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Development and Learning Process Using a New HPWBM on Gulf of Mexico Shelf Wells

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Abstract

A new high-performance water-based mud (HPWBM) system has been successfully used by ChevronTexaco as an environmentally compliant alternative to non-aqueous fluids (NAF) on shelf wells drilled in the Gulf of Mexico. Mud system selection on these wells was previously based on compliance to environmental regulations and satisfaction of technical criteria. However, a proactive initiative was undertaken by ChevronTexaco to raise environmental compliance to new levels without sacrificing drilling performance. The risks involved in replacing a technically competent NAF system on these technically challenging and demanding wells were not trivial. It was felt that these risks could be mitigated by use of the HPWBM.

The system was used to drill wells on the Eastern and Western Shelf of the Gulf of Mexico. This paper will describe the evolution of the HPWBM through a process of lessons learned, best practices and engineering modifications in the system. Through this process of continual improvement, the system has become a technically competent and environmentally acceptable alternative to NAF.

Introduction

The cost and degree of difficulty of shelf wells drilled in the Gulf of Mexico has increased. Development operations continue on the shelf as the economics of exploring and producing for oil and gas have improved with advancements in drilling technology. Advanced drilling technologies such as rotary stearable assemblies, logging-while-drilling (LWD) tools, annular pressure subs and new bit designs have improved the economics of shelf drilling operations. With consideration to reducing drilling problems such as torque and drag, stuck pipe, low rates-of-penetration, depleted sands and well bore stability, these wells have generally been drilled with NAF.

The requirements for managing environmental waste are becoming stricter in the United States. Environmental legislation is continually restricting the discharge limits of spent muds and drilled cuttings. Operators are challenged with achieving a balance between minimizing the potential environmental impact of the drilling fluid against project objectives. The cost of waste management is more than just the cost of collecting and disposing of waste streams and operators must consider the long-term liability of environmental and waste management decisions.

The inherent advantages provided by NAF are increasingly being offset by environmental risks and liabilities. Because of this, ChevronTexaco has placed a great deal of importance on evaluating environmentally compliant HPWBM alternatives to NAF.

Environmental Drivers

Beginning in the late 1970's it became evident that waste discharges from drilling operations could have undesirable effects on the marine ecology.[1] The environmental impact of discharging cuttings and spent water-based mud (WBM) was minimal, however, the waste from NAF created impaired zones in the proximity of drilling operations. The United States Environmental Protection Agency (EPA) adopted national discharge standards for the oil and gas industries in 1993 that established restriction on oily sheens and aquatic toxicity testing for waste discharges.

Operators have used a variety of methods for managing drilling wastes, typically driven by governmental regulations and cost considerations. Three options exist to manage offshore wastes from drilled cuttings and spent drilling fluid: marine discharge, down hole injection, and onshore disposal.[2] All options have advantages and disadvantages with regard to total life cycle environmental impact, safety, cost, and operational performance.

Currently, most synthetic-based mud (SBM) drilled cuttings can be discharged into the Gulf of Mexico, however, SBM whole mud discharge is not allowed. WBM whole mud and cuttings can be discharged provided the fluid meets the aquatic toxicity standards set by the EPA. From an environmental perspective, the worst case is oil-based mud (OBM). Wells using OBM are categorized as “zero discharge” and there can be no discharge of cuttings or whole mud into marine waters. All OBM-contaminated waste must be transported onshore for disposal or be injected underground at the well site.

ChevronTexaco took a proactive approach towards raising environmental standards to new levels by replacing a technically competent NAF system with the new HPWBM on select shelf wells. The HPWBM fully satisfies environmental requirements for use in the Gulf of Mexico and is permitted for discharge of whole mud and drilled cuttings. Use of the HPWBM ideally eliminates waste management infrastructure, equipment and testing costs associated with NAF.

First Generation HPWBM

Initially, the HPWBM design focused primarily on pore pressure reduction in shale.[3] Drilling fluid invasion into shale alters the near-well bore stress state, increases the pore pressure and decreases the differential pressure support at the wall of the well bore.

