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Experience Using Microbubbles-Aphron Drilling Fluid in Mature Reservoirs of Lake Maracaibo

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Abstract

The objective of the paper is to present field results obtained through the evaluation of the Micro-bubble Aphron system, as the drilling fluid in wells VLA-1321, VLA-1325, VLA-1326, VLA-1327, VLA-1329, VLA-1331, VLA-1332, VLA-1334 and VLA-1335 (wells corresponding to Lagomar Integrated Laboratory). This fluid does not require equipment such as compressors, rotary wellhead, equipment to generate and/or inject nitrogen and permits the taking of electric logs conventionally.

During drilling, mud weight varied between 6.8 to 7.9 ppg and very low-pressure zones were run through, with equivalent gradients oscillating between 2.4 ppg and 6.4 ppg, without any problems of loss of circulation.

The micro-bubble fluid presented excellent inhibition values to clay and shale since the Miocene sands of Basal La Rosa and the alternating sand and shale of the Eocene reservoirs were drilled without any problems. Moreover, in well VLA-1321, this lithology was with an exposure time of 25 days, without any instability problem. On the other hand, in wells VLA-1329, VLA-1331, VLA-1332, VLA-1334 and VLA-1335 all the intervals were drilled from 1520’ to 6900’, without using intermediate casing and without great problems, which cut down drilling time to 31.0 days with a saving of 4.7 MMUS$ for the corporation.

It should be pointed out that the fluid has presented rheological properties , which have permitted drilling with excellent hole cleaning.

During the drilling of well VLA-1321, 90’ of samples were taken in the Miocene and 300’ in the Eocene sands with a high percentage of recovery (90.80%) and in well VLA-1326, 411’ of samples were cut with a percentage of recovery of 90.4%.

Additionally, the electric logs were not affected by the micro-buble mud and caliper logs showed a hole of excellent gage.

Judging from the excellent results obtained, the Micro-bubble Aphron system is still being evaluated in the Eocene mature reservoirs of Lake Maracaibo.

Introduction

The Lagomar Integrated Laboratory (L.I.L.) comprises a first stage with the drilling of five vertical wells in order to increase the recovery up to 10% of the POES in the next five years, in the La Rosa Basal sands and “C” of the Eocene through the application of forefront technologies that permit high fluid volumes in the mature reservoirs and with low pressures.

Due to the low gradients of the Eocene sands, the use of a drilling fluid which guarantees the integrity of the hole, without the risk of loss of circulation and with a minimum damage to the productive formation, is necessary. Recently, experiences have been had with aerated fluids, but the wells presented serious operational problems, such as: lost circulation, caving in of the holes due to the presence of unstable shale, impossibility of running logs, pressure taking, taking of samples, etc

A new system has been developed, a water base drilling fluid called Micro-bubble – Aphron, designed to drill low pressure mature reservoirs; this system 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 recirculatable. These Micro-bubbles denominated “APHRONS” are generated by the use of a chemical surfactant that traps the air present in the system (active tank) and/or that is generated at pressure drop created by the jets of the bits. This fluid does not require an external source of injection of air and/or gas (compressors, equipment to generate and/or inject gas, etc.). The Aphrons permits reducing the density of the continuous phase to lesser values than water and the use of balance drilling technique.

The micro-bubbles do not lose their configuration on the surface while passing through screens at atmospheric pressure, and in the hole they have the capacity to arrange themselves and/or create bridging in the micro-fractures thus avoiding the loss of fluid into the formation (see Figure 1).

Background

Recent experience at Block I (Lagomar) with aerated drilling, comprises a group of seven wells: VLA-1271, VLA-1278, VLA-1280, VLA-1283, VLA-1285, VLA-1289 and VLA-1291. In the drilling of these wells an intermediate casing was set at the top of La Rosa formation in order to isolate the normal pressure zone.

In the same wells, the drilling of the productive zone (gradient of the "C" sand formation: 0.16 psi/ft.) was done with aerated mud using a density of 4 ppg. Serious lost circulation problems were observed; besides the C-4U1 and C-4U2 sands presented big shale bodies that generated instability problems in the hole during the drill string trips. Another problem presented itself in the casing cementation job of the zone of interest, due to the occurrence of lost circulation with correspondent formation damage and a deficient cementation.

Additionally, there was difficulty in running wire-line electric logs, having to use LWD, thus generating additional operational cost. By virtue of the aforementioned, it was decided to evaluate the micro-burbles fluid in the field laboratory wells of the Lagomar Area.

Geological and Petro-Phisical Considerations

The structure of the area is defined by a homoclinal with dipping towards the Northeast. In the Eocene it is estimated to go through from C-3, partially eroded, up to C-4L. The stratified sequence that is penetrated during drilling, from the top to the base, is formed by El Milagro of the Pleistocene age, Onia, of Superior Pliocene / Miocene, the formations of La Puerta, Lagunillas and La Rosa (including Santa Bárbara and La Rosa Basal) of Miocene. (See Figure 2.)

Survey Carried Out with Sample From Well VLA-765.

