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Title: Innovative technology improves lubricity in high performance water base mud systems: field application in a challenging HP/HT environment

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Abstract:

This paper describes the use of an innovative high-performance water based drilling fluid system in south Europe. This fluid had been previously used only once in Europe. These wells represent the first applications in worldwide drilling operations outside the United States. The novel drilling fluid has successfully drilled a reentry well for a sidetrack of a deep high pressure high temperature (HPHT) well originally drilled in 1989. Starting from 1998 only low toxicity oil based drilling fluids were used in this area due to the adverse drilling conditions.

Comprehensive laboratory testing carried out during the well planning phase was complimented by further testing conducted during drilling operations. One obvious advantage of this system is its simplicity. It's composed mostly of liquid additives allowing quick and easy rig site preparation. The system is also compatible with the full range of mud densities while exhibiting consistently superior lubricity characteristics.

A tailored version of the system for this sidetrack well in southern Europe required a heavy weighted fluid (up to 2.06 SG) to provide sufficient hydrostatic pressure for well control. The formulation included a high temperature rheology modifier that improved fluid stability at temperatures up to 160°C at total depth.

A high performance lubricant was added to the system to improve drilling rate while using an advanced steerable drilling system. Lubricity coefficients were monitored and recorded daily at the rig site using a standard industry accepted ring and block type lubricity tester with results that improved on values obtained from offset wells in the area. The lubricity values fell in the range traditionally associated with oil base mud usage. The successful sidetrack operations were completed without incident.

Introduction

The well discussed in this article has been drilled as a sidetrack from an existing well (originally drilled in 1989) in southern Europe. The reservoir has two main hydrocarbon zones, an upper reservoir and lower reservoir.

The upper reservoir, the sidetrack objective, is an isolated fault block associated with the West Area of the field. A series of tectonic discontinuities creates a series of faults that potentially result in isolated portions of the reservoir that remain undrained by previous production operations. The reservoir rock is characterized by white light brown dolomite of Triassic age, recognized by a limestone cap rock above a shale marker.

With the target reservoir between 5500 m and 6000 m in an area with high thermal gradients and elevated formation pressures, a 160°C temperature and over 1000 kg/cm² pressure at total depth was anticipated. Historically, these well conditions in combination with the hard formations and high tectonic stresses have resulted in difficult drilling conditions including high torque, low rate of penetration (ROP) and wellbore instability.

Sidetrack Well Design

Planned as a sidetrack from the 7 in production casing of the original well (see Figure 1), the slim hole design called for side tracking from a whipstock and casing exit at 4800 m and drilling to the top of the reservoir at 5632 m using a 5-3/4 in hole size. A 5 in liner was planned to 5492 m TVD / 5632 m MD and a 4-1/8 in hole was planned to 5541 m TVD / 5753 m MD. The well was to be completed as an open hole producer. The wellbore schematic for the sidetrack is shown in Figure 2.

The directional plan was developed to access the isolated fault block and requires two 3°/30 m build sections. The first build section is from 4800 m to 5189 m to an inclination of 39° and another build section from 5442m to 5556 m to a final inclination of 60°. The final angle of 60° was to be held to total depth. This results in a vertical section of approximately 600 m. The expected torque and drag from this directional plan is modest compared to the more aggressive well plans typical of today's horizontal wells.

The rig chosen for the project was a 3000 horsepower conventional deep well rig with top drive, three 1600 horsepower high pressure fluid pumps, and a full complement of solids control equipment.

Given the critical nature of the well, detailed analysis of the casing loads for all possible drilling and production scenarios was conducted to ensure that casing and wellbore integrity was preserved under all possible conditions. The existing 7 in 38 lb/ft production casing was to be logged and tested to confirm its integrity. Well control equipment included a 10K psi Annular and 15K psi Rams in a standard HPHT configuration.

The drilling plan included 87.84 days allocated to drill the 5-3/4 in hole section and 28.83 days to drill the 4-1/8 in hole section. This drilling rate was based on the experience in the area from the wells drilled using low toxicity mineral oil base mud in combination with turbine or mud motors.

Since the design of the drilling fluid is critical to the well success, it is discussed at length in the next sections with a short history of the fluid practices previously used in the area.