The early HPWBM used a unique and novel approach to increase the membrane efficiency of shale by decreasing shale permeability. A first-generation micronized sealing polymer was used, in combination with an aluminate complex, to bridge and plug shale pore throats and micro fractures. The sealing polymer was selected because of its small particle size and deformable nature in the presence of high salt concentrations. A surfactant was added to the original sealing polymer to enhance particle size stability at high salt concentrations.

The aluminate complex works in a manner similar to silicates in reducing pore pressure transmission. The aluminate precipitates as it enters the shale matrix due to a reduction in pH, reaction with multivalent cations, or a combination of both.

The early HPWBM was formulated with 20 % sodium chloride (NaCl) having a water-phase activity (Aw) of 0.84. Sodium chloride creates an osmotic pressure differential and works in combination with the sealing polymer and aluminum complex in reducing pore pressure transmission. Previous work has shown that the early HPWBM exhibits membrane efficiency superior to that of conventional WBM and similar to that of NAF. The high salt concentration had a secondary benefit of stabilizing reactive gumbo clays and cuttings.

Partially hydrolyzed polyacrylamide (PHPA) was used to minimize disintegration of cuttings via an encapsulation mechanism. PHPA polymers encapsulate cuttings, minimize disintegration and improve the efficiency of their removal by the rig’s solids control equipment.

An anti-balling and accretion additive was selected for use in the system after having passed performance and environmental tests. This additive was used as a contingency product and was not a basic component of the system in first two field trials.

The early HPWBM was field tested on two shelf wells in the South Timbalier field of the Gulf of Mexico. These field tests highlighted areas of improvement in chemistry, product mix and applied engineering of the system.

Well #1 South Timbalier

The first field trial of the early HPWBM was for a re-entry well using a 4 ¾” x 6 ¾” PDC and reaming-while-drilling (RWD) assembly. The rheological properties of the fluid were stable, mud weight was controlled with minimal dilution, torque and drag were minimized and the well bore was extremely stable throughout the interval.

The key areas identified for improvements were in the areas of rates-of-penetration (ROP) and foaming control. The average ROP on an offset well, drilled from the same platform and over a similar interval using SBM and a PDC bit, was 34 feet/hour, compared to 25 feet per hour with the early HPWBM. The drilling assembly was pulled out of the hole after drilling another 200 feet and then inspected. Several of the jets in the PDC bit were completely blocked; however, the RWD assembly and PDC bit were not severely balled as shown in Figure 1.

A mill tooth bit was then used to drill the remainder of the well at an average ROP of 25 feet/hour while sliding and rotating (Figure 2). Despite the foaming problems, the shaker screens were screened up to 165 mesh screens and were able to process flow without mud losses (Figure 3). The interval was drilled and a 5” liner was run without problems. Figure 4 represents the good hole conditions on the trip out prior to running the liner.

A post well review of the root causes of slow ROP pointed to chemical and hydraulic-related issues. The root cause of the foaming and air entrainment was identified as coming from the first generation sealing polymer. The foam was managed using defoamers; however, it was not eliminated and was significant enough to cause concerns. The ROP enhancer was not added until after repeated incidents of slow ROP and it is believed that some degree of bit balling had occurred before the material was added.

The hydraulic horsepower at the PDC bit was based on historical use of SBM and not on values recommended for WBM. The PDC bit hydraulic horsepower on this well was roughly 0.5 horsepower per inch^2 (HSI), which is well below recommended levels for use of PDC bits and WBM.

Well #2 South Timbalier

The system was used on a second re-entry well to mill a window in casing and then drill around a salt dome. The well bore stability characteristics of the system were very good and the degree of foaming was reduced, but still persistent. The first short trip was made after drilling 500 feet of open hole. The hole quality was excellent with no tight spots, unusual torque and drag or fill on bottom. A second short trip was made after drilling another 950 feet off open hole with no tight spots or fill on bottom.

A third trip was made after drilling into the rubble and damaging the bit and RWD tool. Additionally, mud losses occurred in the rubble; however, a 7" casing string was run to bottom and cemented in place with no problems.

There were some opportunities for improvement identified in the areas of sliding and ROP. As in the first well, the ROP enhancer was used as a contingency material. Improvements in ROP and sliding were observed after the addition of the ROP enhancer.