Before carrying the field tests with the micro-bubble fluid, laboratory test and/or analysis were first carried out, such as: samples with the corresponding crude to qualitatively determine its compatibility and avoid formation damage because of severe emulsion (see table 1). Secondly, sand plugs of interest were taken from cores of well VLA-765 (depth: 6054' and 6849'), in which the following test were carried out:

- Pore size distribution.
- Permeability return.
- Rheological properties (before and after hot rolling).
- LSRV.
- Rheological properties to reservoir Pressure and Temperature conditions.
- Particle plugging test.
- Dynamic filtration.

The results of these tests are presented in the charts and figures in the appendix.

For the compatibility tests, volumes of fixed crude and mud are mixed (25/75%, 50/50%, 75/25%). The mixture is shaken and maintained at reservoir temperature of 180°F for sixty minutes observing if emulsions are formed. The sample used belonged to wells VLA-879 and VLA-1283. (See Table 2)

In order to determine the optimum size of the fluid bridging material, the distribution of the pore sizes should be analyzed and the pore gap of the prospective sand determined. The method applied was the poresymetry or injection of Mercury (Hg). The permeability to the air (Kaire) observed was 950 mD, corresponding to the plug at the depth of 6180'. The porosity was 26.73% and the pore volume was 2,113 cc (See Figure 3).

In figure 4 the rock composition can be observed. Quartz is the most outstanding mineral element, with a poor cementing capacity between the grains. In figure 5, the type of clay found is *autigenic coalinite*, which is either filling up the pores or on the surface of the grains. In less percentage, *Esmectite* is observed forming bridges between the grains.

The mineralogical composition determined through X-ray diffraction and the solubility to 15% HCI acid and the mixture of acid mud "Regular mud Acid" (12% HCI + 3% HF), can be seen in table 3.

Figures 6 and 7 and table 4 show the corresponding results carried out according to the following conditions:

- Permeability return: at 6180'; T = 180°F.
- Dynamic filtration: P = 500 psi, T = 190°F, Ceramic Disk = 450 mD, 100 rpm.
- Particle plugging: P = 600 psi, T = 180°F, t = 30 min, Ceramic Disk =4 50 mD. (See Figure 6).

The curve (see figure 6) gave as a result that the permeability return of the micro-bubble fluid was 85% or a 15% damage to the core plug. Results of the Dynamic Filtration are shown in the table 4.

Description of the Microbubbles-Aphron fluid

The Micro-bubble-Aphron System is a water based fluid capable of reducing its density to values between 6.8 lpg and 7.5 lpg through the trapping of air or gas in a micro-bubble using a surfactant, as well as generating high viscosity at low shear rate, being ideal for low pressure reservoir.

The micro-bubbles have the property that on being submitted to pressure drops generated at the mixing hopper and in the bit, aphrons of sizes that oscillate between 10 and 100 μc are formed. Due to the interfacial forces successive layers of fluid are created around the aphron, in this manner, an arrangement is created which can contain high energetic charges due to the Laplace pressure. These arrangements create a bridging in the formation. This system uses a polymer capable of generating a high viscosity at low shear rates, stabilizing the aphrons before compression and expansion occurs. As a consequence, during its course through solid control equipment they do not liberate the air or gas nucleus. Among other properties of this system, we have:

- The aphrons do not interfere with down tools (MWD, turbines, motors), resulting in a good option for directional and horizontal drilling.

- The bridging of aphrons, the high viscosity and adequate additives can control the filtration at low values.
- They can effectively control reactive clays or shale lenses.
- They contain a thermal stabilizer that avoids degradation in the polymers.
- As a critical condition, the system should be maintained in a pH range of 9.5 to 10 in a clean environment and be prepared with potable water or a bactericide should be added as a prevention mechanism.

System Formulation.

After multiple laboratory tests, the fluid was formulated with the compositions shown in table 5.

Here is a more detailed description of the products:

Shale/Clay Inhibitor – a mixture of non-toxic surfactants and vegetable oil. They react chemically to inhibit the absorption of water, avoiding the swelling of the shale and/or clay.

Polymer Blend – Fluid loss control and thermal stabilization.

PH Buffer – PH control.

Aphronizer – multi-component mixture of anionic and non-ionic surfactants, co-surfactants and polymers in aqueous solution.

Biopolymer Blend – a mixture of non-ionic polymers that generate high viscosity at low shear rates.

Laboratory Tests carried out with Microbubbles Fluid.

Tests were carried out in the laboratory with Brookfield viscosimeter to evaluate the LSRV, conventional rhelogic tests and tests with FANN 70 equipment. Results can be seen in charts 6,7, and 8.

Process for the Preparation of the System.

For the first well (VLA-1321) the base mud (1200 Bls.) was prepared in three batches of 400 Bls. To carry out the preparation, the order and formulation shown in the table 9 was followed.

After preparing each batch of 400 barrels, the same was mixed and homogenized for 2 hours. Afterwards the rheological properties were checked. These are the values:

- Density: 8.1 ppg
- Funnel Viscosity: 100 seconds /quart.