Historical Drilling Fluid Practices

In the last twenty years, the deeper sections of the wells in this area have been drilled with invert emulsion low toxicity oil based muds (LT-OBM) using paraffin hydrocarbons as base fluid. This solution minimized the issues associated with old technology water based fluid. These water based fluids were not stable and required continuous reconditioning and dilution. The associated costs from additives required by the high dilution rates and environmental disposal charges could be reduced by the adoption of a more stable drilling fluid. In this way, the use of LT-OBM considerably simplified the operations, thanks to its stability under high bottom hole temperatures at high densities.

In this field, the specific gravities (SG) of the muds employed varies between 1,95 and 2,15. The geometry of the wells and the nature of the formations created torque and drag issues, with high risk of stuck pipe and hole instability when water mud was used. The adoption of LT-OBMs reduced these problems due to their inherent stability and lubricity. One area where the LT-OBM does not perform well is when lost circulation issues develop. Although the cost of the operations decreased thanks to the higher ROP and the lower quantities of mud to discharge, the cuttings needed expensive treatments before disposal, so the waste management costs and the environmental impact increased considerably.

High Performance Drilling Fluid Selection

In order to reduce the environmental impact of LT-OBM usage from the operator, it was planned to use more environmentally friendly alternative. The technical solution proposed is a next generation high performance water based drilling fluid (HPWBM) based on fresh water with similar benefits that were obtained from the use of the LT-OBM in previous wells.

As would be expected, a program to qualify the potential fluid was established and executed. For the validation of the fluid, laboratory tests were performed with a review of applicable well histories. Most critical is stable viscosity under the complete range of conditions expected in the well. Drilling operations in the sidetrack well relied on consistent viscosity at temperatures up to 180°C with pressure exceeding 1000 kg/cm² at fluid densities of over 2,00 SG. Fluid exposure time to these conditions can be for several days under static conditions, so the fluid components must remain effective and not degrade with time. The laboratory evaluation

utilized hot rolling and static aging tests of up to 72 hr at 180°C to demonstrate the performance of the fluid using the proposed formulations. Additionally, the HPHT rheological properties were tested under downhole conditions that provided the necessary information to calculate hydraulic parameters associated with circulating the fluid and the effective removal of drill cuttings. Sag of the weighting material has long been an issue in non-aqueous fluids like the LT-OBM used previously in the field^{2,3}. Historically, it has not been a major issue with water based drilling fluids. This was confirmed using testing conducted with a state of the art sag testing instrument⁴.

While laboratory results that demonstrate the HPWBM properties are needed, just as important is proof that the fluid has performed in field operations. The HPWBM selected has been used extensively in North America in land based operations in all the major drilling areas. The area with well conditions closest to this sidetrack is the Haynesville shale of east Texas and north Louisiana in the United States⁵. Additionally, since the Haynesville experience includes horizontal wells averaging over 1500 m lateral length, torque and drag performance can be compared to that experienced in this highly deviated slim hole sidetrack.

After the successful laboratory evaluation and confirmation of the HPWBM performance in field operations, the fluid was selected for this HPHT sidetrack well. In the next sections, the fluid formulation and treating strategy are discussed. As with many applications of the fluid, some customization is required to meet local conditions.

Fluid Formulation

The HPWBM system typically consists of three liquid products and an optional HTHP rheology modifier:

- A synthetic polymer that acts as a primary viscosifier and secondarily as filtrate reducer and coating agent. The polymer is dispersed in an organic carrier and mixes easily even in colder fluids.
- A performance enhancing HTHP lubricant blend that combines effective coefficient of friction (CoF) reduction with thermal stability above 200°C.
- A surfactant wetting agent that ensures that weight material is properly water wet under all conditions, especially at higher temperatures.
- Optional rheology modifier that increases the low shear viscosity at temperatures above 135°C.

The main characteristics of the system are:

- ✓ Water based fluid with low environmental impact (fresh water make up was chosen for this application, but brines have also been used successfully in appropriate situations)
- ✓ Clay free system that avoids the instability associated with clay based fluids
- ✓ Thermal stability to above 220°C
- ✓ Minimal number of products that result in ease of preparation
- ✓ Low thixotropic properties even after long static periods at high temperature

- ✓ Inherently low friction coefficient
- ✓ Unique for a WBM it maintains resistance to contamination from solids and CO₂
- ✓ Ease of storage and reuse

As stated earlier, before use in south Europe, the system has been used to drill under widely different conditions, including HPHT using high mud densities. In every application the system has delivered exceptional performances while minimizing drilling time.