Lessons Learned from First Two Wells

The first two field trials made apparent several areas of needed improvement in the HPWBM. Re-engineering work was done on the system focusing on four key areas of improvement:

- ✓ Eliminate foaming
- ✓ Increase ROP with PDC bits
- ✓ Improve clay and gumbo inhibition
- ✓ Optimize bit hydraulics

Next Generation HPWBM

The root cause of the foaming problem of the system was identified as arising from the surfactant which was added to aid in maintaining the particle size distribution of the original sealing polymer. The foaming problem was corrected by changing to a second generation micronized sealing polymer. The new sealing polymer was extremely stable in the presence of high salts and did not require the use of surfactants to maintain particle size. Laboratory tests confirmed that the stability and particle size of the new sealing polymer in 20 % NaCl were improved compared to the original product and performed equally well in pore pressure transmission (PPT) tests. In addition, the new sealing polymer exhibited superior compatibility with other products in the system, with significant improvements in the areas of foam reduction, filtration control and rheological properties. The pressure transmission and membrane efficiency characteristics of the HPWBM closely mirror that of SBM as shown in Figure 5.

Bit balling and ROP enhancement are strongly influenced by factors such as mud type, hydraulic horsepower, impact force and bit design. A preventative approach was taken to minimize bit balling and accretion and increase ROP with PDC and rock bits. Another change to engineering the system was to use the proprietary, patented anti-balling and accretion additive as a basic component of the system.[4] A proprietary method of addition was developed to inject the additive so that a continual, non-emulsified stream of the material is available at the bit while drilling. This unique method-of-use provides a step change in performance by minimizing emulsification, reducing concentrations and allows the material to coat metal and rock surfaces.

The clay and gumbo inhibition of the new HPWBM was further improved by incorporating an environmentally acceptable, water-soluble clay hydration suppressant (CHS) into the system portfolio. Clay constitutes a large proportion of shale mineralogy and clay swelling is a leading cause of shale instability. The inability to suppress hydration and dispersion in reactive clays leads to problems such as bit balling, accretion, poor solids removal efficiency, high dilution rates and problems managing rheological and filtration control properties. The CHS effectively inhibits reactive clays and gumbo from hydrating and becoming plastic, which provides a secondary benefit of reducing the tendency towards bit balling. CHS concentrations are monitored using a filtrate titration method at the well-site, and engineered so that an excess of the material is available for clay inhibition.

Lastly, increased focus on pre-well planning towards optimizing bit hydraulics was implemented. A target bit horsepower/inch^2 of >2.5 HSI with a minimum of 2.0 HSI was recommended for optimized bit hydraulics.

Field Trials with New HPWBM

The original two field tests highlighted the need for improvements in chemistry, product mix and applied engineering of the system. Afterwards, a field test program was implemented with the intent to test and evaluate the degree of success of engineering improvements, and to measure the overall performance of the system.

The new system is based on a novel "total inhibition" concept, whereby shale, clay and cuttings stability are systematically provided along with benefits in key areas such as ROP, accretion control and torque and drag reduction.[5,6] The drilling performance attributes of the new HPWBM are: 1) shale stability, 2) gumbo and clay stability, 3) cuttings stability and solids removal efficiency, 4) high rates-of-penetration, 5) minimized bit balling and accretion, 6) torque and drag reduction and 7) minimized differential sticking.

West Cameron Well

The first well drilled with the new HPWBM for ChevronTexaco was in the West Cameron field of the Gulf of Mexico. Pre-well planning meetings were held with the drilling engineer to address performance metrics and clarify logistical and operation issues on this well. The primary performance metrics set for the use of new HPWBM in the 12 ¼" interval were to achieve an average ROP of 75 feet/hour using a PDC bit, and to drill the interval in a comparable time frame compared to NAF on offset wells.

