Drilling Fluid Design and Implementation for a Shallow Extended-Reach Horizontal Well

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Abstract

A measure of difficulty for drilling a horizontal well is the ratio of horizontal displacement (HD) to true vertical depth (TVD). A higher ratio involves a more difficult completion. Typically, this ratio is less than one-to-one. However, completions with ratios approaching seven-to-one have been documented. When ratios reach 2:1 or higher the drill pipe is susceptible to excess torque and drag, especially in the case of water-based muds.[1] The challenges for completing a high-ratio horizontal well include reservoir drill-in fluid (RDF) selection and maintenance, wellbore stability, lubricity, torque, cuttings transport, solids control and fracture gradient.

An extended-reach well with 3760 ft of horizontal displacement, including a 2300-ft openhole horizontal section, was recently drilled in the Gulf of Mexico (GoM) at an average TVD of 1868 ft. This completion targeted four bright spots that were separated by shale sections. The longest shale section that was traversed measured 700 ft. in length. The RDF design was integrated with directional, drilling and completion concerns. Primary among these were maintaining wellbore stability and not allowing the extensive shale sections to collapse around the drill pipe. Other concerns included minimizing equivalent circulating densities (ECDs), reducing torque and drag, minimizing formation damage and utilizing a cleanup system that combined simple placement with cost efficiency at the relatively low bottomhole temperature, approximately 110°F.

This paper details the engineering of the RDF system used on this well. It discusses the development of a maintenance schedule used by the fluid and drilling engineers for anticipated and/or potential field problems. Field performance is discussed and lessons learned are contrasted with conceptual design. Breaker design and clean-up data are also discussed. Finally, the initial well-test data are presented.

Introduction

Improved hydrocarbon recovery in producing horizontal wells has provided the impetus for continued development of extended-reach-drilling (ERD) technology. One of the many challenges of ERD is presented by the relatively high ratio of horizontal displacement (HD) to true vertical depth (TVD). As a comparison, this ratio (expressed as HD/TVD) was calculated from published well and completion data using record searches of oilfield periodicals. **Table 1** shows that currently, extended-reach wells (ERW) have achieved ratios as high as 7:1. A sample of published data from the Mineral Management Service (MMS) in the GoM (**Fig. 1**) show ratios that range from approximately 0.1:1 to 3:1. Approximately 88% of these wells/completions exhibit ratios less than 1:1. As the HD/TVD ratio increases, the more difficult the well is to drill and the complexity also increases.[1,2] Therefore, more planning and technology is required to mitigate and even eliminate potential drilling problems. For example, ERW are often drilled at angles where frictional forces prevent the drillpipe from reaching bottom under its own weight.

In September of 2003, the ERW that is the subject of this paper was drilled to a total depth of 5181 ft. At the maximum horizontal displacement of 3760 ft the true vertical depth was 1868 ft. This yields an HD/TVD ratio of approximately 2:1. Based on the sample of data from the MMS, the HD/TVD ratio for the subject ERW well plots in the top 2% of wells drilled in the Gulf of Mexico (**Fig. 1**). While this ratio is less than 3 times that of the highest ERW worldwide we referenced, there are nevertheless challenges for drilling and completing at HD/TVD ratios of 2:1 that require careful planning to avert potential problems.

Project and Reservoir Information

The candidate well is located in the Viosca Knoll area of the GoM. The target sands range in true vertical depth from 1790 to 1868 ft and comprise four separate lobes. **Fig. 2**, a log of the horizontal section in this well, illustrates the log character of these relatively shallow unconsolidated sands.

This gas-bearing reservoir was deposited during the Miocene period and is present throughout onshore and offshore Mississippi and Alabama. Deltaic sedimentation led to the development of this reservoir as a shelf bar. This reservoir was tested in a 1990 completion, but

due to economic considerations, it never produced for any extended period of time. The unconsolidated nature of the sand dictated the need for sand-control measures.

Seismic interpretation showed several pods of sand development at the same vertical level (**Fig. 3**). To make this project economic, it was essential that the pods be connected with a single horizontal well that would transect the top of the pods. The water level at the base of the sand dictated that the drilling/directional plan establish a wellpath clearly above the gas/water contact.

Conceptual Design and Planning

High resolution two-dimensional seismic data was used in conjunction with three-dimensional visionary software (TDVS). This allowed the planning team to design the drilling phase/wellpath for this prospect using three-dimensional image projection. The team consisted of geological, engineering, directional and drilling fluid representatives. TDVS provided resolution of the seismic data that permits and assists the team to systematically define lithological "slices" that should transect the wellbore. This allowed for maximizing contact with the reservoir rock (*i.e.* quartz/feldspar-bearing minerals) versus non-reservoir rock (*i.e.* clay-bearing minerals). Subsequently, the surface location was selected to position the horizontal path to intersect three sand bars that were separated by relatively extended "shaley" sections in the prospect area (**Fig. 3**). An optimum horizontal track was then determined to effectively connect the sand bars. Screen length was limited by the length of the surface/production casing, since exposed screen cannot be situated in the reservoir and across the BOP stack at the same time.

The planned casing program consisted of 26-in. drive pipe to 410 ft, 13⅜-in. conductor to 915 ft, 9⅝-in. surface casing to 2883 ft MD/1886 ft TVD and 8½-in. open hole horizontal to 5181 ft MD. A 2300-ft horizontal was decided upon with a targeted TVD of 1868 ft and a planned angle of 90.5 degrees (**Fig. 4**).

The operator had prior experience with horizontal wells at similar TVD, with approximately 1000 ft to 1100 ft of horizontal length. These represent a HD/TVD ratio of 0.59:1. The current and planned scenario, with a ratio of 2.01:1, more than tripled the HD/TVD ratio this operator had previously designed or completed.

Drilling and Completion Objectives

The objectives and the measured field parameters are summarized in **Table 2**. These objectives are discussed in detail with respect to potential drilling and completion problems.

Torque and drag calculations were performed for the proposed drillstring and screen assemblies (**Table 3**). This data indicated that a 2400--ft screen assembly could be run to bottom at the projected HD/TVD without the use of rollers. Openhole friction factors (OHFF) of

0.3 to 0.5 were used. However, additional string weight greater than conventional drill pipe was required, necessitating the placement of heavy-weight drillpipe (HWDP) in the vertical/low-angle section of the well.

RDF concerns included drilling through significant shale sections (± 700 ft) between the sand bars and enhancing wellbore stability. The need to maintain relatively low drill solids content was of concern as excess solids can contribute to formation damage and result in poor cleanup. The RDF system was optimized for low-shear-rate viscosity (LSRV) to promote optimum hole cleaning.[3] It was decided that the initial RDF system should have a minimum LSRV of 38,000 sec^{-1}. Previous experience[3] indicated that periodic additions of biopolymer, shear and/or temperature would contribute to elevating the LSRV above the desired target of 40,000 sec^{-1}. Another concern included the ability to mitigate losses with a thin and effective filter cake. In addition, as metal-fluid friction was unavoidable, the use of a lubricant would be required. The selected lubricant must be compatibile with the RDF system and not grease or interfere with the cleanup chemicals.

As a result of the relatively shallow TVD, a narrow window existed between the pore pressure and the frac pressure. The component elements of the RDF and ECDs would require careful field monitoring to avoid breaking down the sands. Real-time automated surface data was modeled for calculated ECD values since the drilling assembly did not include a pressure-while-drilling (PWD) tool.

Equally important was the ability to clean up the residual filtercake without the need of an acidizing or stimulation treatment once the screens were spotted in the openhole section. A cost-effective treatment was desired. The treatment could be spotted using the mud pumps or cementing unit. This would reduce rig-time and cost as compared to using a stimulation vessel. The well program included the use of a solids-free RDF to displace the drilling mud from the open hole after drilling to TD to mitigate cuttings beds and excess solids. The breaker would displace the solids-free system from the hole when the screen was in place.