A typical high temperature formulation at 1,85 SG consists of:

Synthetic viscosifier	6 - 12 kg/m ³
Caustic soda	For pH 9,5 - 10,5
Conditioner	3 - 4 kg/m ³
HTHP Lubricant	1 - 2 vol% (8 - 16 kg/m ³)
Barite	1100 kg/m ³
Rheology modifier	2 - 4 kg/m ³

The formulation used for the side track of the well was modified to minimize the lubricant concentration because the sidetrack well did not require the low CoF needed in a horizontal application. Also, the HPHT filtrate needed to be reduced from the typical values for the system. This was accomplished by the addition of a high temperature polymer specifically designed for that purpose⁶ at a concentration of 3 - 7 kg/m³.

Drilling Results

The well was successfully sidetracked at a depth of 4699 m and drilling the 5-3/4 in hole proceeded to the 5 in liner point at 5573 m in 47,71 days compared to the planned 87,84 days (including contingency). Measurement while drilling failure and directional issues caused several unplanned trips that resulted in the extra days for this hole section with a corresponding NPT equal to 19,96 days. The rate of penetration (ROP) for this section was 3,1 m/h versus 0,8 m/hr planned. After setting the 5 in liner, drilling then proceeded for the 4-1/8 in hole to a total depth of 5763 m in 34,31 days including 2 stuck pipe (differential) compared to the planned 28,83 days with ROP equal to 1,6 m/hr versus 0,8 m/hr planned. Overall, the drilling time on the well was 82,02 days compared to the planned 116,67 days, a reduction of 34,65 days from planned.

The cost estimation for the drilling phases is:

	AFE	FIELD EST.	AFE vs FIELD - AFE
5 3/4"	10,7mil	6,9mil	- 35%
4 1/8"	4,4mil	4,7mil	+ 6%

Torque values were low for both hole sections varying in the range of 350 - 550 kg-m. With a vertical section less than 600 m and a maximum angle of 48°, lowering the lubricity CoF of the mud below 0.10 was not critical to the well success and the performance enhancing additive was used as required for drilling rate⁷. So the lubricity of the fluid was monitored regularly onsite and remained at 0.12 to 0.14, well below the value of 0.22 - 0.28 typical for a water mud of this density⁸. Some torque spikes were seen while reaming. These spikes were associated with formation changes in particular the formation identified as Marl of Bruntino. Moreover, there was no evidence of overtorque and overpull due to the hole geometry and no extra circulations were required to clean the hole.

Comparing the average rates of penetration in the different lithologies encountered illustrates the improved performance of the drilling fluid, bit, and drilling system compared to two offset wells (see Figure 3). It is useful to remember that the offset wells were drilled vertically without directional control. This suggests that the combination of the drilling fluid and modern drilling tools (compared to the late 1980s) resulted in big improvements in rate of penetration that resulted in reduced drilling time for the sidetrack compared to the results of the original well bores.

During the drilling of the sidetrack oftentimes the drilling rate was controlled to values less than the maximum possible. This was done for a number of reasons including the need to identify the changes in lithology from cuttings at the surface and the implementation of the directional plan. For this reason, the values for rate of penetration in future wells could likely be much higher if these limitations could be overcome.

Despite the higher volume disposed in this well compared to a similar well in the same area drilled with LT-OBM; the relative costs are comparable (around 5 % higher). In addition the environmental impact was significantly reduced with no dangerous wastes produced. .

Drilling Fluid Properties

Bottom hole temperature (BHT) was between 155°C and 165°C based on the readings from the measurement while drilling (MWD) tools. At these temperatures, the mud components did not undergo any thermal degradation and the mud remained stable with minimal dilution. The mud properties were maintained as specified with rheological values appropriate to the hole size. The rheology also allowed the equivalent circulating density (ECD) and surge/swab pressures to remain well below the fracture gradient. This prevented any lost circulation from occurring.

