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Application of Drilling Fluid System Based on Air Microbubbles as an Alternative to Underbalance Drilling Technique in Reservoir B-6-X.10 – Tia Juana, Lake Maracaibo

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Abstract

After 70 years of continue exploitation, the Bolivar Coast Field, operated by PDVSA in the Lake Maracaibo, is still one of the most complicated areas in which to drill. Wells drilled in these highly depleted reservoirs often encounter severe loss circulation problems and have significant formation damage. This problem has spurred development and evaluation of new technologies directed at increasing recovery of reserves.

Underbalanced drilling techniques were evaluated in depleted reservoir B-6-X.10, with few satisfactory results. The main barrier for application of this technique is the presence of shale intercalation in the objective sand (anisotropy of the reservoirs). This characteristic generates hole instability and stuck pipe problems due to shale collapses when using low mud weights, which in many cases results in abandoning well construction.

A new technology in drilling fluids, designed to drill in reservoir with low formation pressures and high risk of loss circulation, was used as an alternative to underbalanced drilling in this reservoir. The fluid system controls invasion using the concept of bridging by means of air microbubbles, which are generated without the need for additional surface equipment (i.e. rotating heads, compressors, injectors, etc.). The system is applied in overbalanced conditions, facilitating wellbore mechanical stabilization issues.

The paper presents the results obtained in drilling three horizontal wells in the mature reservoir (Misoa formation, Eocene age) using the new fluid system as an alternative to underbalanced drilling. The operational success in the well construction phase confirmed that the system is an excellent alternative for drilling zones with low formation pressure and high risk of loss circulation in these anisotropic reservoirs.

Introduction

Horizontal drilling technology has increased production due to the ability to expose the wellbore to maximum productivity zones. In many cases these zones are interconnected, fractured or have high permeability. These factors, together with a low formation pressure, render well construction more difficult due to severe loss circulation problems. In order to control loss circulation high concentration of different types and sizes of plugging materials are used. In this case use is restricted by the presence of downhole tools (motors, MWD, etc.) and by the damage that these materials could cause to the production zone.

Many articles and success stories have been written about under balance drilling techniques applied in mature reservoirs. The technique consists of air or nitrogen injection into the drilling fluid in order to lower density and generate an under balance condition (well hydrostatic pressure lower than formation pressure). Furthermore dry air and foam have been used as drilling fluids to create these conditions. This technique has resulted in an increase in rate of penetration, minimization of loss circulation problems and reduction of formation damage to the production zone.

To obtain the underbalance conditions while drilling, generally additional expensive equipment to the existing in conventional rigs are required: rotating head, equipment to generate and/or inject nitrogen, boosters, separators, etc. Operational experience shows problems associated to this technique, such as: well control problems, hole instability, variations in fluid properties, drill pipe corrosion and difficulty to use real time data transmission tools.

Overbalance techniques use fluids with a density close to the formation pressure gradient, i.e. the density of the fluid is kept above formation pressure. However, the overbalance has to be low enough for not exceeding rock strength and fracturing the formation.

The application of the drilling fluid system Microbubble – AphronICS in overbalance conditions avoids shale-collapsing problems frequently encountered when drilling through sand/shale intercalation using very low equivalent circulation densities. Usually, the shale intercalation presented in the objective sands requires relatively high mud weight in order to keep them stable and avoid shale collapsing. Also the bridging mechanism of the Aphrons minimizes formation damage and allows drilling in low formation pressure reservoirs with loss circulation risk (*see "DRILLING FLUID: MICROBUBBLE – APHRONICS"*).

Reservoir Information

Figure 1 shows the location of reservoir B-6-X.10. Tables 1 and 2 show lithological characteristics and the most representative petrophysical parameters of the different sections passed through in the drilling of the horizontal wells.

The horizontal wells were drilled in area LL-370 of the Tia Juana field.
In these areas the Miocene consists of unconsolidated formations with highly reactive shale that hydrate easily, with presence of sandy lenses containing pressurized aquifers. Usually the Miocene is drilled with relatively high mud weights that keep the aquifers controlled and avoids the tendency of the hole to close (mud weight around 9.0 ppg)

Immediately below the Eocene Unconformity (see Table 1), sands B-4-X, B-5-X and B-6-X are encountered. The B-5-X sands have the lowest fracture gradient (0.49 psi/ft) and experience the most severe loss circulation problems. The B-6-X sands are the objectives. Two sandy lenses separated by a fine shale layer generally compose these sands. The lower lens contains the reserves not drained while the upper lens usually contains non-desired fluids. Drilling in the Eocene traditionally requires the use of low mud weights in order to minimize formation damage and loss circulation: aerated mud and UBD equipment were used (ECD = 3.0 – 4.0 ppg).

Operational Background of the Area.

Underbalanced drilling (UBD) of horizontal wells using aerated mud in the Tia Juana area started in August 1996 with the drilling of well LL-1174, followed by a campaign of 14 wells in 1997, and 8 wells in 1998.
Figure 6 shows the typical architecture of these wells.
Drilling parameters used in the construction of the horizontal section in the objective sand were:

Circulation pressure:	800 – 1.400 psi.
Flow rate:	120 – 220 gpm.
Compressed Air Vol.:	800 – 1.400 ft^3/min.
Water based mud:	Polymer

The most important aspects of the well construction were:

- UBD using aerated mud minimizes and in some cases controls the loss circulation problems adequately.
- It allows drilling without problems in clean sands.
- In drilling operations, equivalent circulating densities of up to 3.0 ppg were obtained.
- UBD presents serious hole instability problems while drilling dirty sands or when passing through sand/shale intercalations.
- Special downhole motors and measurements tools are required to perform in this environment of high vibration and friction.
- It is necessary to use corrosion inhibitors to protect drill string and drilling equipment.
- The length of the horizontal section varied from 130 to 800 ft; greatest lengths for wells drilled in clean sands, shortest for wells where layers of shale intercalation in the sand were found.
- In the year 1997 hole instability problems severely affected 8 of the 14 wells drilled.
- Horizontal wells require a greater air compressor capacity than vertical wells with the same hole size.
- Experience in using foam in horizontal drilling shows the same hole instability problems as with the use of aerated mud.
- The average for drilling the horizontal section of 443 feet was 27.7 days, with an average production of 253 BOPD.