With the completion design established, the reservoir drill-in fluid was formulated incorporating these fluid objectives.

Laboratory Analyses

The objectives of the laboratory-testing phase were optimization of the RDF properties and subsequent cleanup. The following were considered key to the success of the drilling and completion phases: 1) confirm the compatibility of the base brine and all potential additives of the RDF system; 2) seek to maintain a LSRV of at least 40,000 sec^{-1} after shear and static aging; 3) identify a lubricant that reduces the coefficient of friction (CoF) of the RDF system; 4) minimize bridging solids loading while maintaining relatively low fluid loss;

and 5) maximize cleanup efficiency of the residual RDF filter cake using an enzyme breaker in the presence of elevated drill solids. The enzyme clean-up included an α-amylase at 4% v/v for the purpose of degrading the starch component in the residual RDF filter cake.[4] Various surfactants were considered to help disperse the residual filter cake, creating additional surface area to increase exposure to the enzyme. For comparison, an HCl and an oxidizer (*i.e.*, sodium perborate) cleanup system were tested.   Both systems were unweighted and contained an iron-chelant and inhibitors to more closely simulate field blends.

Design of the RDF System

The following fluid properties were measured and optimized: LSRV and gels, coefficient of friction (CoF), plastic viscosity (PV), carbonate solids loading and its effect on modified High-Temperature High Pressure (HTHP) fluid loss, and density. The goal was to promote good hole cleaning, inhibition, lubricity, a relatively stable and low PV that, in turn, yielded lower ECDs, and minimal concentration of bridging solids. Low bridging solids concentration in the RDF is significant in promoting more efficient cleanup[4] and yields a lower PV, which contributes to low ECDs. Low ECDs enable drilling the length of lateral safely between pressure limitations of reservoir pressure and fracture pressure.

NaCl brine was selected as the base fluid for the RDF system because it is cost-effective, inhibitive of formation shale, compatible with all components of the RDF system and meets the density requirements. Bridging solids were engineered to minimize both fluid loss and volume required. A software program was used to calculate the optimum bridging solids blend. The program utilizes a $D_{\frac{1}{2}}$ rule for developing an ideal packing model.[5] It requires particle-size data of locally sourced carbonate grades and user input of permeability or pore-size data from the target reservoir. The program then generates a target blend based on the user input relative to the reservoir. A closest fit is then calculated using the ideal packing theory. By comparing the calculated blend to the target blend, reiterations can be performed to optimize the bridging solids. **Fig. 5** exhibits the final iteration. This iteration used an input of 600 mD (as a maximum) for the candidate sand. Note that these calculations are independent of solids loading. As such, laboratory testing was performed to confirm these calculations. It was decided that 20 lb/bbl of carbonate would be sufficient. This loading was selected as it was desired to minimize fluid loss and maximize the clean-up..

Relative fluid-loss tests were performed to confirm the calculated carbonate blend. This data is presented in **Fig. 6**. While RDF#4 did not exhibit the lowest fluid loss of the systems tested, other RDF systems with lower spurt loss did not contain a lubricant.   The lubricant was considered essential for reducing friction.

As such RDF#4 was reformulated using 1% v/v lubricant and 7.25 lb/bbl fluid loss additive. RDF formulations #1 through #3 utilized a liquid biopolymer and no lubricant.

The rheological properties of selected RDF systems are shown in **Table 4**. As stated earlier, the objectives of optimizing LSRV, minimizing PV, and achieving relatively low fluid loss were considered essential for driling. It was decided that fRDF#4 exhibited excellent LSRV, PV and fluid loss properties even after simulated aging.

The next objective was to select a lubricant that did not degrade the LSRV properties or initiate sludge and provided a relatively low CoF. An optimum lubricant would not only reduce the CoF but increase the LSRVs. This synergistic mechanism has been observed in laboratory analyses but is not well documented. A Fann lubricity tester was used and all tests were performed at 60 rpm using 150 lb-in of torque. Several lubricants were tested at a loading of 1% v/v. **Fig. 7** shows the relative CoF values. The 1-min LSRV are plotted before and after the addition of each lubricant. For comparison, the CoF of selected RDF systems are shown. From this data, only two lubricants, A and B, provided the desired qualities (reduced CoF and increased LSRV). Lubricant A provided a lower CoF, but Lubricant B was more cost effective and was therefore selected for use.

Enzymes and Cleanup

The next phase of the laboratory testing investigated the cleanup potential of the RDF#4 system (enhanced with respect to fluid loss, PV, and LSRV) using an enzyme treatment.   An enzyme-based treatment was considered the most cost-effective.

Enzymes are highly specialized proteins produced by cells of living organisms which have the ability to act as catalysts to promote specific reactions. Polymer-specific enzymes hydrolyze polymers into non-damaging fragments. As a catalyst, the conformational structure of an enzyme is unchanged by the reaction it promotes. Consequently, the reactivity of an enzyme is essentially infinite.[4, 6-7] Enzymes are safer and less costly to pump because, unlike acids and oxidizers, enzymes are non-corrosive.

Acids and oxidizers are non-specific reactive species that will react with anything encountered that is acid soluble or oxidizable, including tubulars, hydrocarbons, and some formation components. Since acid and/or oxidizers begin spending upon contact with any soluble or oxidizable material, these reactants are at least partially spent prior to arrival at the damaged zone. This is accentuated proportional to the distance of the damage from the casing shoe. In the case of ER open-hole intervals, this phenomenon can pose difficulties in acid placement and result in poor cleanup of the residual filter cake.   To overcome the propensity of acids/ oxidizers to spend quickly, specialized tools may be used to mechanically place this type of cleanup

treatment.

The concerns regarding an enzyme breaker include the ability to place the breaker system in the open hole such that it remains in contact with the residual filter cake to allow the catalytic reactions to commence. The denaturing of the enzyme is a concern where temperature, solids, pH and brine concentration may be excessive.[7]

Several different cleanup treatments were proposed and testing was performed to optimize the cleanup system. A modified HTHP apparatus was used as this facilitated rapid and relative testing. In addition, this apparatus allowed quick comparison of various additives as necessary to improve clean-up. Tests were conducted for degrading residual filter cakes formed from the customized brine-based starch/biopolymer RDF system (RDF#4) using simulated drill solids at various concentrations, in addition to a lubricant. Special attention was focused on the ability of the enzyme to function effectively at the relatively low bottomhole temperature (approximately 110°F) and in the presence of elevated drill solids.

Residual Filtercake Cleanup

A modified HTHP apparatus was utilized to test RDF formulations for clean-up. RDF#4 system was blended and sheared for one hour. Initial rheology was measured to confirm fluid integrity and no simulated drill solids were added at this point. Prior to aging, a blend of 50-50 gravelpack sand/rev dust was added to simulate drill solids. RDF systems were allowed to statically age for 16 hours at 110°F. Rheologies were reconfirmed after this period. A 29-micron ceramic disk (FAO-05) was placed in the receiving end of the HTHP cell. The end caps were secured and approximately 450 psi of differential to air was applied from the top using nitrogen. Fluid-loss data was measured/collected for 16 hours at 110°F to confirm fluid-loss characteristics. After this period, the RDF system was decanted.

A solids-free RDF system (*i.e.*, no carbonate) was poured into the cell using a spatula so as not to disturb the filter cake. An overhead Hamilton Beach blender was used to agitate the solids-free system for approximately 15 minutes. This step simulated the displacement of the lateral from the solids-laden system to the solids-free system. After this period, the solids-free system was decanted and NaCl completion brine was poured into the HTHP cell. Again, the brine was agitated in the same manner.

After this period, the brine was decanted and approximately 120 mL of a selected cleanup treatment was poured into the cell using a spatula, taking care not to disturb the filter cake. The end caps were secured and 450-psi differential to air was applied to the top of the HTHP cell. The bottom valve was opened and filtrate was collected for 1 hour or until a steady stream of affluent was evident. At this point, the valve was

closed and the pressure was reduced to approximately 25 psi to 50 psi. This step simulated the isolation of the lateral from the hydrostatic when the fluid loss control device closes.