The average mud composition, properties and drilling parameters in the different sections are shown in Table 2. Regular samples of the mud were taken to the laboratory in Rome and evaluated for HPHT viscosity and to confirm the onsite properties. A typical HPHT rheological profile is shown in Table 3 and Figure 4.

In addition to the HPHT rheological properties, static aging at bottom hole temperature was used to confirm that barite sag was not occurring. Even in static conditions for more than 72 hours, no sagging of barite occurred.

Conclusions

A successful first-time application of a next generation high performance water-based drilling fluid in HPHT conditions has been reported. The fluid successfully sidetracked a well previously drilled with low toxic oil base mud in the late 1980s. This slim hole sidetrack included two hole sections of 5 3/4 in and 4 1/8 in for a total drilled interval of 1064 m. The combination of stable properties and lubricity comparable to an OBM at downhole conditions up to 165°C and dramatically increased drilling rate resulted in successfully reaching total depth in fewer drilling days than planned. This has shown that this fluid can be used to successfully replace the low toxicity oil base mud used previously in this HPHT field.

Appendices

Tables & Figures

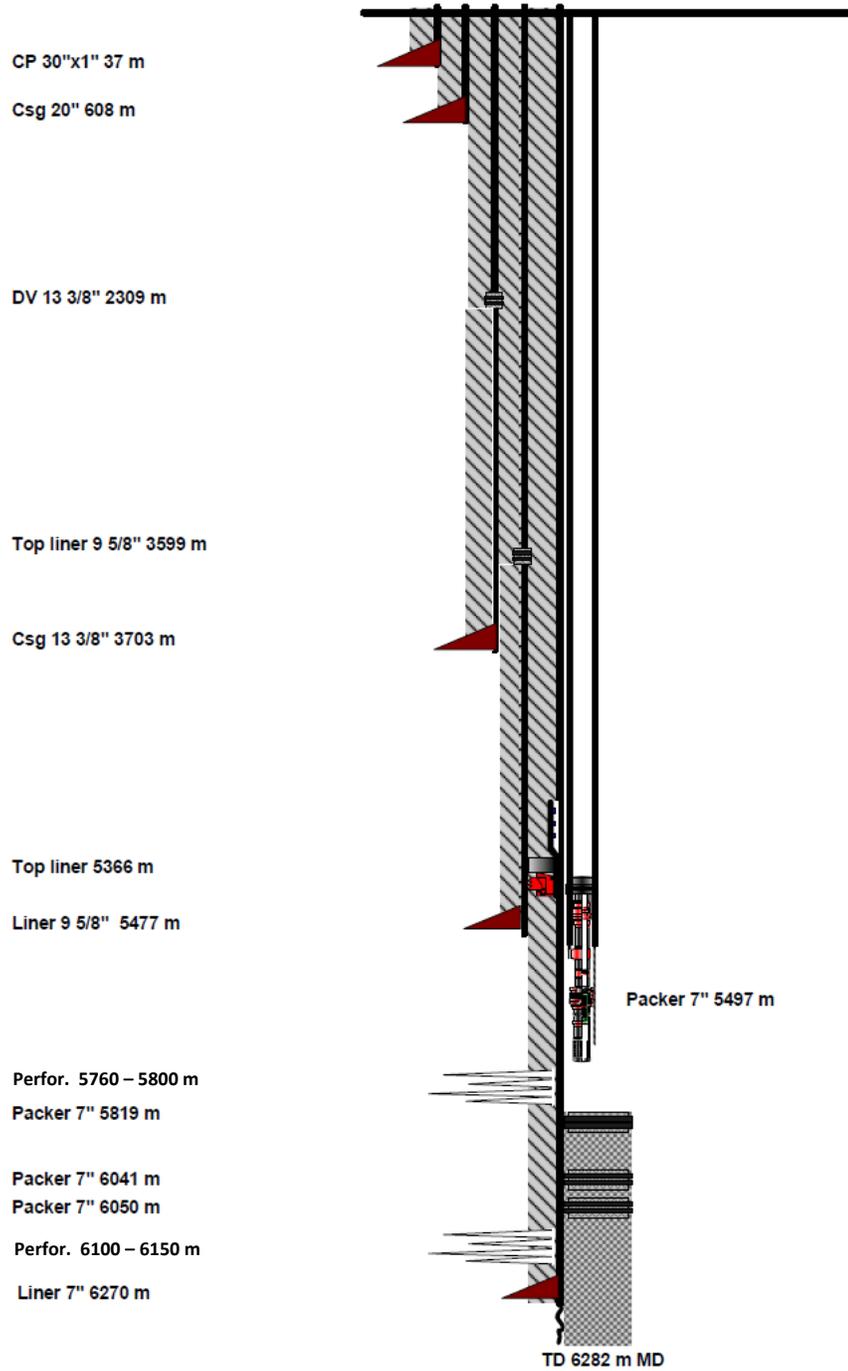


Figure 1 - Original Wellbore Schematic

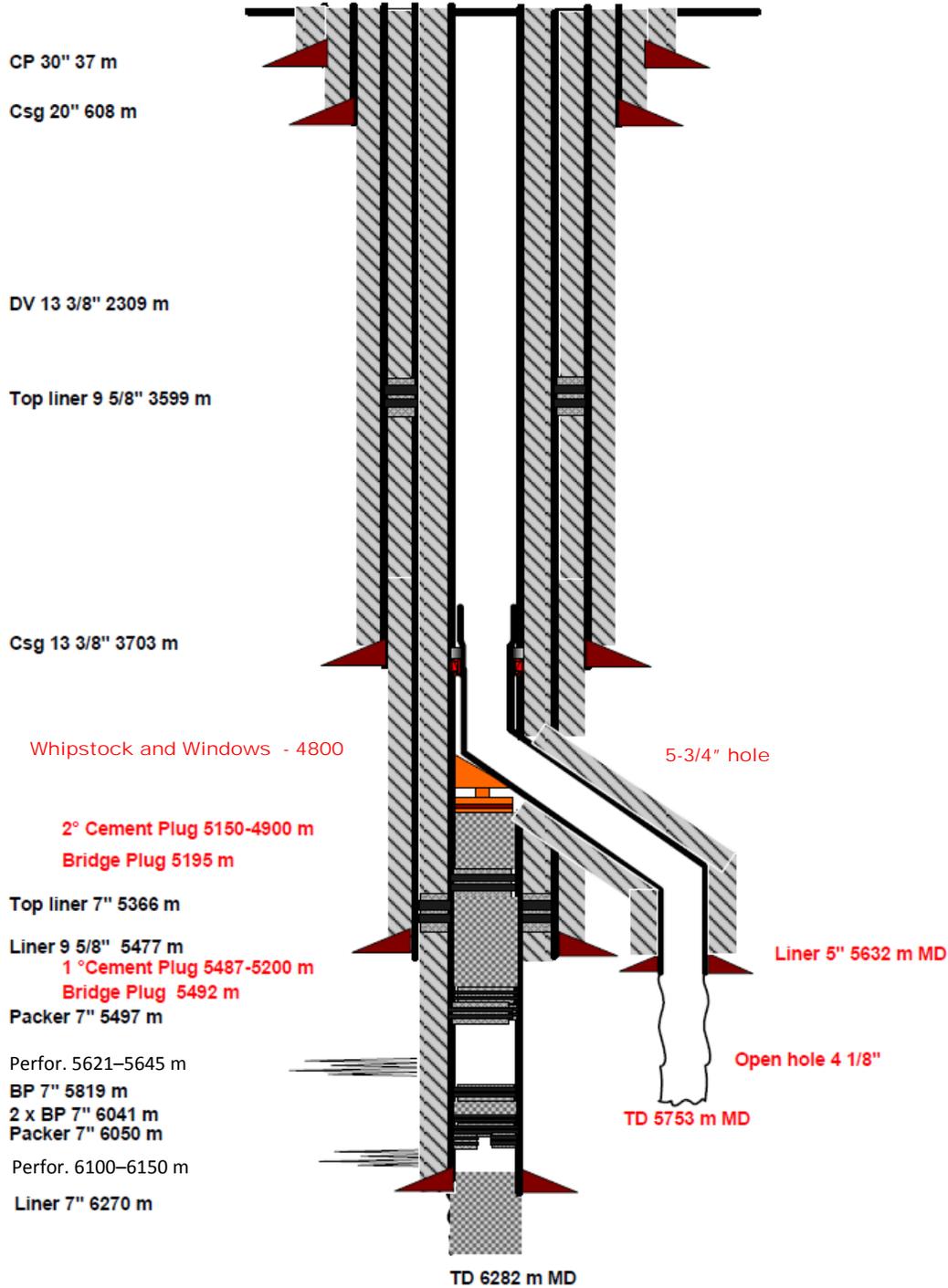


Figure 2 - Proposed Sidetrack Schematic

Lithology	Average ROP (m/h)		
	HPWBM	LT-OBM Well 1	LT-OBM Well 2
Limestone	3,5	1,3	3,3
Marl	3,1	1,6	0,8
Clay	4,0	2,2	0,7