Displacement Process of the Microbubbles Fluid at Well VLA-1321.

In order to displace and drill the pay zone with the micro-bubble fluid, the following procedure was followed:

1. A 12 ¼" bit was lowered to float collar (5226'). The collar, cement and shoe (5268') were drilled with 9.4 ppg. Lignosulphonate. The hole was cleaned up to 5477'. It was circulated until clean returns were observed.
2. 100 barrels of viscous pill with yield point of >30lbs/100 ft^2 was pumped.

NOTE: This pill was prepared in the following manner:

- 2 lbs/barrel of xanthan gum.
- 4 lbs/barrel of starch.

3. The whole system was displaced by 8.1 ppg micro-bubble fluid.
4. The string was raised up to the shoe (5268') and the lines and tanks were washed.
5. The string was lowered once again to the bottom (5477'). The mud was circulated and conditioned with the aphronizer to lower the mud weight to 7.0 ppg.

NOTE: During displacement, there was contamination of the micro-bubble fluid with Lignosulphonate mud and an attack of bacteria arose, making it necessary to apply a severe treatment with bactericide.

Résumé of the Construction of Well VLA-1321.

22" Hole drilled to 1520'. 16" Casing cemented at 1515'.

14 ¾" hole drilled and later opened to 16" to 5477'. On lowering 13 3/8" casing, this could not go further than 5268'. At that depth it was cemented. 209' of the 16" hole could not be covered. In the zone of interest, a 12 ¼" bit was lowered to 5477' and lignosulphonate mud was replaced by 8.3 ppg Micro-bubbles mud. The mud was conditioned to 7.5 ppg and drilled down to 5564' (87').

A core cutter and 8 ½" crown was lowered and 390' of core was cut from 5564' to 5954', with a recovered length of 354.16' and a recovery percentage of 90.81%. These cores were 90' in the Miocene sands and the rest in the Eocene sands.

A 8 ½" bit was lowered to 5954' and drilled down to 6054' (100') with 7.2 ppg micro-bubbles mud. MSFL / HDIL / XMAZ-GR and MRIL / SL logs were run. The bottom was checked at 5977'. Cleaning trip was done. ZDEN /CN-DIEL / SL and STAR (CBIL) / SL logs were run.

12 ¼" bit was lowered and touched at 5311'. 8 ½" to 12 ¼" hole was opened up to 6064' with 6.8 ppg mud. Drilling was continued to 6236' at which debris formed a cave in and the circulation canal blocked with abundant cuttings. Drilling was stopped. Drill pipe was pulled to the 13 3/8" shoe (5268'). During the trip, drag of 60 Mlbs was observed at 6064' and 5964'. In both cases Kelly and pump were used. Once in the shoe, the flow lines, canals and seat traps were cleaned because of abundance of cuttings. The mud in the tanks was conditioned at 7.7 ppg and again the drill pipe was lowered to the bottom (6236'). Treatment to the system was circulated and carried out in order to maintain the range of the solids in conformity to the plan. 200 bls. of new mud was added to the system. Drilling was continued to 6855'(TD) with 7.9 ppg mud. A short trip was made, observing drag of 50 Mlbs at 6555'. Returned to the bottom and conditioned the mud. Pulled the string without any problem. Three log trips were run without cleaning trip (HDIL / GR /SP, density / neutron / dielectric / GR and FMT). Mud conditioning trip was done with 7.9 ppg mud.

9 5/8" casing was lowered and cemented without problems (shoe at: 6843'). (See figure 8)

Analysis of the Behavior of the Micro-Bubbles Fluid – Aphron During the Drilling of Well VLA-1321.

On analyzing the properties of the fluid in well VLA-1321 from 10-21-98 to 11-14-98 (25 days), it is observed that the fluid provided good hole stability, inhibition of shale, excellent hole cleaning and low filtrate loss. The weight could be controlled to values between (6.8 – 7.9) ppg. Besides, the system presented an excellent rheology and high viscosity at low shear rate (LSRV) which permitted drilling a hole with various diameter sections (16", 12 ¼" and 8 ½").

The fluid presented visco-elastic properties, that is; yield point and gels greater than the plastic viscosity.

Thus we have:

- The weight varied between (6.8 – 7.9) ppg.
- Plastic viscosity: (7 – 13) cps.
- Yield point: (46 – 61) pounds / 100 ft^2.
- LSRV varied between (48000 – 348000) cps.
- API Filtrate: (3.5 – 8.9) cc / 30 minutes.
- pH oscillated between 9.5 and 10.

Analysis of the Behavior of the Micro-Bubbles Fluid – Aphron During the Drilling of Wells VLA-1325, VLA-1326 and VLA-1327.

The mud density in wells VLA-1325, VLA-1326 AND VLA-1327 could be maintained in values between 7.4 ppg and 7.7 ppg without lost circulation problems or cave-ins in the hole. During the drilling of VLA-1326 certain drag was controlled by increasing the weight of 7.6 ppg to 7.7 ppg. This density control of the mud in a minimum range reduced the operational risks and products consumption.