The system was allowed to soak statically for 32 hours at 110°F. After this period, the residual filter cake/disk was examined and photographed. The 32-hr period represented the time it would take to pull out of hole with the completion assembly, test BOPs, pick up the production tubing and run-in-hole and sting into the packer. For the last step, the disk was reversed and placed back into the receiving end and production through the disk was simulated. Approximately 500 mL of NaCl completion brine was flowed at 25 psi. The residual filter cake/disk was then removed, examined and photographed.

Fig. 8 and **Fig. 9** exhibit residual filter cakes after the 32-hr soak period. These tests compare HCl-based cleanup to enzyme cleanup treatment. **Fig. 8** shows residual filter cakes where no simulated drill solids were utilized in the RDF system. Note that both cleanup systems (i.e., enzyme and HCl-based) were effective in removing the residual filter cake. **Fig. 9** shows a cleanup test in which approximately 2.5% v/v of simulated drill solids were incorporated into the RDF. From these digital images, it is clear that an increase in drill solids retards the effectiveness of the cleanup systems. It should be noted that these results agree with previously published work detailing the effect of drill solids.[8]

It is clear that the performance of an enzyme cleanup is dependent on minimizing not only the drill solids that would be incorporated into a filter cake but the bridging solids as well. Therefore, an enzyme treatment was formulated using a surfactant to disperse residual solids and a viscosifier to assist with placement of the enzyme clean-up so the losses are mitigated. The next laboratory phase would confirm the performance of the α-amalse component to sensitivity with drill solids. In addition, the compatibility of the α-amalse with the surfactant and viscosifier could also be confirmed. The RDF system would contain 20 lb/bbl of bridging solids.

Fig. 10 shows the results of the enzyme cleanup that contains a surfactant and viscosifier. The simulated drill solids were varied from 1% v/v to 4% v/v. An iodine test was performed to confirm the absence or presence of starch. A black color is positive for starch while a red to yellow color is negative. From these results it is evident that the starch component is degraded. However, the increased presence of drill solids clearly diminishes clean up.

It was clear that the application of an enzyme breaker would be appropriate for this completion. To achieve the optimum performance the drill solids would have to be minimized (*i.e.* < 1.75%). A dilution schedule was developed to assist the field engineers to maintain the desired drill solid content (**Table 5**).

Table 6 shows the final formulation and rheological

properties. Based on the laboratory phase, all design objectives were achieved.

RDF Maintenance

The next phase focused on development of a field maintenance program for the RDF system. The objective was to maintain the relative clean-up efficiency observed in the laboratory testing phase with respect to the potential use of additives and components that would mitigate or denature the enzyme-based system.

The design objectives were incorporated into a field maintenance guide (**Table 7**). This worksheet provides the field engineer pre-meditated guidelines to common and uncommon problems that may be encountered during the drilling of the lateral. All directions consider the potential to denature the enzyme-based clean-up. In addition, the worksheet must be flexible to allow incorporation of problems and subsequent solutions for the unanticipated drilling related problems.   In this manner, the worksheet provides a continuing synopsis of drilling related problems and solutions.

Field Program

The following objectives were key to the success of placing the enzyme breaker system: 1) proper mixing of the system and QC of the α-amylase so that the enzyme does not denature; 2) stable lateral after drilling to total depth and no losses are apparent; 3) LSRV of at least 40,000 sec^{-1} should be maintained for the solids-free RDF; and 4) density and pumping regimes do not exceed the estimated frac gradient for displacement for the breaker and solids-free systems and spacers. The following procedure was utilized to complete and spot the enzyme breaker system in the lateral:

1. After drilling the horizontal section, short trip into the casing then run back to bottom. If any obstructions are found, make a wiper trip using a hole opener. Prepare to displace the open hole.
2. Displace the openhole section with a solids-free RDF system. Check for losses and/or seepage. If losses are excessive, consider spotting a solids-laden sweep pill.
3. Displace the solids-laden RDF with a solids-free RDF, filling the open hole with solids-free and ± 300 ft into the casing. Slowly pull the end of the drilling assembly to approximately 100 ft above the casing shoe.
4. Displace the residual RDF from the casing with NaCl brine. Filter the NaCl brine to the NTU < 30.
5. After the completion brine has been filtered to specification, pickle the workstring.
6. Circulate NaCl brine to spec and POOH.
7. Prepare to RIH with screen assembly. Fill screen and workstring with NaCl completion fluid while running in hole. When the screen assembly is on bottom, displace the solids-free RDF system in the lateral and the NaCl in the workstring assembly by pumping NaCl at 4-5 bbl/min. If necessary, close the isolation valve to isolate the lateral. Finish displacing solids-free RDF system out of well bore with NaCl.
8. Prepare enzyme treatment in advance and perform all QC steps.
9. Begin displacement. The objective is a 1 bbl: 1 bbl return when displacing lateral from NaCl to treatment.
10. Perform toe-to-heel displacement and circulate enzyme treatment down the workstring. With washpipe assembly in circulating position, pump through the float shoe and circulate at 1 bbl/min.
11. Monitor returns carefully while pumping and note any losses. Measure and record volume pumped and volume returned after enzyme treatment reaches float shoe. Record actual displacement rates in table provided.
12. If a 1 bbl: 0.7 bbl return is not realized increase pump rate to 6-8 bbl/min in an attempt to achieve some potential diversion. If returns are still not acceptable stop pumping immediately and pull washpipe assembly to the heel. Attempt to finish pumping the remaining treatment with at least 1 bbl: 0.7 bbl returns ratio from this position. If the desired return rate is still not obtainable, stop pumping immediately and contact the office to discuss options.
13. Slowly pull the washpipe assembly. Monitor well for fluid losses. If flapper is not holding and fluid losses are severe, pump a previously prepared fluid loss control pill.
14. If well U-tubes, follow treatment with a few barrels of 10 lb/gal NaCl liquor.
15. Allow enzyme treatment system to soak for a minimum of 32 hours.

Field Execution

Critical maintenance recommendations provided in the well program specified MBT levels (< 5 lb/bbl), low-gravity solids (< 1.75%), PV (10-15), LSRV (> 40,000) and ECDs below 11.8 lb/gal. During drilling of the 2300-ft horizontal section, MBT was maintained between 1.5 and 2.5 lb/bbl and LSRV remained > 38,000, both, within acceptable performance limits. The PV was maintained less than 15 throughout. Percent drill solids exceeded 1.75% target from approximately 3450-ft MD to 3850-ft MD.

Two unanticipated factors contributed to the higher than expected percentage of drill solids. First, a much longer shale segment was encountered than had been anticipated, causing the RDF to overflow at the shakers. Approxiamtely 1/3 of the RDF system was lost while drilling the first 600 ft of horizontal. Secondly, a delivery of the second 1000 bbl of RDF was delayed by weather and the only fluids available for dilution were 80 bbl built

from sack material and 225 bbl brought out as solid-free RDF. These were insufficient for maintaining the system. At 600 ft the decision was made to pull the pipe from the hole to reposition the HWDP and wait for the new RDF that would be used for dilution. Percent drill solids in the RDF had reached approximately 3%. With the infusion of fresh RDF, the low-gravity solids (LGS) were kept below 1.5% until TD. Another shale section near the toe of the lateral yielded a spike above 3% before the level was lowered again by dilution (**Fig. 11**).

ECD values were calculated throughout drilling of the interval (**Fig. 12**). While two increasing trends are apparent, the ECD was maintained under target through dilution and solids control.

Upon drilling to TD, a final hole opener was run to bottom and no obstructions were encountered. The hole was circulated clean from the active mud system and backreamed to the shoe without problems. Once back on bottom, the openhole section was displaced to solids-free RDF. Over the next 24 hours, pits were cleaned to handle the completion fluid, the casing was displaced to brine and the screen assembly was picked up and drifted in the hole.

