IMPROVED PENETRATION RATES ARE OBSERVED IN NEW DRILLING MUD DEVELOPMENT

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ABSTRACT

This paper describes experiences with a new water-base drilling mud system that has been utilized in diverse geographic locations, formation lithologies, and environments such as temperature, density, salinity and total hardness. In addition to providing versatility in wide-ranging conditions, the original goals of the development were to create an easy-to-engineer mud system that would produce good hole stability and improve rates of penetration with the use of either conventional or polycrystalline diamond composition (PDC) bits.

Background of the technical development of the system will be presented, and case histories from wells where the system has been applied will be documented.

It has been observed in the field that this new drilling fluid has achieved the desired increased rates of penetration with both conventional and PDC bits. This has been accomplished while maintaining good hole stability and fluid properties in even harsh chemical and thermal environments. The system's enhanced performance features and explanations for them are discussed.

INTRODUCTION

Drilling fluid compositions are often made overly complicated, to the point they become difficult to comprehend by anyone other than one experienced in the art. In the extreme, the complex formulations may even contain additives that counteract the effects of other additives. In such cases, even engineering by trained experts may become very difficult.

An effective drilling mud is designed to produce fluid characteristics that satisfy the demands of each unique set of downhole conditions and hydraulic requirements. The basic purposes of the drilling fluid are to control subsurface pressures, clean the hole of drilled cuttings, provide adequate hole stability, cool and lubricate the drill string, and produce meaningful geological information in the form of cuttings samples, cores and logs. In most cases, these fundamentals can be achieved with a minimum number of high-quality additives in the mud system.

The conventional water-base mud systems in use today are generally comprised of the following components: bentonite or attapulgite clay, depending on the salinity and hardness of the mud's makeup water, for solids suspension, hole cleaning, and particle distribution for building of effective wall cake and fluid loss control; caustic soda or sodium carbonate for regulating fluid alkalinities; barite or iron oxide weighting agents for increasing fluid density; various polymers for additional fluid loss control, rheological adjustments, and shale stabilization; lignosulfonate, lignite and tannin compounds for solids dispersion and rheological control; modified lignitic materials for control of filtrate under higher temperature conditions; and asphalt-based additives for HTHP fluid loss and shale control. Various salts may also be employed in muds for added chemical stabilization of sensitive formations and cuttings or for assuring the fluid's chemical compatibility with critical pay zones.

The complexity of proper drilling fluids engineering arises with the many variations of these components that are available, the multitude of possible combinations of materials, and a general lack of understanding within much of the industry of the correct functions of each additive and its interrelation with all others in a system. The potential for misapplication abounds.

This new development was conceived with these facts in mind and with the conviction that a less confusing fluid could simplify on-site handling and engineering as well as relieve much of the mystery surrounding the excessively complex mud systems. With an eye to the most fundamental need of today's oil and gas industry, this mud system has aimed at producing greater economy in total well expenditures through higher rates of penetration and good hole stability.

DEVELOPMENT

Research

Technical development of the system coincided with an ongoing research project whose purpose was to create new polymers for enhanced oil recovery applications. The focus of the research was on polymers functional in harsh oilfield environments of both high temperature and high cationic concentration. The result of this five-year project was the development of not only polymers suitable for EOR use, but it was also evident from the work that some were useful in cements, stimulation treatments, and even drilling fluids under these "hostile" conditions.

The important performance features of the polymers were merged with a long-standing objective to develop the least complicated and most effective mud system possible and with the results of a third project in which the prototype of the system was studied. This was an interindustry study comparing rates of penetration of ten different water- and oil-base drilling fluids using PDC bits to drill cores of a hydratable shale formation. Weight on bit and circulation flow rate were the variables in this laboratory-controlled study. Besides penetration rates, bit balling, cuttings size, and relative system cost were measured. Specific results of the project are confidential to participants. However, the information acquired from the study was applied to the development of the system. With this, the two research phases of the original development concept were completed and work characterizing the system's performance was begun.