Table 1 - Comparison of average rates of penetration for different lithologies

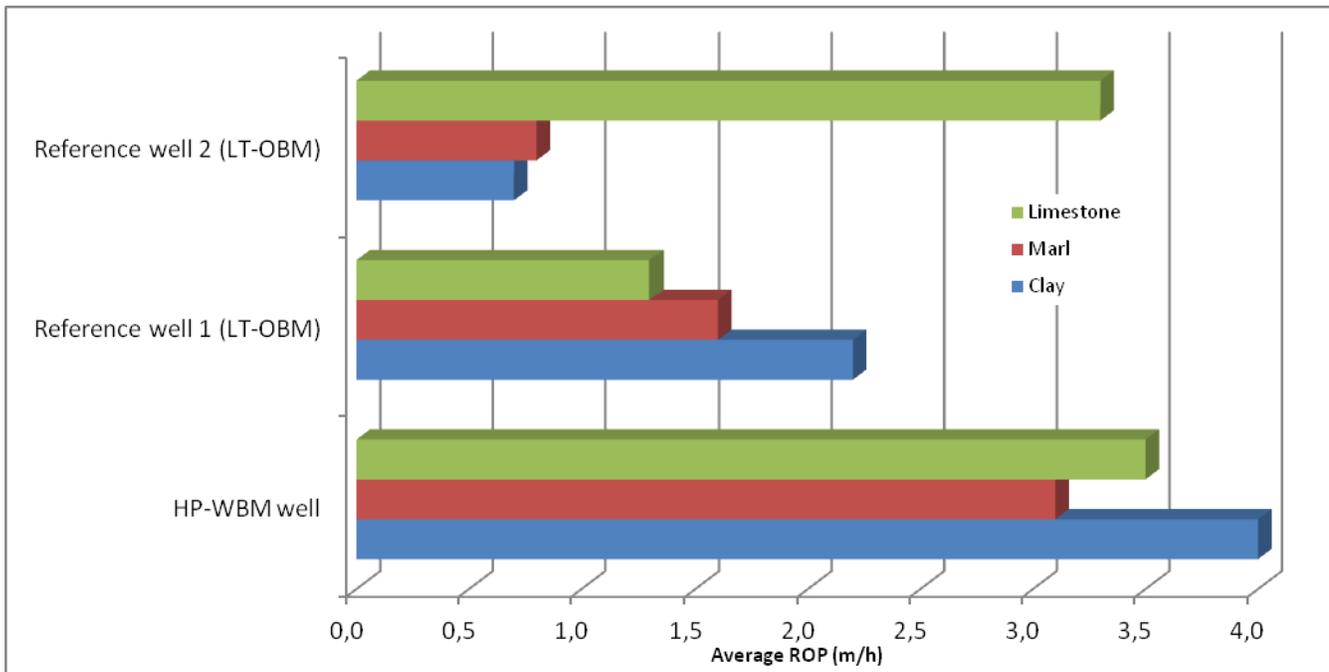


Figure 3 - Comparison plot of average rate of penetration

		5-3/4" section	4-1/8" section
Products		4699-5573 m kg/m ³	5573-5763 m kg/m ³
Caustic soda		2,4	2,3
Soda ash		3,6	3,4
Synthetic viscosifier		8,9	4,7
HTHP Lubricant		2,3	5,0
Rheology modifier		3,8	0,4
Conditioner		1,6	0,7
Defoamer		3,8	3,4
HTHP Filtrate reducer		3,7	7,8
Barite		1464	1379
Mud parameters	Unit		
Density	kg/l	1,82 - 2,05	2,00
Marsh Viscosity	sec/l	54 - 84	68
PV	cP	34 - 50	39
YP	g/100cm ²	6,5 - 10	9
Gels 10"/10'	g/100cm ²	2 - 2,5 / 3 - 3,5	2 / 4
API Filtrate	cc	2 / 4	1
pH	-	8,5 - 8,9	8,8
Pm	cc H ₂ SO ₄	0,4 - 1	-
Pf	cc H ₂ SO ₄	0,3 - 1,3	-