Mechanical Design

Conventional Design: Three Casings

The conventional design for horizontal wells in the area consists of three casings and an open hole completion in the producer zone (Figure 6). In this case well construction is as follows:

- Surface hole 17 ½”; 13 3/8” casing set @ 1000’, in order to provide mechanical support to the foundation and isolate upper aquifers.
- First Intermediate hole 12 ¼”; 9 5/8” casing set at the top of the Eocene Unconformity, isolating the zones with higher pressure of the Miocene from the depleted zones with lower pressure of the Eocene, where severe loss circulation problems are common. This configuration avoids mechanical instability of the Miocene in case of having loss circulation in the depleted zones of the Eocene, preventing subsequent problem of having influx from the upper pressurized zones, and hole closing due to the lack of a mechanical barrier (mud weight). This section is drilled with Disperse Polymer mud.
- The second intermediate hole is drilled up to the top of the objective sand and the 7” casing is run and cemented, isolating intermediate zones with non-desired fluids from the objective. Aerated mud is used.
- The 6 1/8” production hole is drilled horizontally into the producer sand using under balance drilling techniques with aerated mud or foam, and is completed open hole.

In order to achieve the conventional well construction design, two drilling rigs had to be used. The first rig was a conventional drilling rig (drilling barge type), and was used to construct the well up to the top of the objective sand. In some cases a supply boat with equipment for drilling using aerated mud (compressors, air/nitrogen generators, etc) had to be used additionally. The second rig was a coiled tubing unit type, adapted to drill in under balance conditions (rotating head,

compressors, etc), which was used to drill in the objective sand. As a coiled tubing unit, this unit had no rig capacity to drill a 17 ½" hole and run a 13 3/8" casing.
The average well construction time for these wells in the conventional design was 55.8 days.

Because of low level of success obtained in these wells construction, extraction of reserves in this Eocene reservoir remained suspended until the development of new technologies that render recovery economical.

Drilling Fluid: Microbubble – AphronICS.

The Microbubble – AphronICS system is a new technology in "Drill in" drilling fluids. It controls invasion using the concept of bridging by means of micro air bubbles, called "***Aphrons***", which are generated without using pneumatic equipment (Figure 2).

The system is designed to drill mature and low formation pressure reservoirs. It present a continuous phase with high viscosities at low shear rate and contains an internal phase of micro bubbles of air or encapsulated gas, non coalescent and that can be circulated through the system. These Aphrons are generated through the use of chemical tensoactives, not by the external injection of air and gas. The Aphrons are responsible to form a "Micro environment" in the low pressure zones to bridge high permeability formations without using solids materials.
Aphrons are generated under conditions of pressure drop and turbulence. This condition exists in the drillstring and bit nozzles. When the fluid pass through the bit nozzles, the Aphrons are energized, containing internally the pressure under they were formed (Figure 3). When the micro bubbles are in front of low-pressure zones, they expand and form a microenvironment that severely increases the viscosity of the fluid. These two facts, the expansion and the viscosity increase of the continuous phase, bridge and reduce the invasion of the fluid into the reservoir, minimizing damage (Figure 5).
The Aphrons exist as independent spheres with a core of air or encapsulated gas surrounded with a film of various layers of waters. The tensoactive produce the superficial tension necessary to form and contain the Aphrons and the multilayers around it.
The Aphrons are unique in structure and size. Typical size ranges are between 10 to 100 microns at surface. This allows circulating them through the system even when the solid control systems are used (Figure 4).

Due to their low mass, high-speed shakers with fine screens, hydro-cyclones or high-speed centrifuges do not easily remove Aphrons.
Downhole tools, such as MWD, turbines and motors do not suffer interference by Aphrons, which is ideal for horizontal and directional drilling.

The system has excellent rheology and increases the viscosity at a low shear rate, which helps to control the invasion of the drilling fluid and the mud filtrate due to its high resistance to movement. These properties allow drilling formations of high permeability or with micro fractures, with a minimum loss circulation risk.

Advantages of the Microbubble – AphronsICS.

The main advantages of the system are:

- It is a water base "Drill in" system, bridging free solids in the fluid with excellent shale inhibition properties and invasion control.
- Minimum damage to the producer formation.
- Standard directional tools can be used to obtain real time reservoir data: LWD, MWD.
- Excellent cleaning and hole stability properties.
- Stable properties.
- Minimizes well control risks.
- Logs and wireline logs can be run conventionally.
- All solid control equipment can be used.
- Does not require additional equipment when used on a conventional drilling rig.
- Costs are lower than UBD.

Fluid Base Formulation.

The Formulation (2) of the Microbubble – Aphron drilling system is as follows:

Product	Function	Concentration
Go Devil II	Viscosifyer	4 - 5 lpb
Activador I	Filtrate control	4 - 5 lpb
Activador II	Thermal and pH stab.	1 - 2 lpb
Actiguard	Shale inhibitor	1 - 2 lpb
Blue Streak	Aphron generator	1 - 2 lpb
Safe Cide	Bactericide	0.10 - 0.15 lpb

Operational Planning

Objective

The objectives of drilling the three horizontal wells, were:

- Eliminate one intermediate casing/hole interval in the well construction using two casing strings only (surface, intermediate), and open hole completion in the producer sand; instead of the conventional design of the area that used three casing strings (surface, two intermediate) and open hole completion (see Figure 6 & 7).