No obstructions were encountered going in hole with the completion assembly, which consisted of approximately 2250-ft, 7.38-in. OD 8-gauge pre-pack screen. The production packer was set and the enzyme cleanup was spotted in the openhole before pulling pipe. Fluid loss was controlled by a flapper valve below the production packer. After pulling out of the hole and going back in with the production string, inihbited packer fluid was circulated into the casing annulus and the production tubing was stung into the packer. The breaker was in the open hole for about 36 hours. No measurable losses were observed during any of these procedures.

Field and Production Results

The well was subsequently tested using well test equipment after running tubing and installing the wellhead. Initial test data showed:

10.1	MMCF/D
0.0	BC/D
14.0	BW/D
720	FTP, psi
782	SITP, psi (stabilized with 5 min.)
39/64	Choke

Nodal analysis (based on surface pressure data) showed a negligible downhole drawdown. The well is currently shut-in awaiting pipeline construction and tie-in. Another completion in this reservoir in 1990 tested at 4.561 MMCF/D with FTP=718 psi on a 36/64-jn. choke.

Conclusions and Lessons Learned

Based on the data presented, the following conclusions can be drawn:

1. No stimulation equipment was required to spot the breaker because a readily available pump was used.
2. An enzyme-based breaker was effective in degrading laboratory-prepared RDF filter cakes (without simulated drill solids) within 32 hours at 110°F.
3. The same breaker was ineffective in degrading a drill-solids laden residual filter cake formed at 110°F. This cake was formed from an RDF that contained 4% drill solids.
4. After reducing the drill solids to 2%, the same breaker was effective in degrading the residual filter cake within 32 hours at 110°F.
5. Hole stability prior to the completion operation should be closely monitored.
6. An openhole that exhibits fluid losses will lead to losses of the enzyme breaker during placement
7. The percent drill solids should be monitored and maintained to a minimum at the wellsite. Their incorporation into filter cakes can reduce the effectiveness of the clean-up system.

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Table 1 Selected ERW Data Ratio of Horizontal Displacement : True Vertical Depth				
Approx. Date	**Area**	**Horizontal Displacement (ft.)**	**True Vertical Depth (ft.)**	**Ratio**
2000	Emirate of Abu Dhabi	13,780	4,968	2.77
1999	Hidra Field	34,134	4,921	6.96
1998	Hidra Field	26,161	5,299	4.94
1997	Goodwyn Field	24,190	9,400	2.57
1997	South China Sea	26,453	3,855	6.86
n/a	Offshore California	12,740	n/a	2.90
n/a	Offshore GoM	6,091	n/a	2.70
n/a	Offshore GoM	7,387	n/a	2.40
n/a	Offshore California	14,671	n/a	2.90
n/a	Offshore Tierra del Fuego	17,234	5,577	3.68

Table 2 RDF Objectives		
Phase	**Objective**	**Target / Method**
Drilling Lateral	Reduce Torque & Drag	Maintain 1% - 3% v/v lubricant
	Minimize Fluid Losses	< 1/bbl/hr using sized carbonate
	Minimize Drill Solids	< 1.75 % using dump/dilute method
	Minimize Cuttings Beds	> 40,000 LSRV using biopolymer
	Minimize PV	< 16 using dump/dilute and solids control as necessary
	Maintain low ECD	< 11.8 lb/gal
	Maintain below fracture gradient	< than 12.1 lb/gal
Clean-up of Lateral	Ease of treatment placement	Pump with available rig equipment
	No fluid losses while spotting treatment	Minimal losses acceptable while POOH.

Table 3 Torque and Drag Analyses for Running Screens*			
CHFF	**OHFF**	*No rollers* **Final Measured Weight**	*With rollers* **Final Measured Weight**
0.2	0.3	61.1	84.6
	0.4	44.9	76.4
	0.5	28.2	68.3
* proprietary calculations			

Table 4
Summary of RDF Formulations and Rheology

Products	Units	RDF4	RDF4a	RDF2	RDF2a	RDF3	RDF3a	RDF5	RDF5a	RDF6	RDF6a	RDF7	RDF7a
9.3-lb/gal NaCl	lb	410.0						410.0		410.0		410.0	
9.5-lb/gal NaCl	lb			440.6		440.6							
Biopolymer	lb	**1.25**		**2**		**2.5**		**1.25**		**1.5**		**1.5**	
Fluid Loss Agent	lb	**7.25**		**3.5**		**3.5**		**6.0**		**6.0**		**7.25**	
Inhibitor	lb	3.7		3.7		3.7		3.7		3.7		3.7	
Lubricant	lb	3.4		3.5		3.5		3.5		3.5		3.5	
Carbonate 1	lb	4		4		4		4		4		4	
Carbonate 2	lb	12		12		12		12		12		12	
Carbonate 3	lb	4		4		4		4		4		4	
simulated drill solids:													
Rev Dust	lb		9		9		9		9		9		9
Gravel Pack Sand (50/70)	lb		9		9		9		9		9		9
PERIOD AGED	hr	Initial	16	Initial	16	initial	16	Initial	16	Initial	16	Initial	16
TEMPERATURE	°F		110		110		110		110		110		110
DYNAMIC/STATIC	D/S		D		D		D		D		D		D
RHEOLOGY:													
TEMP.	°F	120	120	120	120	120	120	120	120	120	120	120	120
600 RPM		46	61	59	54	69	58	42	50	41	53	54	67
300 RPM		39	48	50	42	57	47	32	40	32	44	41	54
200 RPM		31	41	41	38	51	43	28	35	28	36	37	48
100 RPM		26	34	34	31	44	36	23	28	23	30	31	40
6 RPM		14	18	20	18	27	22	13	15	13	17	17	23
3 RPM		11	15	18	16	24	20	11	13	11	15	14	19
GELS 10-sec	lb/100 ft^2	12	14	19	18	24	22	13	13	13	13	14	17
GELS 10-min	lb/100 ft^2	16	17	24	24	31	29	16	16	15	17	19	22
PV	cP	7	13	9	12	12	11	10	10	9	9	13	13
YP	lb/100 ft^2	32	35	41	30	45	36	22	30	23	35	28	41
LSRV	0.0636 sec-1												
1 min	cP	32093	43191	53189	67506	115000		26123	36092		36392	33093	59887
2 min	cP	33093	45390	58787	71985	115000		27123	36492		39891	34093	66386
3 min	cP	33093	45690	63986	73984	115000		27123	36592		39891	35100	66586

Table 5
Dump & Dilute Schedule
For a 8.5-in. wellbore

Retained solids (%)	Dilution (bbl/100ft)	Est. dilution volume (bbl)	Total volume required (bbl)
0.75	158.4	3950	4465
1.00	112	2800	3315
1.25	83.2	2080	2595
1.50	64.8	1620	2135
1.75 **(target)**	**51.2**	**1280**	**1795**
2.00	41.2	1030	1545
2.25	33.6	840	1355
2.50	27.2	680	1195
2.75	22.2	555	1070
3.00	18	448	963

Table 6 Final Formulation and Rheological Properties			
Products	**Units**	**4**	**4A**
9.3-lb/gal NaCl	lb	367.42	
NaOH pH 9.0 - 9.5	lb		
Biopolymer	lb	1.25	
Fluid Loss Additive	lb	7.25	
Inhibitor	lb	3.6	
Lubricant	lb	3.4	
Carbonate 2	lb	4	
Carbonate 10	lb	12	
Carbonate 40	lb	4	
Rev Dust	lb		9
Gravel Pack Sand (50/70)	lb		9
PERIOD AGED	hr	Initial	16
TEMPERATURE	°F		110
DYNAMIC/STATIC	D/S		D
Rheology			
Temperature (°F)		120	120
600 RPM		46	61
300 RPM		39	48
200 RPM		31	41
100 RPM		26	34
6 RPM		14	18
3 RPM		11	15
GELS 10-sec	lb/100 ft^2	12	14
GELS 10-min	lb/100 ft^2	16	17
PV	cP	7	13
YP	lb/100 ft^2	32	35
LSRV	0.0636 sec^{-1}		
1 min	cP	32093	43191
2 min	cP	33093	45390
3 min	cP	33093	45690