Mf	cc H ₂ SO ₄	3,1 - 6,3	-
Solids	%	27 - 34	34
MBT	Kg/m ³	10 / 18	16
Physical parameters	Unit		
Average torque	Kg*m	310 - 320	330 - 390
Average lubricity coefficient	-	0,13	0,14
Average ROP	m/h	3,5	4,0

Table 2 - Composition, fluid properties, and parameters by hole section

Parameter	50 °C 1 kg/cm ²	90 °C 1 kg/cm ²	90 °C 1055 kg/cm ²	160 °C 1055 kg/cm ²
600 rpm	108	66	111	59
300 rpm	67	41	69	37
200 rpm	49	29	49	28
100 rpm	29	19	32	24
6 rpm	6	5	8	8
3 rpm	5	3	5	6
Gels 10" (g/100cm²)	2.9	6	6	8
PV, cP	41	25	42	22
YP (g/100cm²)	12.7	7.8	13.2	7.4

Table 3 - Typical HPHT rheological properties

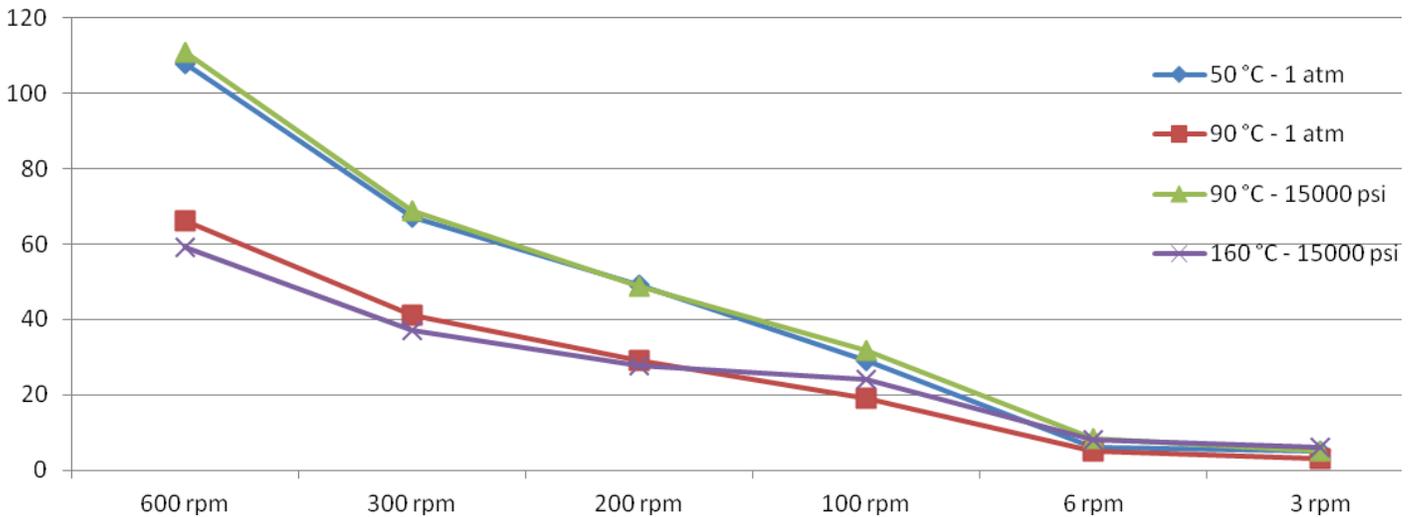


Figure 4 - Typical HPHT rheological properties

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