- Evaluate the application of Aphron system in the intermediate hole construction, replacing the use of aerated mud of the conventional design.
- Evaluate the application of Aphron system in the production hole construction, replacing the use of underbalance drilling techniques.
- Reduction of costs and time, rendering the extraction of reserves economical.

Also, for this well construction was planned to use only one rig.

New Mechanical Design: Two Casings

The proposed new mechanical design, considering the advantages of the Microbubble – AphronICS system, consists of a configuration of two casings and an open hole completion (Figure 7):

- Surface 9 5/8" casing is set at 1500' in order to provide greater mechanical strength to the casing shoe, containing the unconsolidated upper sands. Water gel is used as drilling fluid.
- The 8 ½" intermediate hole is drilled up to the top of the objective sand passing through Miocene and Eocene. This section is drilled in two phases; the first phase is drilled vertically up to the top of the Eocene Unconformity using conventional Polymer mud. Microbubble – AphronICS mud, displaces the Polymer mud at open hole. Then the second phase is drilled from the top of the Eocene unconformity up to the top of the objective sand.
- The 6 1/8" production hole is drilled horizontally and completed open hole also using a Microbubble – AphronICS system.
- Time for well construction was estimated in 28 days.

Risk Assessment Matrix

Because of the configuration proposed presented a higher level of risk compared to the conventional design, a risk analysis was performed in order to establish the variables of control while well construction.

Intermediate Hole – Vertical Section: The drilling fluid should be able to provide enough weight to control formation pressure of the Miocene aquifers and mechanically stabilize the borehole walls, preventing them from closing. Furthermore the fluid inhibits the reactive shales of the Miocene that will be exposed for a longer period of time, avoiding hole closing and/or hole collapsing. Additionally the fluid should have excellent hole cleaning capacity.

Intermediate Hole – Build up Section: this is the most critical section. The ECD should be controlled carefully in order to avoid fracturing the formation and inducing loss circulation in the weakest sand of the Eocene (B-5-X). In most cases loss circulation has been so severe that the well had to be abandoned at this stage.

Production Hole – Horizontal Section: The drilling fluid should have enough weight in order to avoid intercalated shale collapsing while drilling in the objective sand, good bridging properties in order to minimize loss circulation in the depleted zone, and minimize formation damage.

Execution

Summary of the construction of well LL-3616.

- Surface hole 12 ¼" was drilled as per program and 9 5/8" casing was set at 1500'.
- 8 ½" intermediate hole was drilled up to 4300' (top of the Eocene Unconformity) where the Polymer mud of 9.1 ppg was displaced by Microbubble mud of 9.0 ppg.
- Total loss circulation @ 5021' TVD while construction of build up section. ECD of 9.7 ppg overcame fracture gradient of B-5-X sands (9.4 ppg). Loss circulation controlled with LCM pills. Microbubble mud weight was set at 8.6 ppg and drilling was resume.
- Involuntary sidetrack while running in directional BHA in a trip. A cement plug had to be pumped and hole was abandoned.
- New 8 ½" hole drilled using Microbubble mud formulated @ 8.7 ppg.

Others problems encountered were:

- Pipe stuck differentially while drilling at 5356' MD. Drillstring was freed pumping ID-FREE pill.
- Total loss circulation at 5356' MD. Unfortunately the ID-FREE pill was not circulated out but incorporated into the system affecting the generation of the Aphrons. The strong surfactant broke the Aphrons destabilizing the microenvironment formed in the low-pressure zones. Once the Aphrons were broken the bridging mechanism was lost and total loss circulation occurred. The loss circulation was treated with CaCO3 without success. Finally loss circulation was controlled pumping InstanSeal* system.
- While running casing, the annulus packed off and only partial circulation was observed. The casing had to be pulled out to surface. A wiper trip was done and the casing was ran again. Finally the casing was cemented using light cement slurry of 9.2 ppg (100% circulation).
- Before drilling out the shoe, a pressure test was performed obtaining circulation through the 9 5/8" x 7" annulus. The casing was badly cemented due to poor centralization (centralizers were taken out in order to be able to run casing successfully). A repair job pumping cement and holding pressure was done, the annulus was sealed.

The 6 1/8” production hole was drilled to the total depth of 6303’ MD. The drilling of this section was done using Microbubble formulated at 7.9 ppg and no loss circulation problems were observed.

The well was completed open hole with a slotted liner and gas lift equipment. The well finished with a total time of 42.8 days against 28 days estimated.

Summary of the construction of well LL-3627.

- Surface hole 12 ¼” was drilled as per program and 9 5/8” casing was set at 1508’.
- 8 ½” intermediate hole was drilled up to 4150’ (top of the Eocene Unconformity) where the Polymer mud of 8.8 ppg was displaced by Microbubble mud of 7.8 ppg. After displacement well flowed 2-3 bbls/hour, and mud weight had to be increased up to 8.2 ppg. Then the wiper trip was performed.
- Drilling the Eocene was done controlling ECD (ECD was calculated each 50 feet) and no loss circulation problems were encountered (Figure 8).
- The casing was run using a casing fill up tool, circulating each joint. The casing was cemented using light cement slurry of 11.0 ppg.

The 6 1/8” production hole was drilled to a total depth of 6202’ MD. Drilling of this section was done using a Microbubble system formulated at 8.2 ppg and no loss circulation was observed.

The well was completed open hole with a slotted liner and gas lift equipment. The well finished with a total time of 22.0 days versus an estimated of 28 days.

Summary of the construction of well LL-3633.