Table 7 **Field Maintenance Guide**		
Potential Problem	**Target**	**Course of Action**
MBT High	< 5 lb/bbl	**1st:** Dilute with base brine, increase lubricant. Do not use drill water. **2nd:** Follow Dump & Dilute Schedule and increase lubricant.
High LGS	< 1.75%	**1st:** Run Centrifuge. **2nd:** Follow Dump & Dilute Schedule.
Sloughing Shales		Increase system weight with dry salt base and rebuild system with additives.
High Torque & Drag	> 40,000	**1st:** Increase LSRV with biopolymer **2nd:** Treat with additional lubricant at 1-3%. **3rd:** Spot beads.
Stuck Pipe		**1st:** Spot a lubricant pill. **2nd:** Pump 25-bbl acid pill, treat mud after pipe is free. Note: If differential, reduce hydrostatic. If cuttings, raise properties and use frequent wiper trips.
Maintain Density	Max of 10.2	Use base salt up to 0.2 lb/gal increments and maintain target properties.
High PV	10 – 15 Never > 15	**1st:** Follow Dump & Dilute Schedule. **2nd:** Dilute with base brine and maintain target properties.
Low Gels	> 7/8	Increase with biopolymer.
Low 6/3 Readings	> 6/7	Treat system with biopolymer in 0.25 lb/bbl increments.
Hole Cleaning	> 40,000	**1st:** Backream every stand and circulate minimum of 3 bottoms-up every 500 ft **2nd:** Increase LSRV with biopolymer.
Cement and Green Cement	pH to 9-10	With hard cement drill ahead. With green cement treat with acetic acid and Bicarb.
Seawater or Formation Water contamination		**1st:** Treat with fresh system and add Sodium Hydroxide as necessary as formation water may be acidic. Maintain target properties. **2nd:** Increase system weight with dry salt.
CO_2 & H_2S in System	pH to 9-10	Raise pH with Sodium Hydroxide for CO_2. Use H_2S scavenger.
Low pH	pH to 9-10	Raise pH with Sodium Hydroxide, Do Not Use Potassium Hydroxide.
Lost Circulation		
Severe Losses		**1st:** Pump 50-bbl pill with 50 lb/bbl carbonate 40, 250, 500 and fiber for fractures up to 2 mm. Check downhole tool clearances before mixing/spotting pill. **2nd:** Reduce system density and maintain target properties.
Moderate Losses		Pump 50 bbl pill with 25 – 50-lb/bbl carbonate 40
Seepage Losses		**1st:** Increase fluid loss additive concentration. **2nd:** Sweep hole with 50 bbl pill with 25 lb/bbl carbonate 10.

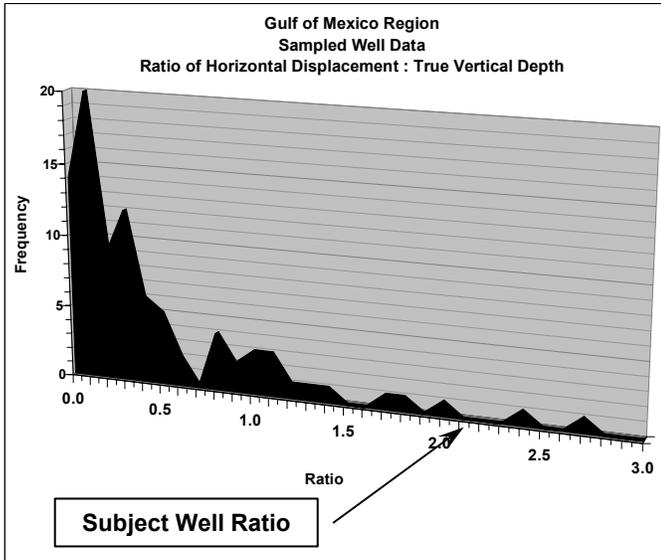**Fig. 1 -** This completion plots in the 98% percentile based on well data collected from the MMS, GoM Region.

Fig. 2 - Log character showing separate lobes.

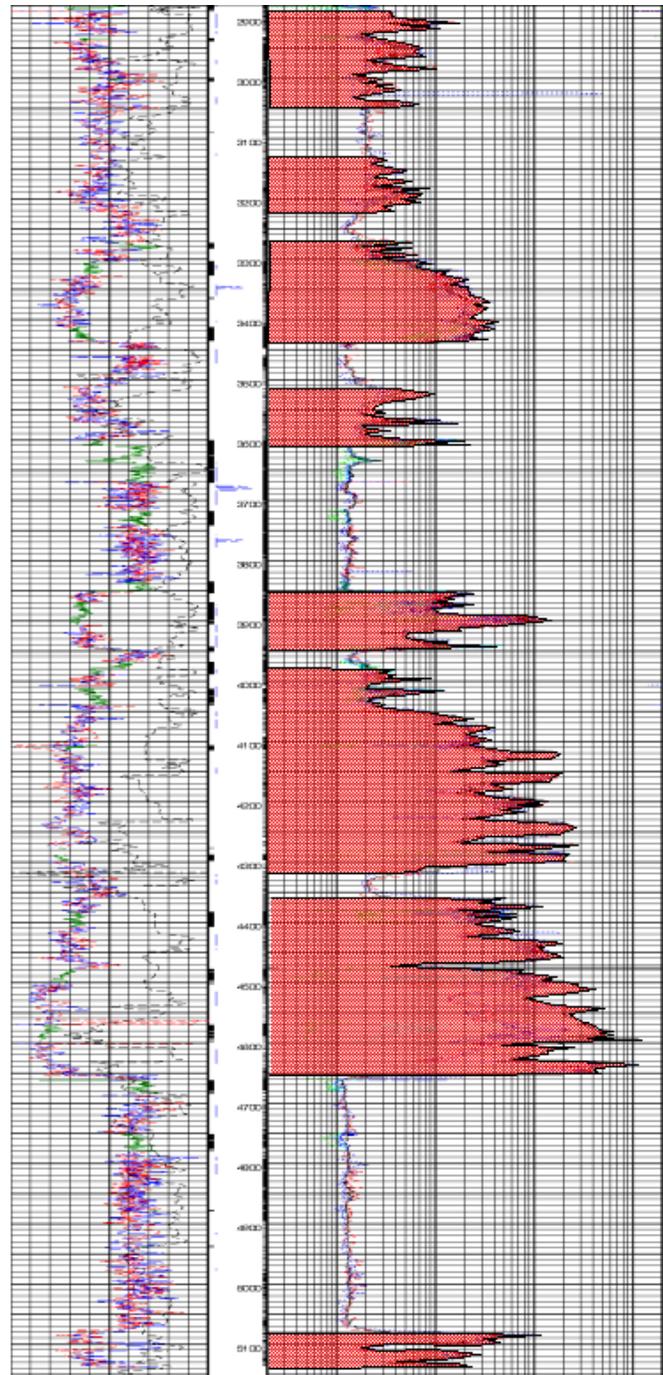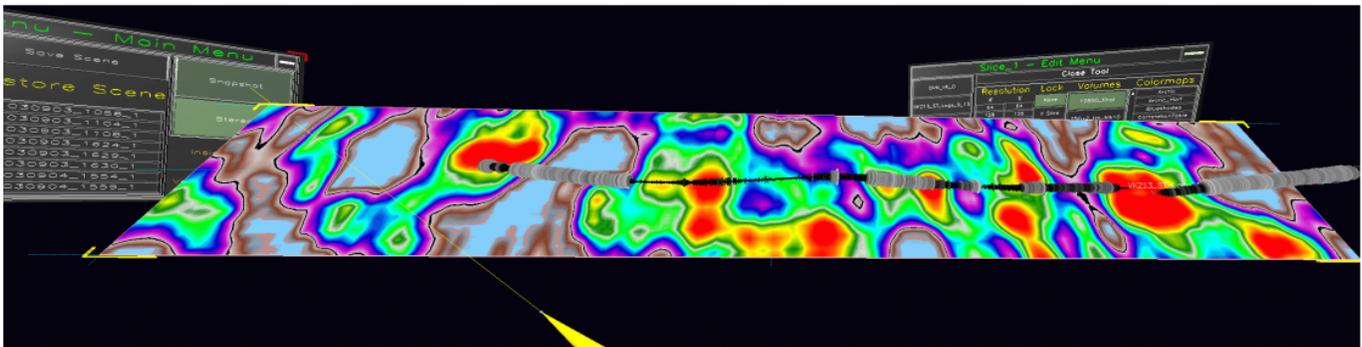N   S