A total of 5,668 feet were drilled at an average ROP of 93 feet/hour and within a time frame comparable to that of NAF offset wells. Well bore and cuttings stability were characterized as excellent, with three wiper and two round trips being made without any incidences of tight hole, fill on bottom or gumbo attacks. The interval was drilled and casing was run without problems. Figures 6 and 7 are photographs of the new HPWBM in the surface pits and at the shakers and show that the foaming problem has been resolved. Figure 8 shows system performance in preventing the occurrence of balling and accretion on tool joints and stabilizer of the 12 ¼" drilling assembly. Figures 9 presents ROP versus measured depth data from this well drilled with a PDC bit. The inability of the shakers to handle high flow rates considerably hampered the rate of penetration in that whole mud losses occurred. The inadequacies of the solids control equipment, along with losing mud in the massive sand sections caused a large reduction in penetration rates. Basically, we could have drilled as fast as we wanted (+/-300ft/hr instantaneous) if we would not have had these problems.

Eugene Island Well #1

This next shelf well was drilled with the HPWBM in combination with an AutoTrak® rotary steerable assembly and a rock bit. Key concerns on this well included hole cleaning lost circulation and differential sticking in depleted sands. Additionally, gumbo attacks had been a recurring problem on offset wells drilled with conventional WBM.

Figure 10 presents the ROP as a function of measured depth for this interval. Highlights from this well include an average ROP of 105 feet/hour, with no gumbo attacks, bit balling or accretion. The interval was drilled and casing was run without problems.

Eugene Island Well #2

The HPWBM was used on this well after repeated and catastrophic losses of diesel-based NAF. NAF mud losses were as high as sixty (60) barrels per hour and did not respond to remedial treatments with lost circulation materials. Due to possible losses at an anticipated mud weight of 16.9 lb/gal in the production sand, it was decided to displace the NAF system with the HPWBM system.

An open hole displacement from NAF to the HPWBM was made and the system handled contamination with NAF very well. The mud weight was eventually increased to 16.1 lb/gal while drilling with a 4 ¾" x 7" bi-center bit. Drilling continued to total depth, with a maximum angle of 63°, mud weight of 16.1 lb/gal and bottom-hole temperature of 150° F.

Highlights from this interval include: 1) being able to safely drill and complete the interval, 2) stable properties despite contamination with NAF, 3) significant reduction in mud losses compared to NAF and 4) the HPWBM eliminated problems related to ballooning in the fractured shale. The interval was drilled and casing was run without problems.

Ship Shoal Well

The HPWBM was used on this well with an AutoTrak® rotary steerable assembly to drill the 9-⅞" and 6 ½" intervals. It was estimated that 1,650 barrels of oil-contaminated cuttings and 600 barrels of oil-contaminated waste would have been generated using an NAF. Other factors influencing the decision to use the HPWBM were deck space, logistics, and crane lift issues. The primary driver was the liability associated with a spill of non-compliant NAF.

The 9-⅞" interval was drilled at an average overall (PDC and mill-tooth bit) ROP of 102 feet hour. The PDC bit used to drill the upper portion of the 9-⅞" interval at an average ROP of 115 feet per hour is shown in Figure 11. Figure 12 is a photograph of the PDC bit and rotary stearable assembly after tripping out of the hole. A mill-tooth bit was then used to drill the lower portion of the interval at a controlled ROP for reservoir navigation purposes. A photograph of the bit is shown after completion of the interval in Figure 13. The 7 5/8" casing string was run to bottom without problems.

The system was then used to drill the 6 ½" interval at a controlled ROP of 55 feet per hour. Figure 14 is a photograph of the PDC bit when tripping the 6 ½" assembly out of the hole. Figure 15 presents ROP as a function of measured depth in the lower interval.

Comparison of Field Results

Results from wells drilled with the new HPWBM demonstrate that problematic areas with the predecessor system had been resolved. There were no further incidents of foaming on subsequent wells after modifications to the sealing polymer.

A comparison of field results on Eastern and Western shelf wells drilled with the HPWBM are presented in Table 1. The South Timbalier wells were drilled with the first generation HPWBM, while the others were drilled with the new HPWBM. The system(s) exhibited stable rheological and filtration control properties on all wells. The key, measurable area of improvement was in ROP between the wells. ROP was optimized on the wells using the new HPWBM. Controlled drilling was done in the Eugene Island and Ship Shoal wells for ECD management and reservoir navigation, respectively. Generally, bit hydraulics was optimized on all wells with the new system. The Eugene Island well had bit hydraulics of 0.2 HSI because flow rates were reduced to minimize ECD and lost circulation which previously occurred with OBM.