- Surface hole 12 ¼” was drilled as per program and 9 5/8” casing was set at 1506’.
- 8 ½” intermediate hole was drilled with a Polymer mud of 8.8 ppg up to 4260’, where the system was displaced by Microbubble mud formulated at 8.2 ppg. After displacing the system, the well flowed at 2-3 bbls/hour. The mud weight was increased to 8.4 ppg and the well was controlled. A wiper trip was performed.
- Partial loss circulation (50-60%, 55 bbls/hour) at 5015’ MD was observed. The amount of Aphrons was increased (by pumping a Blue Streak pill) and circulation was recovered 100%. Mud weight was set at 8.2 ppg and drilling continued with intermittent partial loss circulation up to the entry point at 5691’ MD.
- The 7” casing was run and cemented using a light cement slurry of 11.0 lpg.

The 6 1/8” production hole was drilled from 5691’ MD to 6293’ MD with a Microbubble system of 8.4 ppg without having loss circulation.

The well was completed open hole with a slotted liner and gas lift equipment. The well finished with a total time of 25.5 days against an estimated of 28 days.

SUMMARY OF OPERATIONAL EXPERIENCE

- Drilled in one interval Miocene and Eocene, passing through formations with pressures from 6.7 ppg to 2.9 ppg.
- Drilled in the objective sand (formation pressure 2.8 ppg) using Aphron system of 8.4 ppg without loss circulation problems. The bridging mechanism of the Aphron system allowed drilling with a differential pressure against the formation of about 1500 psi.
- ECD was calculated using conventional hydraulic calculations (calculations validated with the use of real time downhole annular pressure measurement tools in previous jobs).
- The first well LL-3616 showed that severe loss circulation occurred in B-5-X sands, with the lowest fracture gradient (0.49 psi/ft), when ECD overcame the fracture gradient. Once the formation was fracture, it was very difficult to cure the losses even using combination of Aphron, LCM or $CaCO_3$.
- Using freeing pills requires carefully spacing when drilling with Aphron system because the surfactant present in the pill destroys the Aphrons loosing bridging mechanism and having loss circulation and wellbore desestabilization. The spacing should be specially considered in high inclination section where pill canalization is highly probable.
- Displacement of Polymer mud by Aphron system of less weight generates wellbore mechanical unstabilization after displacement due to hole closing tendency. The stability could be restore with wiper trips after displacement instead of increasing mud weight, however trips should be done carefully cause string could get packed easily while tripping out.
- Difference between formulation mud weight and mud weight in/out is and indicative of the amount of Aphron present in the system. (i.e.: formulation mud weight = 8.4 ppg, mud weight out = 7.8 ppg, 20% Aphron).
- In this type of wells trips are the most important issue. NPT due to backreaming while tripping was the major source, exception: loss circulation in the first well, where backreaming while tripping was second (Figure 11). Thus, operational practices for tripping are essential for success.

Results

- Wells constructed as per new design, eliminating one intermediate casing / hole interval.
- Intermediate hole constructed using Aphron system, replacing drilling with aireated mud.
- Production hole constructed using Aphron system without loss circulation/hole instability problems, replacing underbalance drilling.
- Use of only one rig for well construction.
- More than 50% reduction in well construction costs, comparing with the conventional design, due to: less construction time (see Figures 6, 7 & 10), eliminate costs associated with one intermediate hole (see Figure 10), and use of one conventional rig (no special equipment of underbalance drilling required).
- Production obtained equal to estimated production with underbalance drilling (600 bbls/day).

Conclusions

- The Aphron system replaced successfully Underbalance drilling in reservoir B-6-X.10, characterized by having low formation pressures and sand/shale intercalation that required mud weight to avoid shale collapsing.
- The application of the Aphron system in the well construction using the overbalance drilling made possible 50% cut down cost comparing with the application of underbalance techniques, allowing the economic exploitation of these reservoirs.
- The knowledge of the operative handling of the Aphron system was crucial for the successful application of this technique.

Bibliography

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- Evaluación Sistema Microburbujas. Roffer Alvarez. Correspondencia Interna Dowell