System Characteristics

The result of the development project is a blended liquid, one-component system that consists of viscosifiers, fluid loss control agents, shale inhibitors, lubricants, and a small amount of isoparaffinic oil. There are four versions of the system, each designed for application in distinct well conditions from low to high temperature and from fresh water to brines of high hardness and salinity. The chemical composition of each of the versions is modified to suit the specific requirements of the drilling environment for which it was designed. The system is compatible with most known water-base additives, though in all cases of field use it has been the heavily predominant component of the mud system.

Enhanced penetration rates are principally achieved through the system's inhibition of sensitive formations and cuttings, excellent lubricity, and generally low fluid viscosities. Inhibition imparts hole stability and reduces bit balling. The system's lubricity reduces friction through the drillpipe and wellbore and allows effective transmission of energy to the bit. The shear thinning characteristics of the fluid provide improved hydraulics and, again, more horsepower delivered to the bit.

The effects of addition of high concentrations of hydratable North Sea gumbo shale solids on the system have been studied. The results (Table I) have indicated the highly inhibitive nature of the system when compared to one of the more commonly used water-base muds. A 14.0 ppg seawater mud containing only 10 ppb prehydrated bentonite and 20 ppb of the new additive was subjected to increasing additions of Ekofisk gumbo. The shale was ground to 70% less than 200-mesh particle size and contained 10-15% moisture by weight. Yield point and gel strength values before and after gumbo additions of up to 50 ppb remained nearly constant when measured at room temperature. After aging 16 hours at 176 F, allowing for shale hydration, yield point and gel strengths were again low and stable, indicating the effects of inhibition on the solids by the system. The dispersed seawater-lignosulfonate-polymer mud, on the other hand, showed the dramatic effects of solids hydration initially and after aging at 176 F. In a similar study, an 11.5 ppg seawater - 6ppb KCl - 20 ppb additive mud with up to 100 ppb Ekofisk gumbo added was also tested under the same conditions described above. Plastic viscosity, yield point, gel strengths and fluid loss were again stable, reaffirming the effective inhibition of reactive clays by the system. The implications of these findings reach beyond the system's use in seawater muds for drilling the younger, reactive gumbo shales. With its low fluid loss and its shale stabilization components, the system also possesses the ability to protect mechanically unstable shales, such as fractured or sloughing-prone shales, making it suitable for such field applications also.

The system's inhibition is produced by a combination of mechanisms. One is the already well-described encapsulating ability of certain anionic polymers. The second is the stabilization of clay particles by the specific surfactant components of the system. With respect to lubricity, the particular oil and lubricants in the system combine to produce a fluid of substantially lower surface tension than conventional water-base muds. In practice, this package distributes the active surface area and the effects of the oil and lubricants far more thoroughly throughout the system than would be expected from the component concentrations. This lubrication appears to prevent agglomeration of drilled solids to the bit and drill string or to each other by filming their surfaces.

The temperature stability of the system has been demonstrated in both the laboratory and actual field experiences. The performance of the system at high temperatures can be principally attributed to the hostile environment polymers in the product formulations, although other components contribute to this characteristic as well. The proprietary polymers are synthesized such that they undergo minimal degradation under harsh well conditions and therefore remain in solution to perform their desired functions. One 14.0 ppg fresh water laboratory mud with 15 ppb additive had a 5.2 cc API 30-minute water loss and a 32.2 cc HTHP fluid loss (at 300 F) after overnight aging at 335 F. With the addition of 0.5 ppb of a chrome-free tannin (CFT) additive, these values were 4.0 cc and 24.0 cc, respectively, following the 335 F aging (Table II). A special project in the laboratory has also produced a mud formulation containing the HTHP version of the additive, lignite, a sulfonated asphalt, and the CF tannin. That mud exhibited a 4.3 cc API and 21.0 cc HTHP fluid loss (at 400 F) after aging at 450 F. The fluid losses were 15.6 cc and 47.0 cc, respectively, after aging at 500 F. The 450 F-aged sample is the base fluid shown in Table V.