The rheological properties such as the Yield Point (YP), the Plastic Viscosity (PV) and Gel Resistance did not indicate evident differences between one well and another. In the case of well VLA-1326 mud coming from well VLA-1327 was used. For the wells under study the Plastic viscosity varied between 10 – 12 cps. The Yield Point varied between 36 – 56 pounds/100 ft^2. The Gel resistance was between 28-32 lbs/100 fr^2. These values are characteristics of fluids with visco-elastic properties. The Brookfield viscosity (0.3 r.p.m.) oscillated between 45.000 and 97.000. In the case of well VLA-1326 the LSRV reached values of 36.000 cps, owing to the fact that it is recycled mud and maintaining it was difficult at the end of the drilling, because of the prolonged use of the mud while taking 411' of core.

The API filtrate rate in the first two wells was controlled between 3.5 – 6.8 cc/30 min., but in the last wells this value was higher (7.2-12) cc due to the fact that recycled mud was used. Other properties such as the MBT varied between 2.5 and 10.0 of clay content. The percentage of sand varied from traces to 0.75 and the pH which is a property of great importance between 9.0 and 10.2. These values are recommendable to avoid fractures in the polymer chain.

Analysis of the Behavior of the Micro-Bubbles Fluid – Aphron During the Drilling of Wells VLA-1329, VLA-1331, VLA-1332, VLA-1334 and VLA-1335.

With the use of micro-bubble fluid in these wells, the intermediate hole and the producing zone were jointly drilled, eliminating the use of the intermediate casing, resulting in a reduction in time of 31.0 days and savings of approximately 4.7 MMUS$. (See table 10).The density was maintained between 7.7 and 7.8 ppg.

Moreover, the intermediate hole was drilled with low density without any problem. In the offset wells, these formations used to be drilled with densities between 9.4 to 10.0 ppg., with many drag problems and instability due to swelling clay. This situation was not observed in the 5 drilled test wells.

The rheological properties such as the yield point (YP), the plastic viscosity (PV) and the gel resistance did not show evident differences to the previous wells drilled. The plastic viscosity varied between 9 – 14 cps. The yield point varied between (37 – 73) pounds/100p^2. The LSRV viscosity oscillated between 60000 to 144000 cps. The filtration rate was controlled between (7.5 – 9.0) cc/minute. The MBT was increased up to the values of 20.0 due to the massive incorporation of clay from the intermediate zone. The pH varied between (9.37 – 9.9).

Analysis of the Logs Run in the Wells.

In all the wells, the fluid permitted carrying out 3 log trips without a cleaning trip (see table 14). Another condition of demand resulted the core samples in wells VLA-1321 in which 390' were cut and 354.3′recovered (90.8%). In VLA-1325 68' of core were cut and 66.6' (90.8%) recovered. Finally in VLA-1326, 411' were cut and 371.6' recovered (90.4%). From the foregoing, 91.2% of recovery was obtained.

In wells: VLA-1321, VLA-1325, VLA-1326, VLA-1329, VLA-1331, VLA-1332 and VLA-1334, pressure logs were run (RFT).

In the case of Basal La Rosa sands, the pressures varied between 713 psi and 955 psi and in the Eocene sands, the pressure varied between 848 psi and 2563 psi.

The Caliper log of well VLA-1321 (See table 11) shows an average hole of 13 ½" which is 10.2% larger than the bit diameter of 12 ¼". In well VLA-1326 the caliper shows an average diameter of 7 7/8" and in the well VLA-1335 (See table 13) the hole diameter was exactly the diameter of the bit (7 7/8"). This is an indication of a hole in gage.

Analysis of the Mud Density with the Depth

With the objective of analyzing the behavior of the fluid density with the depth; with the RFT log, the density was verified at various depths in wells: VLA-1329, VLA-1331, VLA-1332 and VLA1334.

The results obtained indicate that the density in the hole varied between 8.6 ppg to 11.9 ppg despite the fact that on the surface, the mud weight determined by the conventional methods was 7.9 ppg (maximum) See Figure 9.

Results

- A sealing action of the micro-bubble fluid has been observed in conditions of differential pressure against the formation up to 2000 psi.
- The pressure measured at the Eocene level has been as low as 713 psi at 5629', equivalent to 2.4 ppg.
- The formation of the Aphrons depends on the appropriate operation in the mixing hopper, which should not have high back pressure. As far as possible, eliminate curves and shorten the distance between the hopper and the suction tank.
- Cavitation in the mud pumps was observed when air through a hose was supplied directly in the suction tank.
- The fluid density within the hole measured with the RFT is greater than that observed on the surface with the API conventional method.
- The density decreases while ascending from the bottom, corresponding to the expansion of the micro-bubbles with the hydrostatic pressure reduction.
- The increase in density observed near the surface, seems to indicate accumulation of debris or lack of circulation time to completely clean the annular space.
- The incorporation of natural clay to the mud, negatively affects its rheological properties and increases the use of additives which increases the cost, because the contaminated mud must be diluted or partially replaced.
- The optimum functioning of the solids control equipments, that includes a centrifuge to discard the low gravity solids (natural clay), is indispensable to maintain the costs of the mud.
- The cost per barrel of the Micro-bubbles fluid varied between 83.97 $/barrel to 155.34 $/barrel (see table 15 and 16).
- The average real production of these L.I.L. wells was 464 bpd vs. 350 bpd estimated (see table 17).
- The VLA-1321 well is injecting 1000 bpd of water in the C-4 and C-5 sands without presenting any operational problem.