Figure 1. Location of the reservoir B-6-X.10

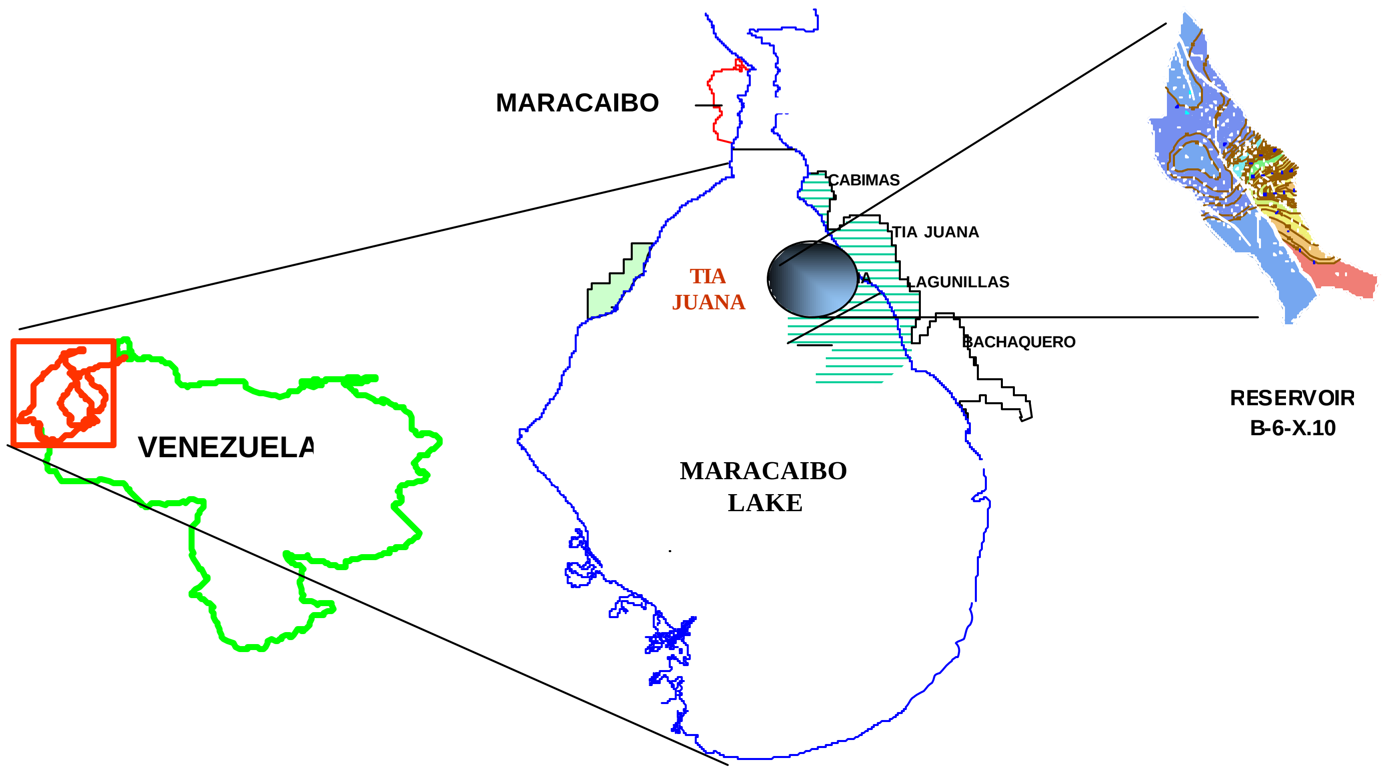

Table 1. Stratygraphic Column and petrophsycial characteristics

FORMATION	MEMBER	Reservoir	Vertical Top (ft) RKB: 42'	Subsea Top (ft)	Fluids	Pressure (psi)	Pressure (ppg)	F.G. (psi/ft)	Porosity (%)	Permeab. (mD)
ISNOTU										
LAGUNILLAS	BACH. SUP.	----------	2118	(-2076)	Water			0.61	20 – 25	500 – 1000
	BACH. INF.	----------	2320	(-2278)	Water			0.61	20 – 28	400 – 800
	LAGUNA SUPERIOR	----------	3176	(-3134)	Water	----------	----------	0.61	20 – 25	300 – 700
	LAGUNA INFERIOR	----------	3421	(-3379)	Water	----------	----------	0.61	20 – 30	300 – 700
	LL-INF	----------	3736	(-3694)	Oil/Water	1294	6.7	0.61	20 – 30	800 – 1000
LA ROSA	LA ROSA	----------	4019	(-3977)	Water	1394	6.7	0.61	20 – 25	300 – 700
	SANTA BARBARA	----------	----------	---------	----------					
ICOTEA	ICOTEA	----------	----------	---------	----------					
	Eocene Unconform..	----------	4158	(-4116)	----------					
	B-1-X	----------	Worn out	----------	----------					
	B-2-X	----------	Worn out	----------	----------					
	B-3-X		Worn out	----------	----------					
MISOA	B-4-X	B-4-X.10	4158	(-4116)	Oil	900	4.2			
	B-5-X	B-5-X.50	4568	(-4526)	Oil	900	3.8	0.49	16 – 22	350 – 800
	B-6-X	B-6-X.10	5209	(-5167)	Oil/Gas	800	2.9	0.58	16 – 22	350 – 800
	Objective	B-6-X.10	5347	(-5305)	Oil	800	2.8	0.58	16 – 22	350 – 800

Table 2. Litological characteristics of the Members.

FORMATION	MEMBER	LITOLOGY
ISNOTU		
	BACH. SUP.	Unconsolidated clean Sandstone, with gray clay intercalations with red tones, very plastic and hidratable
	BACH. INF.	Unconsolidated clean Sandstone, medium to fine grains, gray clay intercalations, with red tones, very plastics and highly hidratables, accessories minerals: hematite and limonite
LAGUNILLAS	LAGUNA SUPERIOR	Unconsolidated clean Sandstone, intercalated with unconsolidated light brown limonite and gray-red clays
	LAGUNA INFERIOR	Unconsolidated Sandstone, intercalated with soft limonite and plastic clays of gray red color, soft and hidratables.
	LL-INF	Unconsolidated Sandstones of clean grains, soft, with fine intercalations of hard light gray shales, highly hidratables. Accessories Minerals: abundant free quarz, iron oxide, remainder fossils
LA ROSA	LA ROSA	Dark shales, hard to moderately hard, hidratables, intercalated with fine grain unconsolidated sandstones, regularly selected, some silt y.
ICOTEA	SANTA BARBARA ICOTEA	
	Eocene Unconform.	
	B-1-X	
	B-2-X	
	B-3-X	
MISOA	B-4-X	
	B-5-X	Gray shale sequence with sand of cream to gray color, in dirty parts of fine grains, unconsolidated. The ambient of deposition is deltaic with tides influence.
	B-6-X	Transition from deltaic depositions to fluvial depositions, fine to medium grains sandstones, very clean in the central part, shale and limonite intercalations at the top and at the base.