Two separate offshore wells using the system have exceeded bottom hole temperatures of 300 F. One, in the North Sea, had a SBHT of 320 F with a system containing approximately 20 ppb of the low viscosity version of the additive. The other well, in the Texas Gulf of Mexico, was at one point not circulated for 21 days due to mechanical problems with 17.2 ppg hematite-additive mud in open hole at 300 F bottomhole temperature. Upon circulation, virtually no conditioning of the mud was required to restore the original flow properties. Typical mud properties from this well are shown in Table III.

It should be noted that the system, as formulated, possesses an inherently low fluid loss, lower than is often required by normal drilling practices in top hole and many intermediate hole sections. However, due to the system's low solids content and shear thinning rheology, the low fluid loss values have not detracted from actual penetration rates. Filter cakes are very slick and thin, often only a film in unweighted muds.

The polymers are again responsible for the stability against chemical contaminants displayed by the HV and HTHP versions of the system. Laboratory and field tests in hard brines (Williston and Michigan) have been performed. Lab mud properties of fluids designed with actual field brines are illustrated in Table IV. Stable flow properties and water losses are observed initially and after aging at 250 F. Chemical analyses of the brines were: a) Williston hard brine - 24,000 ppm total hardness and 190,000 ppm chlorides, and b) Michigan hard brine - 86,500 ppm total hardness and 187,000 ppm chloride ions.

In anticipation of other potential incidents of contamination in the field, sodium bicarbonate, sodium sulfide and calcium chloride were also used to contaminate laboratory seawater muds (Table V). In each case, there was essentially no sign of ill effects on flow properties or fluid loss either initially or after aging at 400 F. Two of the earliest field trials of the system were conducted in North Dakota using a hard brine as the makeup water. One of these wells is documented in Table VII.

When correctly formulated, the described systems behave in many ways like an oil-base mud. This was, in fact, one of the objectives of the original product concept. It has been demonstrated that the system can be designed to be extremely temperature-stable and tolerant to contamination and solids buildup. It is also an effective lubricant and inhibitor. It has been pointed out that the inhibition mechanism of the system is not by means of osmotic dehydration as is the case with oil muds. Nevertheless, its ability to inhibit the swelling and dispersion of potentially hydratable shales appears to be notable in relation to other water-base mud systems.

ENGINEERING

In field application, the makeup fluid may be mudded up with the additive either while circulating (typically while drilling and over one circulation) or by batch mixing. Both methods have been employed with equally good results. The product is a black, viscous liquid suspension supplied in 55-gallon drums. It is best added by use of an electric drum pump directly into the suction pit of the mud circulating system over an agitator or mud gun. It has also been pumped into the mixing hopper as well as gravity fed into the suction pit from the top of the pit or from an above deck. The material is readily soluble and requires little more shear than that from normal pit agitation to properly disperse it into the active mud system. An example of the product's ease of mixing was one of the first experiences with it in North Dakota. At a temperature below 0 F, the product was transferred by drum pump through 2-inch hose to the active system at a rate of 5 minutes per drum. This 20-drum mud-up was accomplished in one circulation while drilling. This rate is typical of other field applications of the product.

Other operating procedures that have been adopted and discoveries made during use of the system are:

1. Consistent with normal good drilling practice, solids from any previously used mud should be diluted to 15 ppb equivalent or less MBT before mudding up with the additive. Any necessary prehydrated clay should also be incorporated before the additive is mixed.

2. Maintenance treatments vary with desired properties and dilution rate. Filtration rate is a good indicator of the need for maintenance additions. In general, experience has shown one to two drums to be required for every 300 feet of 8 3/4" hole drilled. This is again largely dependent on the type of formation being drilled and dilution rate. Water additions are often associated only with building new volume.

3. It has been noted that addition of 1-2% salt (NaCl or KCl) to fresh water systems has improved the stability of fluid properties.

4. If there is any residual starch from previously used mud in the makeup fluid, a preservative should be added to the system.

5. The viscosifier version of the additive may be used to increase the yield point of the system. This will also enhance its carrying capacity if needed. Other conventional viscosifying polymers, clay, or shredded paper have also been applied.

6. Especially in applications requiring inhibition of highly active shales, it is imperative to maintain the prescribed concentration of additive in the system.

7. For best results on offshore installations, the product should be transferred to a bulk container for easier handling and mixing than is permitted by individual drums.