Conclusions

- The micro-bubbles present in the fluid have acted as bridging materials, since they passed through zones of very low pressure with equivalent gradients varying between 2.4 ppg and 6.4 ppg, without presenting any lost circulation problem.
- The micro-bubbles system presented excellent inhibition values to the clays and shale.
- The fluid presented rheological properties that permitted drilling the wells with excellent hole cleaning.
- The fluid permits drilling the intermediate and production holes jointly, thus eliminating the use of a casing string.
- A better fluid response was observed, when the viscosity at low shear rate (LSRV) varied between values of 80000 and 120000 cps.
- The electric logs run were not affected by the micro-bubbles mud.
- It permits information: geological, petro-phisical and sample taking.
- The caliper logs showed a hole of excellent gage.
- It permitted increasing the cement slurry density from 11.5 to 12.5 ppg, improving the quality of the cement jobs and the interpretation of the cementation logs.
- The micro-bubble fluid is water-based, without any oil in its formulation; thereby providing a minimum environmental impact.

Acknowledgement

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3. Daily operational and mud reports of wells: VLA-1321, VLA-1325, VLA-1327. VLA-1326, VLA-1329, VLA-1331, VLA-1332, VLA-1334 and VLA-1335.

Appendix

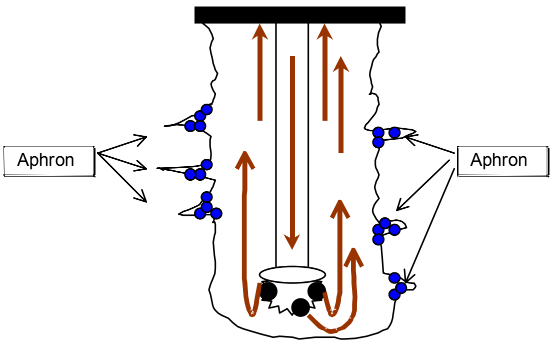

Figure 1 – Bridging Mechanism with Microbubble

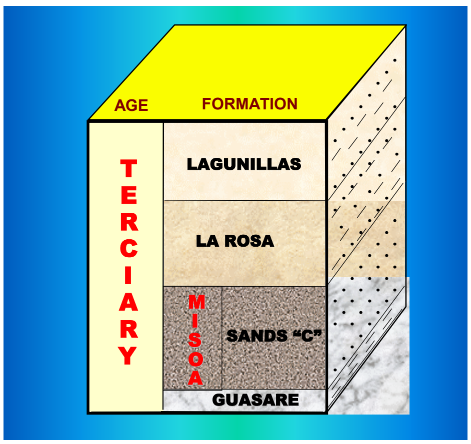

Figure 2 -Lithological Column of Block-1

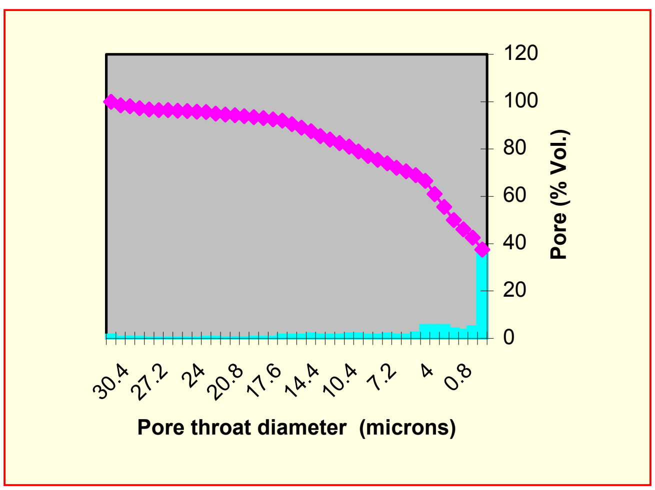

Figure 3 - Distribution of Pore Size

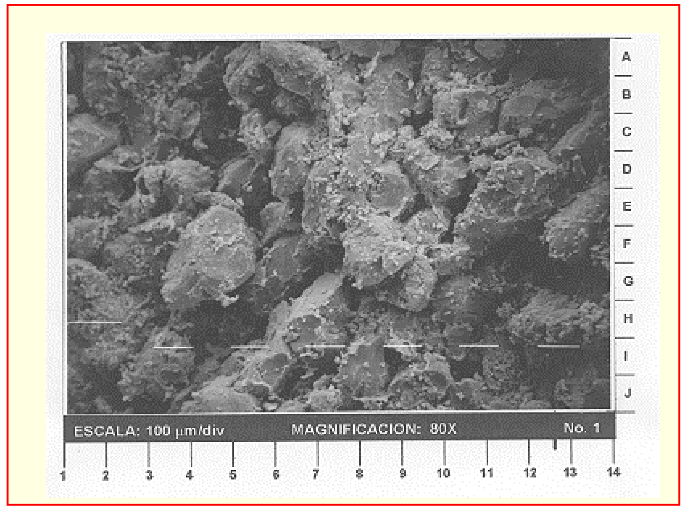

Figure 4 - Microphotography of the Nucleus. Depth: 6180'