Figure 2. Microbubble System

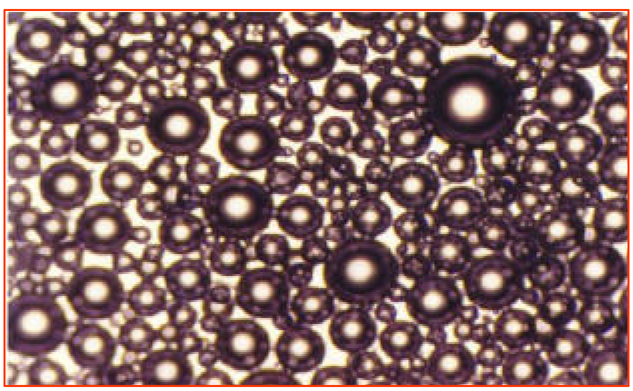

Figure 3. Schematic of the compression

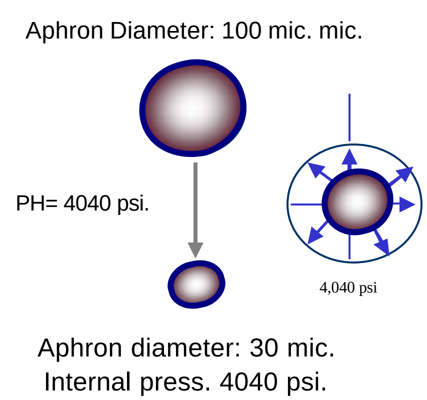

Figure 4. Aphron, Screens 175 Mesh. Flow: 340 gpm.

Figure 5. Aphron's bridging mechanism.

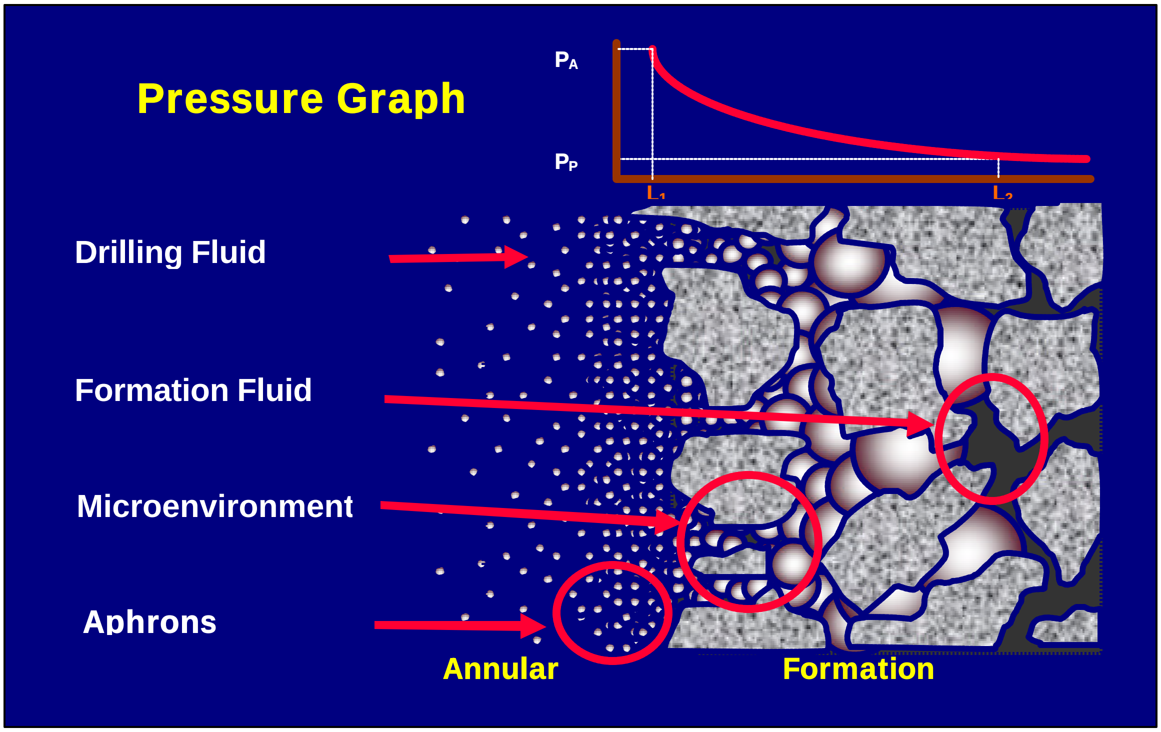

Figure 6. Conventional Design.

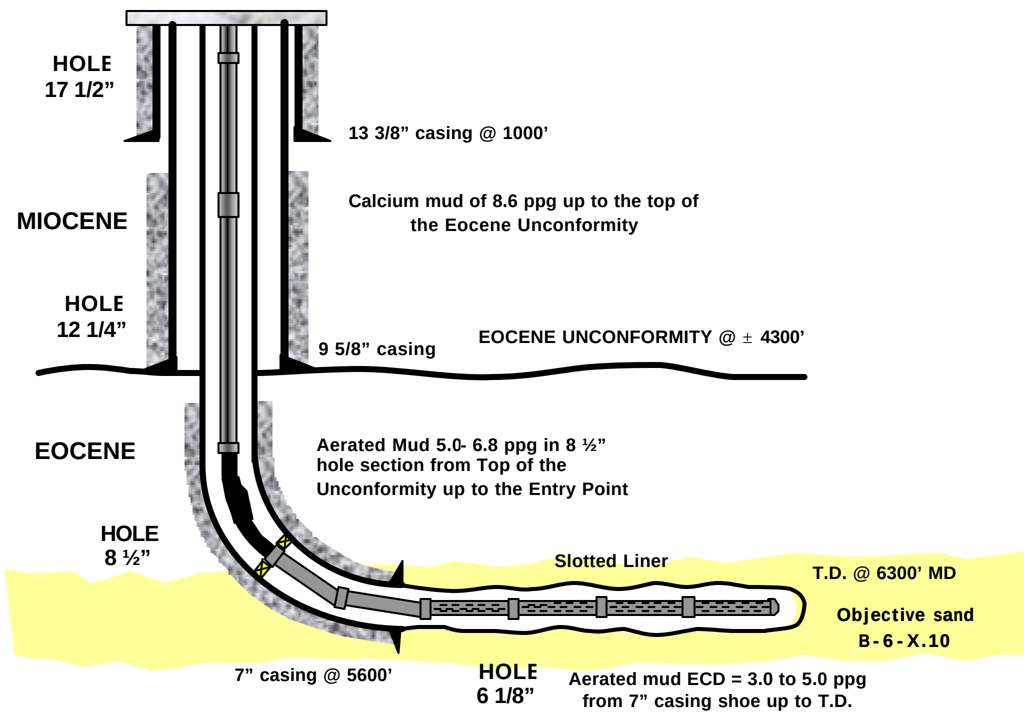

Figure 7. New design: Miocene – Eocene in one phase.