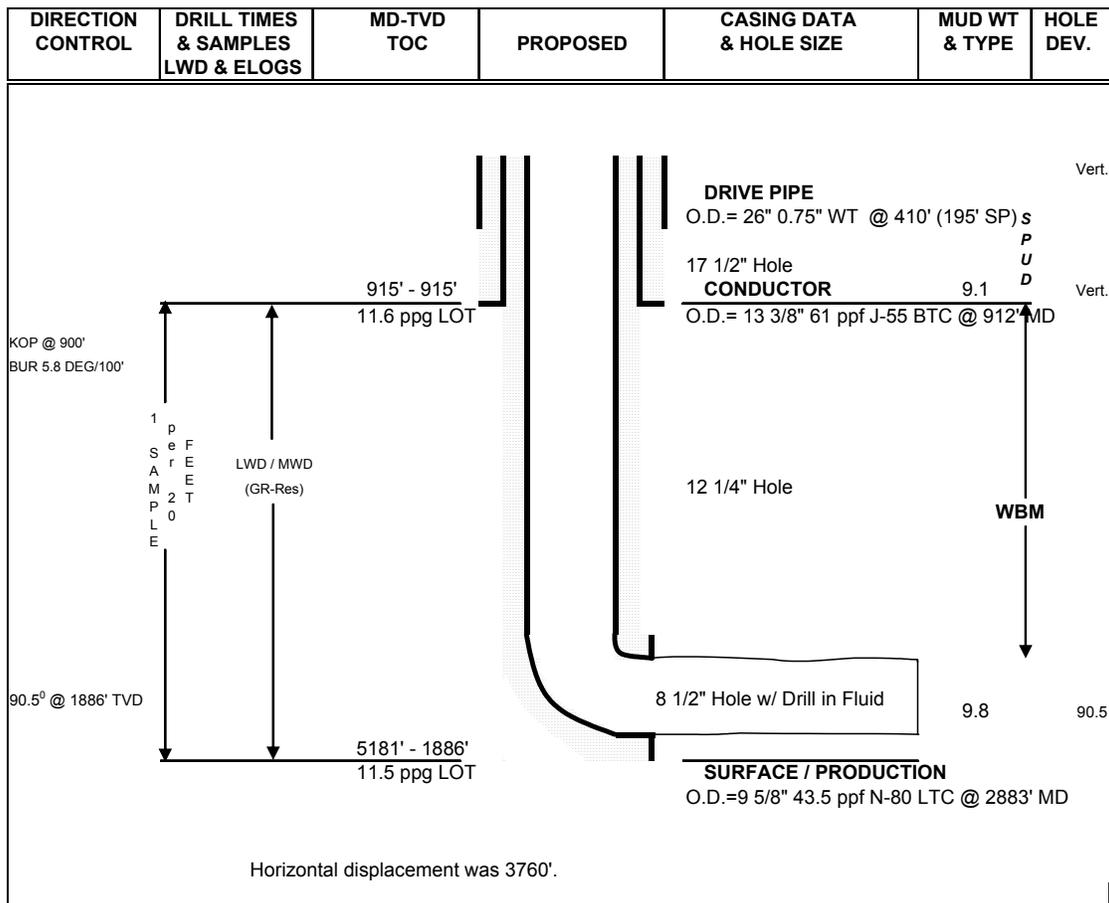**Fig. 3 -** Reality Time Slice of 3-D seismic showing the four lobes/targets and projected well path of the "A SAND" completion.
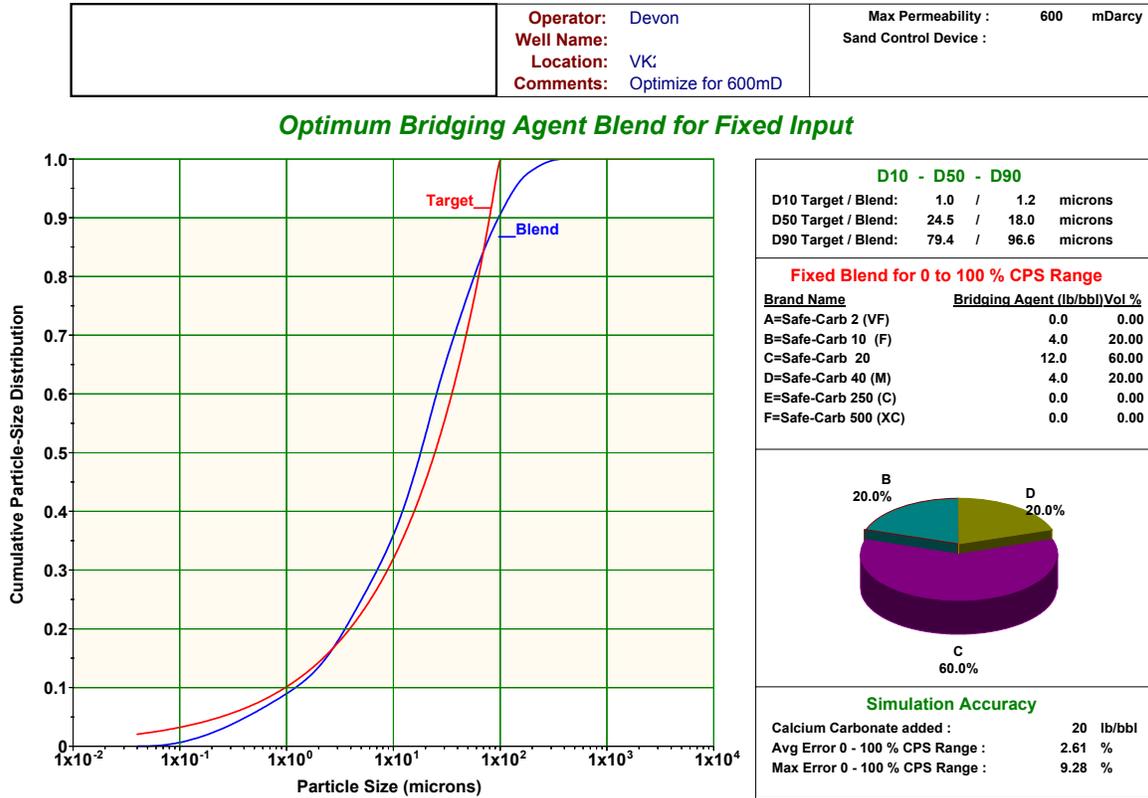

Fig. 4 - Proposed well schematic.