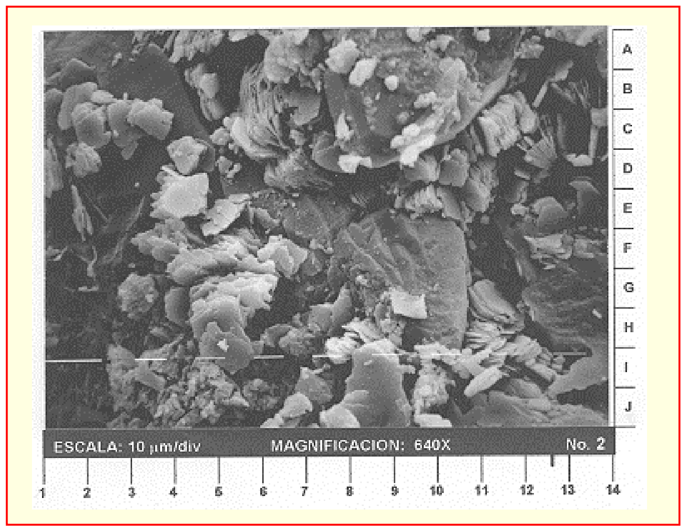

Figure 5 - Microphotography: Caolinite Clay

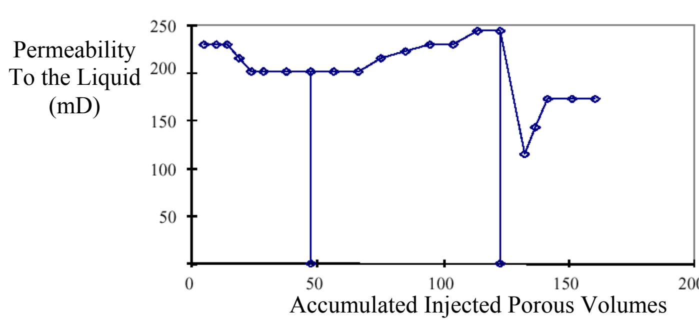

Figure 6 - Permeability Return

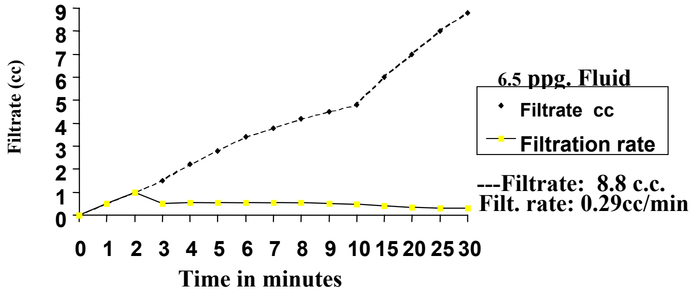

Figure 7 - Plugging Tests per Particles

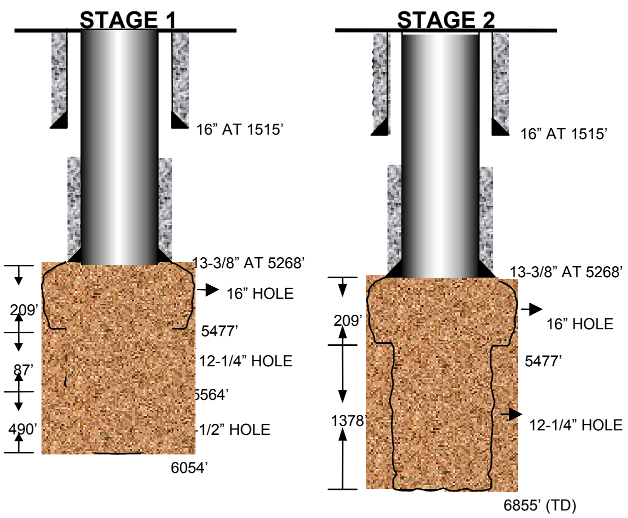

Figure 8 - Drilling of Well VLA 1321

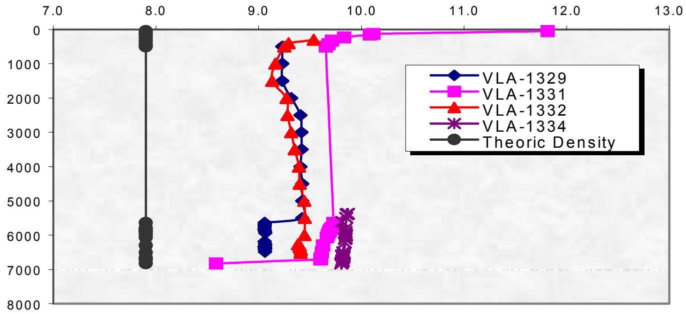

Figure 9 - Mud Density Vs Depth

Table 1 – Basic Data of the Test

1.	WELL	VLA-765
2.	WATER	2% KCI
3.	TEMPERATURE	180 F
4.	OVERLOAD PRESSURE.	4000 psi
5.	FORMATION PRESSURE.	1000 PSI.
6.	DEPTH.	6180 FEET.
7.	DRILLING FLUID.	Micro-bubbles
8.	DENSITY.	6.4 LPG.
9.	HYDROSTATIC COLUMN.	2056 psi.
10.	CRUDE.	VLA-879
11.	NUCLEUS:	Sample #1.
	Porosity	27%
	Permeability	950 Md.

Table 2 - Compatability Tests Results

WELL CRUDE	RELATION		SEPARATION	TIME	EMULSION
	MUD %	CRUDE %	%	MIN.	%
VLA-876	50	50	100	5	0
VLA-1283	50	50	100	5	0

Table 3 - Mineralogical Composition

Composition	Content (%)
Quartz	92
Albita	2
Ortosa	-
Calcite	-
Siderite	
Clay	6
Solubility in Acids	
HCL (15%)	RMA
3%	5%

Table 4 - Results of the Dynamic Filtration

PPT, cc	26,8
SPURT, cc	1,2
FILTRATE, cc	12,8

Table 5 - Formulation of the Micro-Bubble Fluid

PRODUCTS	CONCETRATION	FUNCTION
Biopolymer Blend	5lbs/barrel	Viscous properties
Shale/Clay inhibitor	0.1% V/V	Inhibitor
Polymer blend	5lbs/barrel	Thermal Stability/filtration control
PH Buffer	0.5 lb./barrel	PH control
Aphronizer	1.0 lb./barrel	Aphron Generator
Biocide	0.05 lb./barrel	Bactericide
Pasivator	0.05 lb./barrel	Antifoam

