drilled in the same area with the Aphron ICS mud, and it experienced no losses of the Aphron ICS mud and even greater production.

A solids-free Aphron drilling fluid was used to drill successfully into the oil-bearing, fractured granite basement of the KHA 403 well in central Yemen. The production interval was drilled at an initial inclination of 36°, reaching 55° at total depth. Conventional logging on wire-line was carried out without problems prior to completing the well open hole.

Drilling through fractures tends to produce mud losses, which was made evident on this well by the correlation of drilling breaks of up to 40 m/h with gas shows. Losses were halted by increasing the fluid LSRV and concentration of Aphron. As shown by FMI logs, the Aphron drilling fluid system drilled fractures, a fault, and breccia while limiting losses and preventing deep damage by mud or entrained drilled solids. This allowed the KHA 403 to clean up quickly and become a high-volume oil producer.

Based on laboratory determinations, the smallest size for a gas-core Aphron is 25 μm . The bubbles smaller than this size are not able to maintain the surfactant-based boundary separating them from the bulk water and thus get dispersed in the continuous water phase.

Filtrate control in the APHRON ICS system is a combination of LSRV, the Aphron bridging mechanism, and the filtration control thermal stabilizer, Activator I. Typical API fluid losses will usually run <10.0 mL with no problems.

Aphron concentration in the system is dependent on the LSRV properties of the fluid and the surfactant concentration. Maintaining the LSRV at a minimum of 50,000 cP is critical as this helps to stabilize the Aphrons.

Depending on the application and objectives, density reductions of 8.0-12.0% are normally sufficient. Anything less usually indicates a need to increase the Aphron concentration to maintain optimum system performance.

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