The performance of the HPWBM system(s) as a function of hole size is presented in Tables 2 through 5. These tables present drilling performance ranking of the HPWBM compared to NAF for shelf wells having open hole diameters from 12 ¼" to 6 ½". The distance drilled and total drilling hours are presented for each mud system. The systems are ranked in order of performance in distance drilled as a function of time. The data presented in these tables demonstrates that the drilling performance of the HPWBM compares favorably with that of NAF.

Environmental Benefits

SBM contain the desirable drilling qualities of OBM but are more attractive than OBM in the area of environmental compliance. SBM are free from aromatic hydrocarbons, more readily biodegrade and have lower aquatic toxicity compared to OBM. Therefore, SBM cuttings are less likely to cause adverse affects on the marine environment compared to OBM. The EPA recognizes this product substitution as an example of pollution prevention by the oil and gas industry. While SBM are more benign to the environment, compared to OBM, there still remain noxious effects of SBM, hence whole mud discharges are not allowed. The use of the HPWBM in lieu of NAF (OBM & SBM) takes the product substitution and environmental excellence to a higher level.

All of the wells drilled with the HPWBM would have been previously drilled with NAF, rather than conventional WBM. Use of the HPWBM has allowed ChevronTexaco to realize the drilling performance and economics benefits of NAF, while setting a new benchmark of environmental compliance.

From an environmental perspective ChevronTexaco has generally eliminated the rig setup, HSE risks and waste management costs associated with NAF on most wells. There were two exceptions which had to go to zero discharge because of contamination of the HPWBM with NAF or crude oil. In most cases, use of the HPWBM has allowed for cuttings and whole mud to be discharged overboard with full environmental compliance.

Conclusions

- A new HPWBM has been field tested and proven to be an environmentally compliant alternative to NAF for shelf wells drilled in the Gulf of Mexico
- The system has evolved through a process of continual improvement, lessons learned and engineering modifications
- The HPWBM has eliminated the environmental risks and costs associated with waste management of OBM/SBM.
- The system is environmentally friendly and has been approved for use in the US Gulf of Mexico

Acknowledgments

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Nomenclature

BHA = *bottomhole assembly*
MWD = *measurement-while-drilling*
LWD = *logging-while-drilling*
PDC = *polycrystalline diamond cutters*
RWD = *reaming-while-drilling*
ROP =*rate-of-penetration, feet per hour*
AV = *annular velocity, feet per minute*
TVD = *true vertical depth, feet*
TD = *total depth, feet*
TFA = *total fluid area, inch²*
PV = *Bingham Plastic Viscosity, cP*
YP = *Yield Point, lbf/100 feet²*
HTHP = *high temperature/high pressure filtrate*
HSI = *bit horsepower per inch²*
HP = *horsepower*
BHT = *bottom hole temperature, °F*
F = *temperature, Fahrenheit*

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Figure 1 – PDC Bit and RWD assembly – Field Trial #1