Table 6 - Brookfield Viscosimeter Results

Reading at 60 rpm	1848 cps.	Reading at 3 rpm	24680 cps.
Reading at 30 rpm	3321 cps	Reading at 1.5 rpm	44880 cps.
Reading at 12 rpm	7430 cps	Reading at 0.6 rpm	96600 cps.
Reading at 6 rpm	13760 cps	Reading at 0.3 rpm	168800 cps

Table 7 - Rheology with Conventional Viscosimeter

Weight	< 6.0 ppg /6.4 ppg after pressurizing
Viscosity @ 120F	
Reading at 600 rpm	68
Reading at 300 rpm	59
Reading at 200 rpm	54
Reading at 100 rpm	49
Reading at 6 rpm	32
Reading at 3 rpm	28
Plastic Viscosity	9 cps
Yield point	50 lbs/100 p^2
Gels	30/39 lbs/100 p^2
pH	9.62

Table 8 - Results of the Fann 70 at Variable Temperature and Pressure

Temperature, F	100	150	200
Pressure, psi	500	750	1000
Reading at 600 rpm	89.2	82.2	79.2
Reading at 300 rpm	73.2	69.2	67.2
Reading at 200 rpm	66.2	64.2	67.2
Reading at 100 rpm	61.2	57.2	55.2
Reading at 6 rpm	39.7	33.4	32.3
Reading at 3 rpm	39.7	32.4	28.1
Viscosity, cps	16	17	12
Yield Point	57	52	55
Tau 0	39.7	31.6	23.9

Table 9 - Preparation of the System.

ADDITIVES	QUANTITY	MIXING TIME
1. Fresh water	400 Bls.	-
2. Shale/Clay inhibitor	4 Kegs	1 minute/keg
3. Biopolymer blend	60 sacks	4 minutes/sack
4. Polymer blend	40 sacks	4 minutes/sack
5. Biocide	4 units	1 minute/unit

Table 10 - Cost of the Wells of Lagomar Project (2 Casings)

	COSTS (MMUS$)		TIME (DAYS)	
WELL	ESTIMATE	REALITY	ESTIMATE	REALITY
VLA-1329	2.4	1.3	21.7	16.8
VLA-1331	2.4	1.6	22.7	17.1
VLA-1332	2.4	1.6	22.0	15.75
VLA1335	2.7	1.3	22.0	12.4
VLA-1334	2.0	1.4	20.0	14.6
TOTAL	11.9	7.2	107.7	76.65

Note: 550Bs./$ (year 1998).