		Operator:	Devon		Max Permeability :	600	mDarcy
		Well Name:			Sand Control Device :		
		Location:	VK:				
		Comments:	Optimize for 600mD				

Optimum Bridging Agent Blend for Fixed Input

D10 - D50 - D90

	Target	/	Blend	
D10 Target / Blend:	1.0	/	1.2	microns
D50 Target / Blend:	24.5	/	18.0	microns
D90 Target / Blend:	79.4	/	96.6	microns

Fixed Blend for 0 to 100 % CPS Range

Brand Name	Bridging Agent (lb/bbl)	Vol %
A=Safe-Carb 2 (VF)	0.0	0.00
B=Safe-Carb 10 (F)	4.0	20.00
C=Safe-Carb 20	12.0	60.00
D=Safe-Carb 40 (M)	4.0	20.00
E=Safe-Carb 250 (C)	0.0	0.00
F=Safe-Carb 500 (XC)	0.0	0.00

Simulation Accuracy

Calcium Carbonate added :	20	lb/bbl
Avg Error 0 - 100 % CPS Range :	2.61	%
Max Error 0 - 100 % CPS Range :	9.28	%

Fig. 5. Final iteration of the carbonate blend refinement for the RDF bridging solids. Note that while the larger carbonate grains in the final blend "overshoot" the target, these particles are most likely reduced in diameter by mechanical forces.
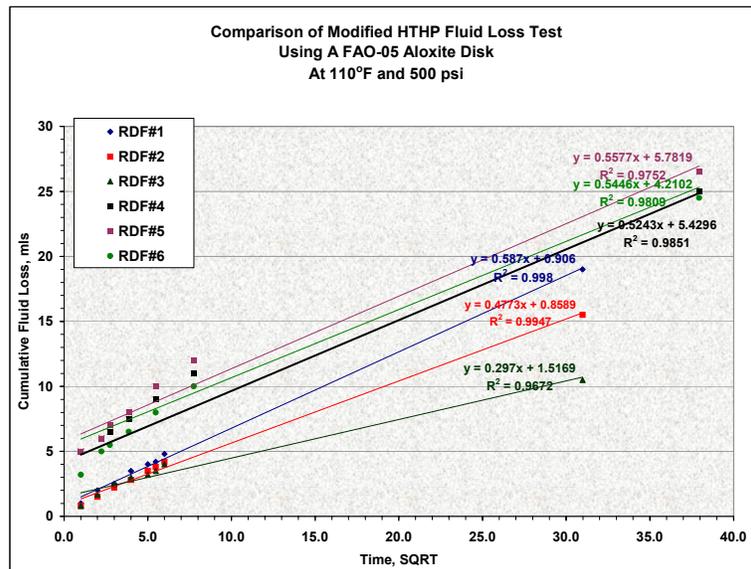

Fig. 6 - Relative HTHP fluid-loss data with 20-lb/bbl carbonate as bridging solids. RDF#1 through #3 were made with biopolymer and no lubricant. RDF#4 was formulated with biopolymer, starch and a lubricant.
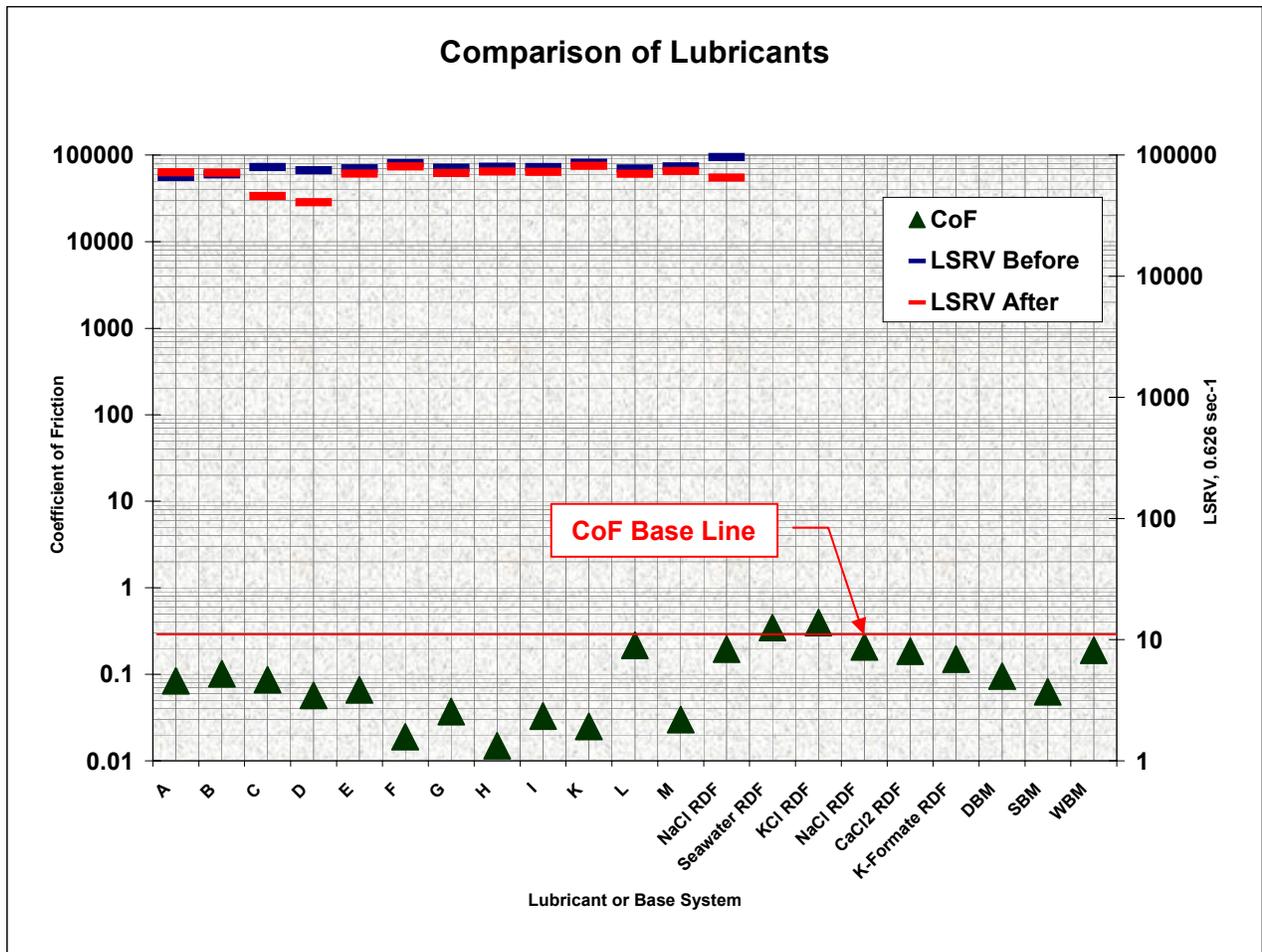
Figure 7. Comparison of selected lubricants in an NaCl-based RDF. All lubricants were loaded at 1% v/v. For comparison, the CoF of various drilling systems without a lubricant are shown on the right. Lubricant B exhibits a relatively good reduction of CoF and an increase in LSRV.

Fig 8. Comparison of laboratory cleanup using an HCl-based treatment (left) and an enzyme-based treatment (right). Both RDF systems contained no simulated drill solids.