Figure 2 – Mill-tooth Bit – Field Trial #1

Figure 3 – Foam generation at shakers – Field Trial #1

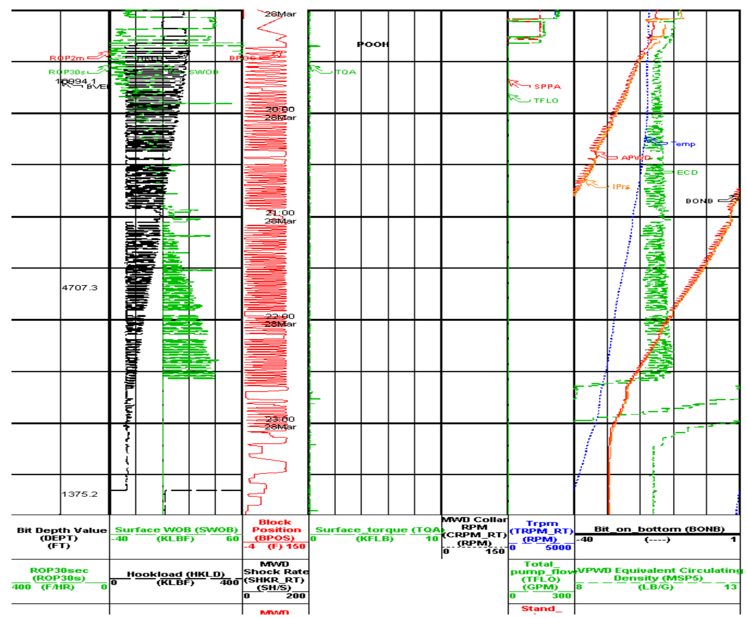

Figure 4 – Trip Out at Total Depth – Field Trial #1

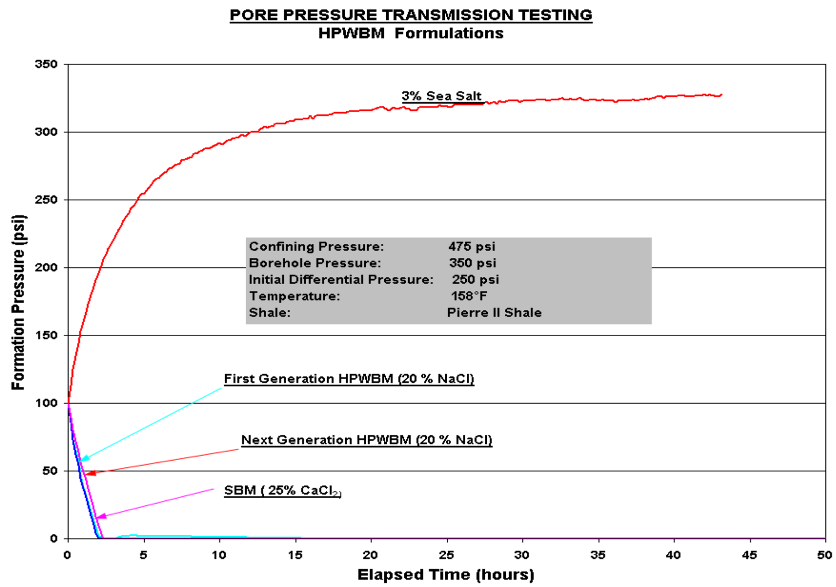

Figure 5 – PPT test data comparing HPWBM and SBM

Figure 6 – Next generation HPWBM in surface pits

Figure 7 – Next Generation HPWBM at Shakers

Figure 8 – BHA pulled from well – West Cameron well

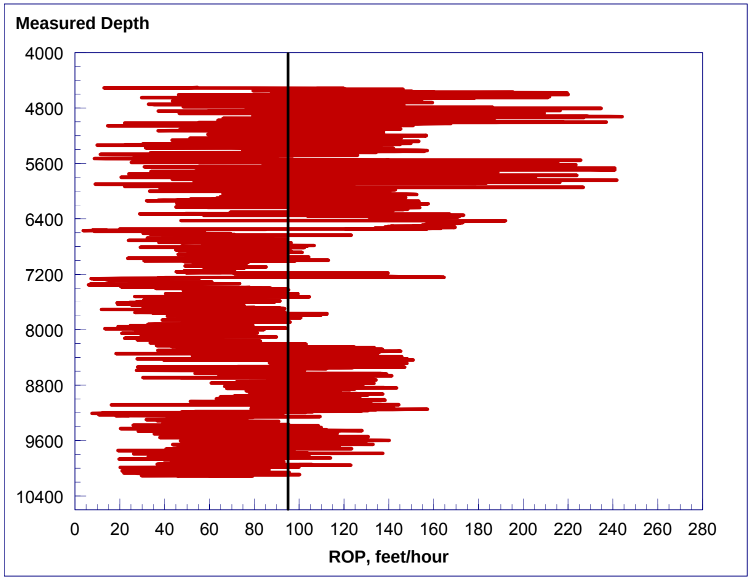

Figure 9 – ROP vs. Measured Depth – West Cameron well

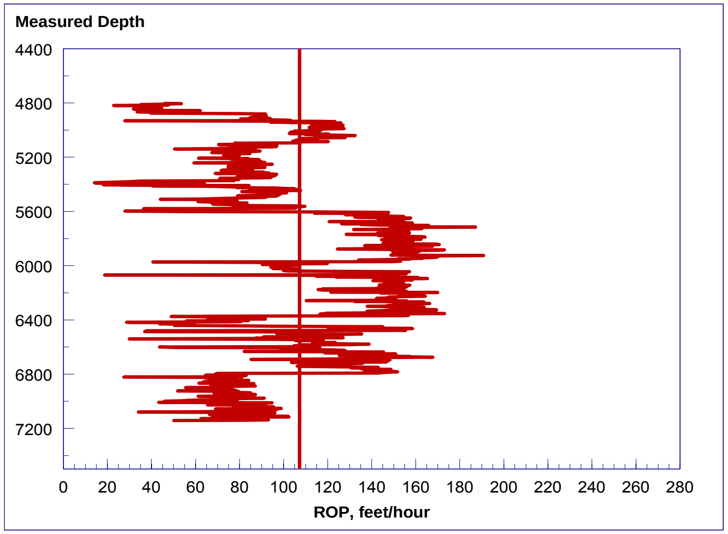

Figure 10 –ROP vs. Measured Depth – 81/2" Interval of Eugene Island Well

Figure 11 – 9 7/8"PDC Bit – Ship Shoal well

Figure 12 – 9-7/8" PDC Bit and AutoTrak® RCLS assembly

Figure 13 – 9-7/8" Rock Bit – Ship Shoal well

Figure 14 –6 ½" PDC Bit – Ship Shoal well

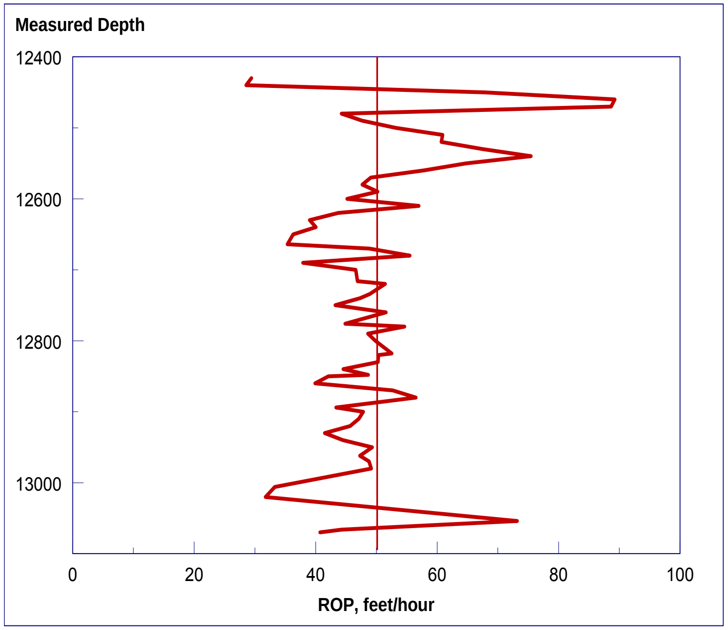

Figure 15 –ROP vs. Measured Depth in 6 ½" interval – Ship Shoal well

Table 1
Well Information using HPWBM

Property Name	South Timbalier	South Timbalier	West Cameron	Eugene Island	Eugene Island	Ship Shoal	Ship Shoal
HPWBM System	First Generation	First Generation	Next Generation	Next Generation	Next Generation	Next Generation	Next Generation
Hole Size, inches	4 ¾" x 6 ¾"	6 ½"	12 ¼"	8 ½"	4 ¾" x 7"	9 7/8"	6 ½"
Maximum Angle, °	25°	46°	6°	73°	63°	55°	56°