8. As previously mentioned, other additives such as deflocculants, viscosifiers, clay and salts may be incorporated into the system. These would be for fine-tuning properties and generally used only in small concentrations.

9. Good solids control is important for the most efficient performance of the system. A fine-screen shale shaker, desander and full-flow desilter are recommended for unweighted systems. A mud cleaner and centrifuge, if high mud weights are anticipated, are also desirable.

10. Upon completion of the well, the mud systems containing the additive have been disposed in the reserve pit on location. On two occasions, the system was stored and transported for use on a second well.

On the whole, it could not be said that the system is limited to any particular type well, hole section or downhole condition. It has to date been utilized successfully in a wide range of applications. Total well economics, taking into account the advantages of increased penetration rate, should dictate its use. Areas known to pose difficulties for traditional water-base muds might also prove to be targets for its application.

FIELD RESULTS

The new mud system has been utilized in wells from south Texas to North Dakota in the U. S. and internationally in Canada and the U. K. sector of the North Sea. The formations of principal interest in the test wells have been problem shales which, along with carbonate, sand and salt sections, have been drilled successfully. Hole temperatures have ranged from low to 320 F in the North Sea, and mud densities have varied from unweighted to 17.2 ppg. Salinity and hardness of the systems have been fresh water in Texas and Oklahoma, KCl and seawater on several wells, and saturated sodium chloride brine with greater than 40,000 ppm calcium hardness in the Williston Basin. Specific hole and fluid conditions have dictated which particular formulation of the additive to use.

The system has proven technically successful relative to other water-base mud systems in each area where it has been applied. When sufficient material concentration is maintained, the system produces very good hole and cuttings integrity. Instances of insufficient concentration in hydratable shales of south Texas, Canada, and the North Sea have been readily corrected by increased product additions with the expected results. Proper concentration is manifested by firm, distinct cuttings at the shale shaker. This quality has been essential in managing solids buildup and maintaining penetration rates, especially in high operating cost areas such as the North Sea. Coring, logging and running drillstem tests have been accomplished virtually trouble-free in all areas. Core analysis of one of the North Sea wells indicated minimal formation damage when compared to other water-base drilling fluids. Fluid loss control and rheological properties have tended to remain quite stable with few adjustments necessary by other more conventional additives. Most exceptions have involved the occasional use of a sulfomethylated tannin deflocculant to reduce viscosity. It has been learned that this can be minimized by careful selection of the correct viscosity grade of additive and proper maintenance of product concentration. Both of the hard brine North Dakota test wells required additional viscosity for hole cleaning, which was achieved with standard viscosifiers as well as with a viscosifier version of the additive. A small amount of clay is also normally added to the system.

Ease of handling and mixing on-site have been two of the system's chief attributes. As field experience has been gained with it, the system has become simple to engineer due to the stable nature of fluid properties and the minimal dilution and product maintenance requirements. In general, the new system has been more costly than conventional muds, approximately 30% on average, when considering only charges for the mud system and not total well costs.

Comparative data from three different projects are presented in Tables VI and VII and Figure 1. In these cases, the principal goal of the tests was to maximize penetration rates. In addition, inhibition of formation and drilled solids were chief objectives in the Canada and Hidalgo County, Texas, wells. Increased hole stability through the salt sections of the North Dakota well was a second objective of that test. Summarized results of the wells indicate the effective penetration rates achievable with the new mud system when compared to muds customarily utilized in the areas.

CONCLUSIONS

1) In every case where data has been available to make valid comparisons, penetration rates on wells where the new system has been utilized have exceeded normal rates for the area. To the best of our knowledge, in many cases they have produced record penetration rates for the area. On occasion, rates have improved by as much as 50% over conventional water-base mud systems.
2) Good hole stability has been consistently achieved.
3) Chemical and thermal stability of the system, as reflected by steady fluid loss and rheological properties, have been maintained even in harsh environments.
4) When correct product concentration is maintained, excellent solids tolerance and wellbore and cuttings inhibition have been experienced.
5) Total well costs may be reduced through higher penetration rates. This should offset the generally higher cost of the system. There is a relatively high front-end expense for mud-up and generally lower maintenance costs thereafter. Total system costs are, therefore, reduced with increasing well depth.
6) The system has proven easy to engineer and appears to have viable application in many areas and types of wells.