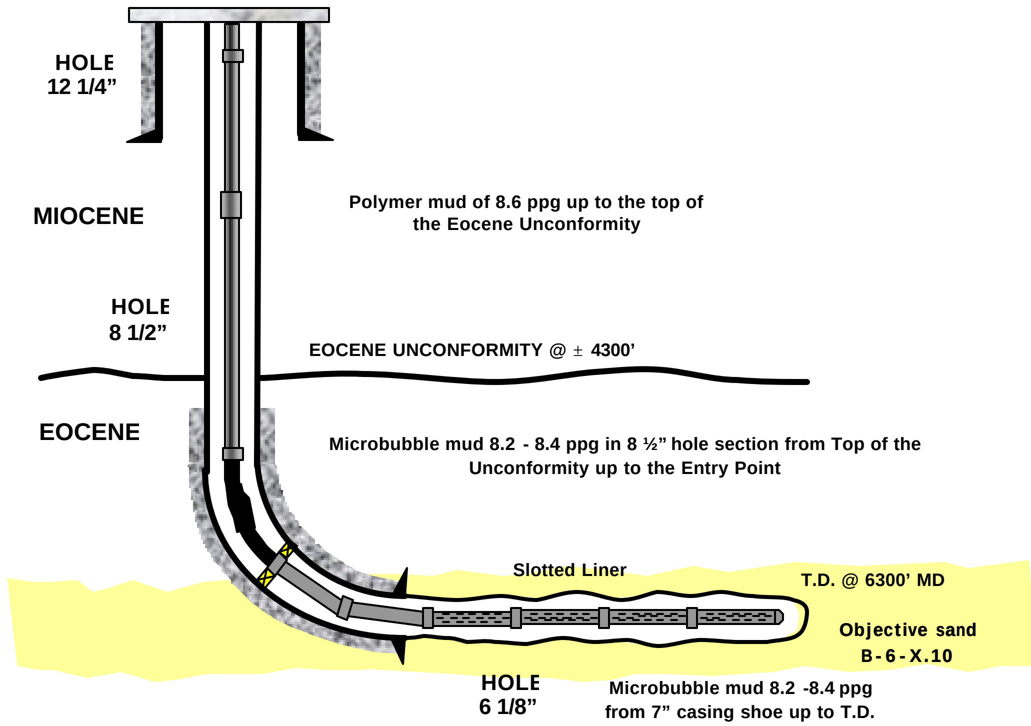

Figure 8: Control of ECD – Well LL-3627

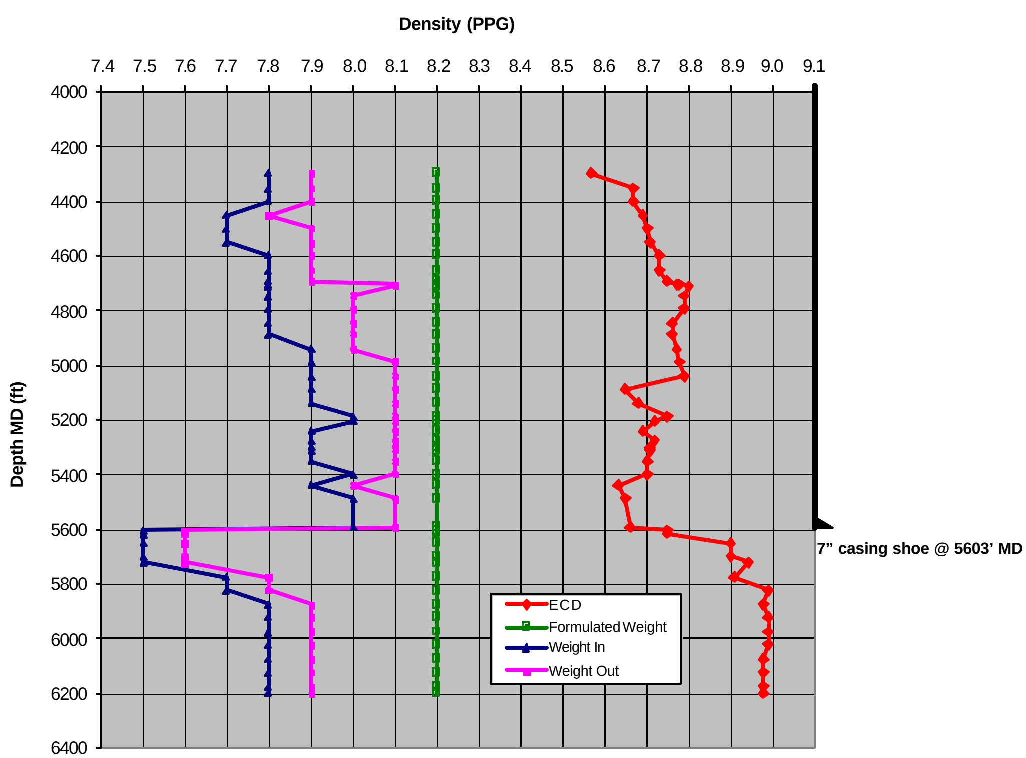

Figure 9: Control of ECD – Well LL-3633