Interval Length, feet	1,635	3,500	5,646	2,270	483	7,896	1,139
Bit Type	PDC & Mill Tooth	PDC	PDC	Mill Tooth	Bi-center PDC	PDC & Mill Tooth	PDC
AV - Casing, feet/second	419	307	159	214	149	218	262
AV - Open Hole, feet/second	660	282	257	384	317	391	324
TFA, inch²	0.773	0.624	0.978	0.442	0.771	1.052	0.601
HSI, HP/inch²	0.5	2.2	3.1	4.3	0.2	1.9	1.1
Average ROP, feet/hr	25		93	105	25 (Control)	102	55 (Control)
Bottom Hole Assembly	MWD/LWD	MWD/LWD	MWD/LWD	Rotary Stearable	MWD/LWD	Rotary Stearable	MWD/LWD
Density, lb/gal	10.5	12.3	12.7	12.3	16.1	12.5	14.3
Circulating BHT, °F	178	149	183	140	144	164	216
Flow Line, °F	119	114	140	137	108	133	121
PV, cP	14	22	22	20	43	25	23
YP, lbf/100ft²	13	19	19	19	23	24	14
10 sec Gel, lbf/100ft²	3	11	5	7	5	7	4
10 min Gel lbf/100ft²	8	22	12	19	11	15	7
30 min Gel lbf/100ft²	10	25	14	24	15	21	12
API Filtrate, ml	3.0	3.4	4.1	5.5	4.4	3.6	4.3
HTHP Filtrate, ml	10.2	11.6	13.8			11.2	13.6

Table 2
Drilling Performance Comparison in 12 ¼” Hole Size

Mud System	Distance Drilled (feet)	Drilling Time (hours)	Average, feet/hour	Max Mud Weight (ppg)	Max Deviation (deg)
NAF	4034	54	75	10	0
NAF	7541	112	67	13	21
NAF	13597	219	62	10	22
HPWBM	**5646**	**92**	**61**	**12.6**	**0**
NAF	4642	75.5	61	13	36
NAF	6931	154.5	45	13	33

Table 3
Drilling Performance Comparison in 9-⅞” Hole Size