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Table 1
Effects of Addition of Hydratable Drilled Solids to 14.0 PPG Sea Water Mud

	New System				Lignosulfonate Mud			
	Initial Properties							
Gumbo, ppb	PV	YP	Gels	WL	PV	YP	Gels	WL
0	41	23	4/7	--	59	24	2/4	--
25	43	24	4/9	--	85	60	9/28	--
50	46	27	5/14	--	88	68	15/52	--
	Aged 16 Hours at 176 F							
0	44	15	3/3	4.9	65	24	3/4	5.8
25	48	18	3/10	5.4	101	60	10/25	4.3
50	45	23	4/15	6.0	97	66	15/49	4.3

New System Base Mud		Lignosulfonate System Base Mud
219.0	Water, ml	219.0
8.0	Bentonite, g	8.0
8.8	Sea salt, g	8.8
16.0	Additive R, g	--
--	Lignosulfonate, g	3.2
--	CF Tannin, g	0.8
--	LV PAC Polymer, g	2.4
--	pH	9.5
231.0	Barite, g	231.0

Table II
Thermal Stability of the New Mud System in 14.0 PPG Fresh Water Mud

Depth, ft	13,335
Density, lb/gal	17.2
Viscosity, sec/qt	44
Plastic Viscosity, cp	29
Yield Point, lb/100 ft^2	11
10 sec gel, lb/100 ft^2	2
10 min gel, lb/100 ft^2	14
pH	10.8
API Filtrate, ml	5.1
HTHP, ml	14.3/300F
Cake Thickness, 32nds/in	2
Chloride, mg/l	5,500
Total Hardness, mg/l	80-250
Sand Content, %/vol	Tr
Oil Content, %/vol	1.5
Water Content, %/vol	70.5
MBT, meg/ml	18
Bottom Hole Temp, F	300+

Table III
Properties of Field Mud Offshore Texas Gulf Coast

New System Base Mud					0.5 ppb CF Tannin Added				
Initial Properties									
PV	YP	Gels	WL	HTHP*	PV	YP	Gels	WL	HTHP*
36	27	10/24	3.4	--	45	12	7/21	2.8	--
Aged 16 Hours at 335 F									
48	23	8/50	5.2	32.2	33	12	4/13	4.0	24.0

*At 300 F

Base Mud	
Tap Water, ml	225.0
Bentonite, g	4.0
P-95 Clay, g	12.0
CP NaCl, g	1.5
pH with NaOH	8.5
Barite, g	240.0
Additive HTHP, g	12.0

Table IV
Properties of Williston and Michigan Brine Laboratory Muds

Williston Brine (Unweighted)					Michigan Brine (15.0 ppg)				
PV	YP	Gels	WL	Settling	PV	YP	Gels	WL	Settling
Initial Properties									
17	38	18/24	4.8	--	58	13	1/8	0.8	None
Aged 16 Hours at 250 F									
12	31	15/16	5.6	--	59	2	1/3	1.3	None

Williston Base Mud		Michigan Base Mud
325.0	Brine, ml	285.0
7.5	Attapulgite, g	5.0
15.0	Rev Dust, g	15.0
10.4	Additive HV, g	20.0
3.0	Additive V, g	--
--	Barite, g	290.0

Table V
New System Resistance to Chemical Contamination

Contaminant, ppb	Initial Properties				Aged 16 Hrs. at 300 F					Aged 16 Hrs. at 400 F				
	PV	YP	Gels	WL	PV	YP	Gels	WL	HTHP	PV	YP	Gels	WL	SS**
0*	33	14	3/16	1.8	--	--	--	--	21*	28*	9*	2/5*	4.3*	130*
$NaHCO_3$, 1.0	27	11	1/3	2.2	--	--	--	--	--	26	12	2/3	2.4	90
Na_2S, 2.6	28	9	2/7	1.9	--	--	--	--	--	28	15	3/6	2.0	110
$CaCl_2$, 3.4 & NaCl, 17.5	27	7	6/12	8.8	26	8	6/9	9.5	21	--	--	--	--	--