Fig. 9 - Comparison of laboratory cleanup utilizing an HCl-based treatment (right) and an enzyme-based treatment (left). Both RDF systems contained 2.5% simulated drill solids by volume.
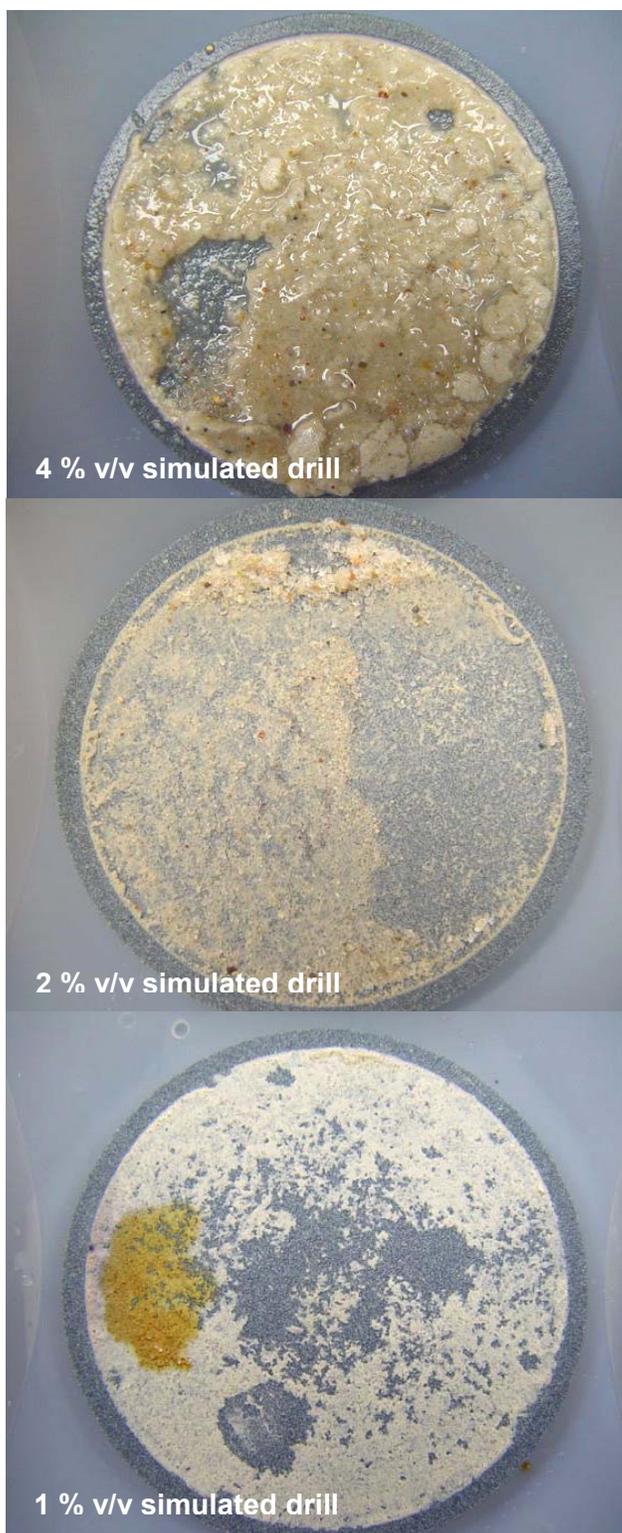
Fig. 10 - Comparison of relative HTHP cleanup tests after simulated flowback using NaCl brine and 25 psi. Iodine was placed on the residual filter cake to confirm the presence or absence of starch. The yellow-red color is indicative of no starch.
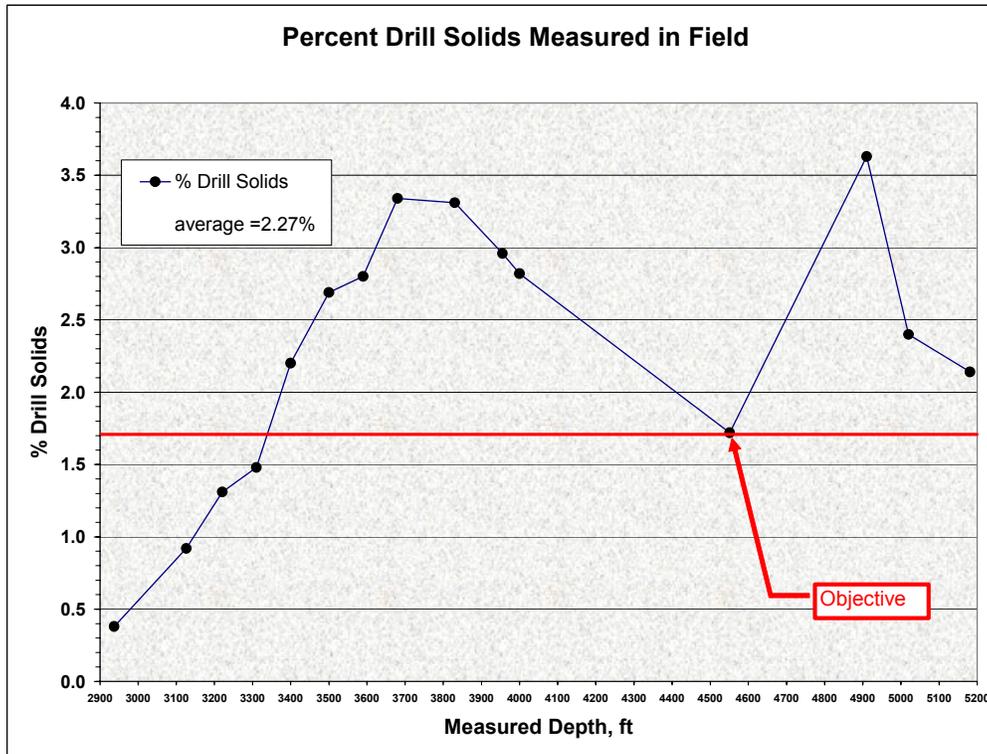
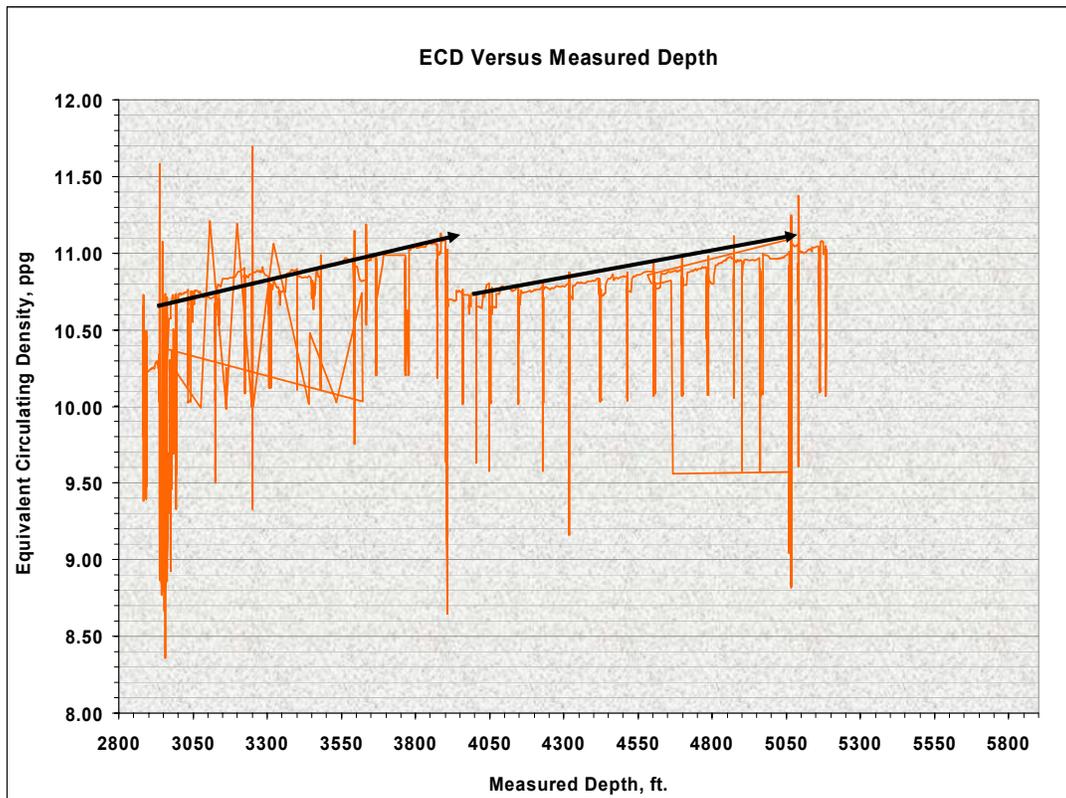Fig. 11 - Percent drill solids calculated from recovered cuttings samples.

Fig. 12 - Calculated ECD values versus measured depth.