Mud System	Distance Drilled (feet)	Drilling Time (hours)	Average, feet/hour	Max Mud Weight (ppg)	Max Deviation (deg)
NAF	8975	102	88	11.5	38
NAF	7447	87	86	11.6	19
NAF	6036	81	75	11.9	32
NAF	9294	136	68	12.0	47
HPWBM	**7896**	**136**	**58**	**12.5**	**55**
NAF	11510	203	57	11.1	37
NAF	2175	51	43	13.9	27
NAF	1778	44.5	40	13.5	36
NAF	4334	154	28	13.1	36
NAF	5238	199.5	26	13.1	47
NAF	4478	197.5	23	10.6	24

Table 4
Drilling Performance Comparison in 8 ½" Hole Size

Mud System	Distance Drilled (feet)	Drilling Time (hours)	Average, feet/hour	Max Mud Weight (ppg)	Max Deviation (deg)
NAF	11439	44	257	13.0	35
NAF	7120	40	178	10.5	52
NAF	7120	40	178	10.5	52
NAF	12299	81	152	12.3	42
NAF	3403	31	110	11.0	66
HPWBM	**2270**	**31**	**74**	**12.5**	**73**
NAF	6627	90	74	12.7	50
NAF	13597	219	62	9.5	22
NAF	4642	76	61	13.3	36
NAF	5057	88	57	12.4	50
NAF	4599	81	57	12.6	47
NAF	1272	29	45	13.8	60
NAF	2175	51	43	13.9	27
NAF	2541	62	41	12.1	22
NAF	1778	45	40	13.5	36
NAF	5238	200	26	13.1	47
NAF	4478	198	23	10.6	24

Table 5
Drilling Performance Comparison in 6 ½" Hole Size

Mud System	Distance Drilled (feet)	Drilling Time (hours)	Average, feet/hour	Max Mud Weight (ppg)	Max Deviation (deg)
NAF	8309	66.5	125	13.1	31
NAF	3639	66.5	55	12.2	35
HPWBM	**3488**	**124.5**	**28**	**12.3**	**46**
HPWBM	**1139**	**43.0**	**26**	**14.3**	**56**
NAF	473	20.0	24	14.0	2
NAF	340	17.0	20	16.2	27