*Uncontaminated sample was aged at 450 F; HTHP at 400 F
**Shear strength, lb/100 ft^2

Base Mud	lb/bbl
Sea Water	
Prehydrated Bentonite	7.5
Dry Bentonite	10.0
CF Tannin	4.0
Lignite	4.0
Additive HTHP	20.0
Sulphonated Asphalt	4.0
Barite, density (ppg)	12.0

Table VI
Comparison of New System to Offset Wells - Alberta, Canada

Well Name	Test Well	Offset #1*	Offset #2	Offset #3
Mud Type	New System	KCl-PAC	LSND**	LSND
Total Depth	8147'	8327'	8235'	7625'
Hole Size	8 7/8"	8"	8 7/8"	8 7/8"
Mud-up Depth	5729'	6726'	4498'	5374'
Cores	1	0	2	1
DST	2	2	2	0
Total Days	22	18	33	26
Total Rotating Hrs.	255	208	406	327
Core Depth	7136'	--	7779'	7471'
Rot. Hrs. to Core Pt.	170	208	346	310
Ft/Hr to Core Pt.	41.7	40.0(TD)	22.6	23.9

*Record well in the area
**LSND-Low solids, non-dispersed

Table VII
Comparison of New System to Offset Wells — McKenzie Co., N.D.

	Test Well	Average Of 11 Offsets
Location	20-15N-104W McKenzie Co., N.D.	Within 20-Mile Radius of Test Well
Mud Type	New System-Brine	Starch-Attapulgite-Brine
Mud-up Depth	3100'/8000'*	4710'
Hole Size	8 3/4"	8 3/4"
Total Depth	12,820'	12,864'
Rotating Hours	558	658
Days to TD	36	50.6

*Starch-Attapulgite at 3100'; Additive HV at 8000'

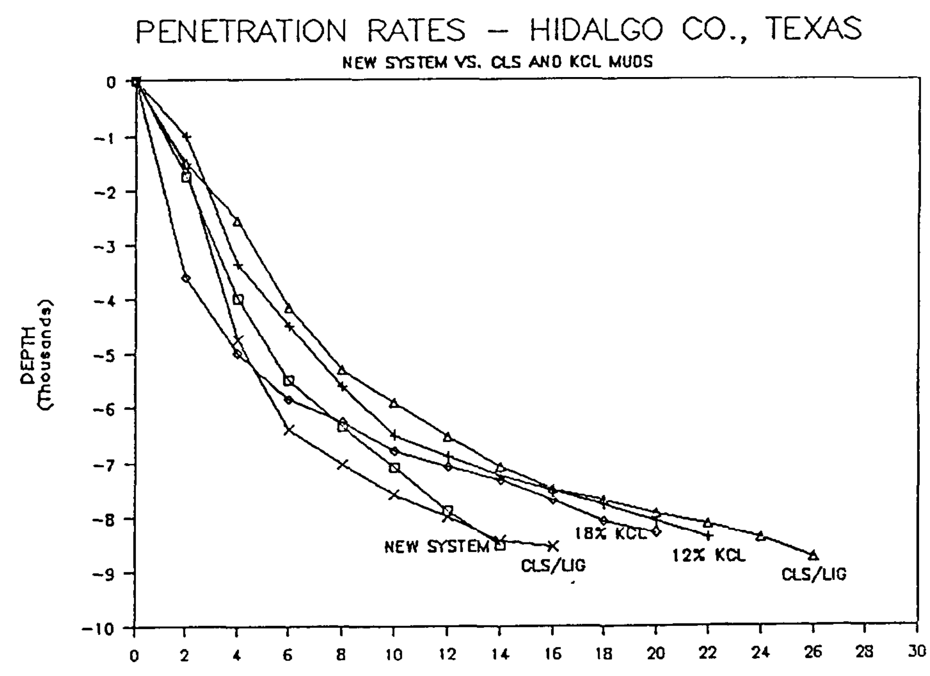

Figure 1