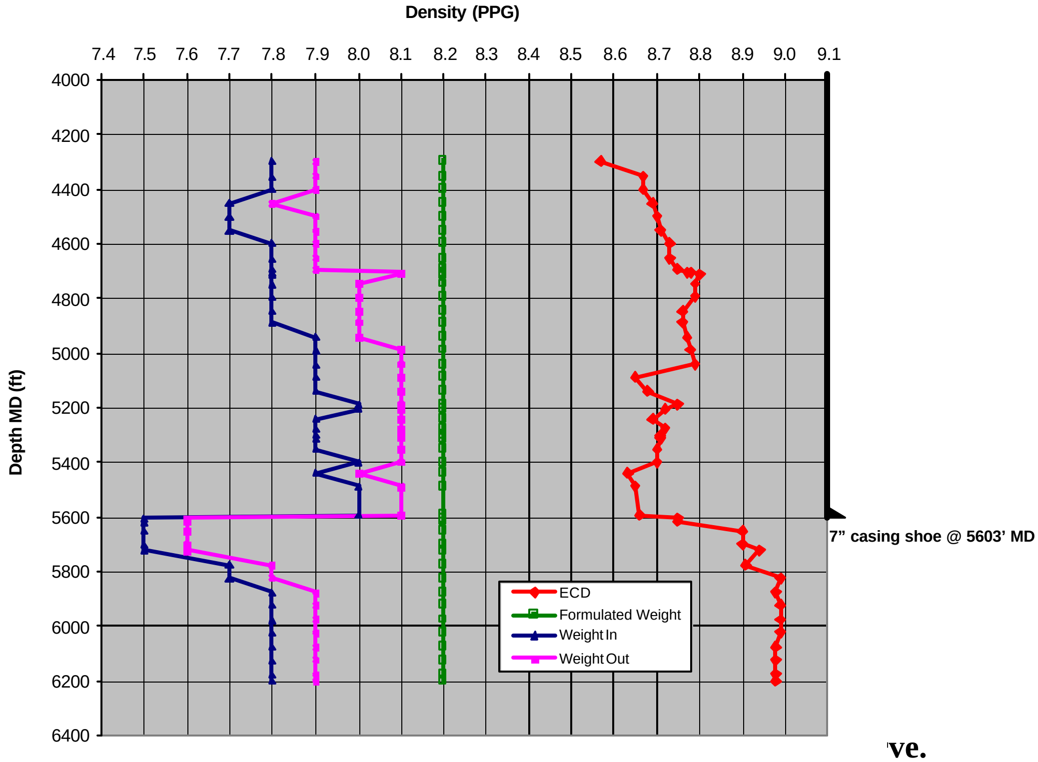

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Figure 10: Time vs Depth curve.

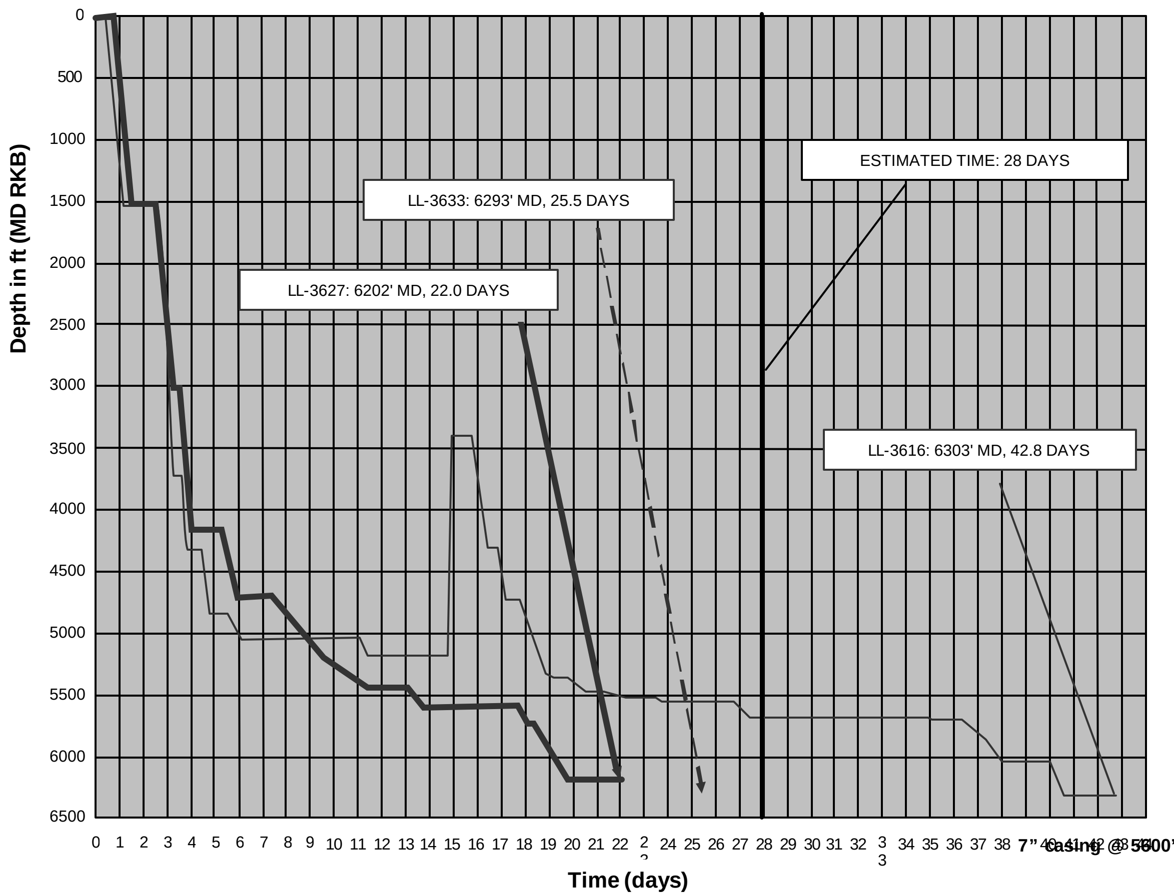

Figure 11: NPT Breakdown