Table 11 - Analysis of Caliper logs

WELL: VLA-1321		WELL: VLA-1326	
DEPTH (Feet.)	**Average Diameter (inches)**	**DEPTH (Feet.)**	**Average Diameter (inches)**
5750 – 5800	14 ¼	5600 – 5650	8 ½
5800 – 5850	14	5650 – 5700	7 ¾
5850 – 5900	14	5700 – 5800	8 ¼
5900 – 5950	12 ½	5800 – 5900	8 ¼
5950 – 6000	13 ½	5900 – 5950	8 ¼
6000 – 6050	13 ¾	5950 – 6000	8 ½
6050 – 6100	13 ¾	6000 – 6100	8 ½
6100 – 6150	12 ¼	6100 – 6150	13
6150 – 6200	12 ¼	6150 – 6200	8 ½
6200 – 6250	12 ¼	6200 – 6250	8 ½
6250 – 6300	12 ¼	6250 – 6300	8 ½
6350 – 6400	12 ¼	6300 – 6350	8 ¼
6400 – 6500	12 ¼	6350 – 6400	8 ¼
6500 – 6800	12 ¼	6400 – 6440	8
Average Diameter of Hole 13-1/2”		**Average Diameter of Hole 8 2/3”**	
Length of the hole: 1050’		**Length of the hole: 840’**	

Table 12 - Analysis of Caliper logs

WELL: VLA-1329	
DEPTH (Feet.)	**Average Diameter (inches)**
5400 – 5450	7 ¼
5450 – 5500	7 ½
5500 – 5550	7 ½
5550 – 5600	7 ¼
5600 – 5650	7
5650 – 5700	6 ¾
5700 – 5800	6 ¾
5800 – 5900	6 ¾
5900 – 6000	6 ¾
6000 – 6100	6 ¾
6100 – 6200	6 ¾
6200 – 6300	6 ¾
6300 – 6400	6 ¾
6400 – 6500	6 ¾
6500 – 6600	6 ¾
6600 – 6700	6 ¾
6700 – 6750	6 ¾
6750 – 6780	6 ¾
6780 – 6790	6 ½
6790 - 6800	5 ¾
Average Diameter of Hole 6 5/6”	
Length of the hole: 1400’	

Table 13 - Analysis of Caliper logs

WELL: VLA-1334		WELL: VLA-1335	
DEPTH (Feet.)	**Average Diameter (inches)**	**DEPTH (Feet.)**	**Average Diameter (inches)**
4950 – 5210	7-7/8	5200 – 5260	7 ¾
5210 – 5235	8 ½	5260 – 5280	7 ½
5232- 5250	7-7/8	5280 – 5300	7
5250 – 5270	9	5300 – 5380	7 ½
5270 – 5280	8 ½	5380 – 5520	7 7/8
5280 – 5336	7-7/8	5520 – 5650	8 ¼
5336 – 5362	8 ½	5650 – 5800	7 7/8
5362 – 5396	7-7/8	5800 – 5850	8
5396 – 5440	8 ¼	5850 – 5900	8 1/8
5440 – 5550	8	5900 – 6790	7- 7/84
5550 – 6870	7-7/8	_	_
6870 – 6930	7	_	_
Average Diameter of Hole 8 1/11”		**Average Diameter of Hole 7 7/78”**	
Length of the hole: 1970’		**Length of the hole: 1590’**	

Table 14 - Logging time in the L.I.L . wells

WELL	TIME (HOURS)
VLA-1321	69.9
VLA-1325	51.5
VLA1326	66.5
VLA-1327	23.0
VLA-1329	42.0
VLA-1332	40.5

Table 15 - Cost per barrel of the Micro-Bubble Fluid

Well	Mud Volume Handled (Barrels)	Cost per Barrel	
		Bs. / Barrel	**$ / Barrel**
VLA-1321	2368	68459,67	124,47
VLA-1325	945	64069,86	116,49
VLA-1327	944	67325,11	122,41
VLA-1236	1690	50318,06	91,49
VLA-1329	1362	69876,06	127,05
VLA-1331	1930	63469,53	110,00
VLA-1332	1530	89607,84	155,34
VLA-1334	1657	58720,58	101,78
VLA-1335	2281	48443,66	83,97

Table 16 - Cost Per Foot of the drilled Interval

WELL	INTERVAL (FEET)	FEET DRILLED	COST PER FOOT	
			Bs. / Foot	$ / Foot
VLA-1321	5477 – 6843	1366	118676,83	215,78
VLA-1325	5605 – 6450	845	71652,09	130,28
VLA-1327	5800 – 6135	335	189716,13	344,94
VLA-1236	5600 – 6604	1004	84698,73	153,99
VLA-1329	4000 – 6805	2805	33929,18	61,69
VLA-1331	4020 – 6930	2910	42096,22	72,95
VLA-1332	3680 – 6790	3110	44083,60	76,42
VLA-1334	3755 – 6990	3235	30077,28	52,13
VLA-1335	4000 – 6860	2860	38636,36	66,98

Table 17 - Real production of the L.I.L. wells

WELL	BPD
VLA-1325	360
VLA1326	544
VLA-1327	443
VLA-1331	493
VLA-1332	438
VLA-1335	507