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An Integrated Approach of Drilling and Completion Fluid Solutions and Facilities Drives Efficiencies in Gulf of Mexico Deepwater

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Abstract

The Gulf of Mexico (GoM) deepwater environment presents the potential for a variety of operational challenges. Synthetic-based fluids (SBF) are the fluid-of-choice in deepwater wells as they provide excellent wellbore stability and rates of penetration (ROP) compared to water-based fluids; however, equivalent circulating density (ECD), circulation initiation and surge pressures are often more challenging with SBF due to temperature and pressure effects on rheological properties and fluid density. The inability to control these parameters can result in downhole losses, which negatively affect operating costs and non-productive time (NPT). This paper highlights the development and field trials of a flat-rheology, synthetic-based fluid (FR-SBF) designed to overcome the problems associated with pressure management in deepwater operations.

The design, development and field testing of the unique FR-SBF in GoM deepwater wells was coupled with the commissioning of a unique, next-generation offshore supply base in Port Fourchon, Louisiana. Timely supply and delivery of drilling and completion fluid solution are integral elements of GoM deepwater supply, logistics and distribution programs. Key elements of the newly commissioned facility include the reduction of time for mixing and transferring fluids, automation of workflows and the ability to simultaneously prepare, load and transfer fluids to multiple offshore supply vessels.

The transition from drilling to completion activities is a discrete operation, one that requires specialized expertise and technology. Reservoir drill-in fluids (RDF) are minimally-damaging fluids designed to meet the drilling performance requirements of drilling engineers and reservoir integrity requirements of completion engineers. A greater focus on open hole completions in the GoM market has seen a significant push for optimized and minimally damaging RDF. This paper discusses important design considerations for development and use of these reservoir fluids in GoM open hole completions.

Introduction

Inherent risks to deepwater drilling operations in the GoM include wellbore instability, gas hydrate formation, pressure management and downhole losses. The narrow pressure window between pore pressure and the fracture gradient exacerbates the technical challenges associated with these operations. GoM deepwater wells are characterized by a dual temperature gradient, with temperatures decreasing through the water column from ambient (surface) temperature towards 40°F at the seafloor, and then increasing along the geothermal gradient towards approximately 300°F at total depth (TD). These highly varying temperatures present extraordinary challenges with respect to managing rheological properties and densities of drilling fluids. As water depths increase from deepwater depths of 1,000, and to ultra-deepwater depths in excess of 5,000 feet, the cooling effect on the drilling fluid across the length of the riser increases viscosity, flow properties and gel strengths.

When using conventional SBF in this environment, elevated pressure required moving the cold fluid often results in downhole losses while tripping, running casing and cementing, particularly after extended static periods. As operations transition towards ultra-deepwater, the challenges encountered became more critical, particularly with regard to pressure management, safety and NPT. In response to these challenges, the industry has seen the evolution of SBF used in deepwater operations to mitigate these operational challenges and risks.[1,2,3,4,5,6] This paper highlights the development and field trials of next generation SBF technologies designed for use in challenging deepwater wells. The integration of adjacent technologies and capabilities, such as engineering software, new facilities and reservoir technologies into the operational workflow is presented, as well.

Fluid System Design

Ideal drilling fluids for deepwater operations are those that satisfy all technical, performance, safety and environmental goals, while also managing costs and NPT. This section highlights the development of the latest generation of FR-SBF designed for use in challenging and complex deepwater wells. The new fluid exhibits a rheological profile nearly independent of the temperature and pressure conditions typically encountered in deepwater operations. The fluid’s unique rheological profile translates to a significant reduction in surge pressures, ECD, downhole losses and barite sag, while also improving hole cleaning efficiency when drilling at high ROPs.

A team of chemists and engineering professionals developed the FR-SBF in several phases. Key design parameters included rheological properties (gel strengths, plastic viscosity (PV), yield point (YP) and 6/3 rpm readings), resistance to barite sag, ECD management and conformance to GoM environmental regulatory guidelines. The design team used novel and proprietary chemistry and evaluated individual components, as well as combinations of components, to achieve the design objectives.

The project data showed that both the type and quantity of organophilic clay used affected the performance of the system. This observation led to the identification and use of a high-quality organophilic clay designed to balance flat rheology, hole cleaning and barite sag objectives. Another key attribute of the system was the application of a unique polymeric viscosifier designed specifically for use with the organophilic clay and filtration control additives. Having established compatibility of the basic constituents of the system, the development team began a rigorous process of optimization of product mix and concentrations to cover the spectrum of potential applications. In order to demonstrate the capability of the fluid, the development team built formulations over a wide range of operationally feasible temperatures, oil-water ratios and densities. Successful formulations were tested at densities of 8.0 – 16.3 lbm/gal and at temperatures in excess of 350°F. Once completed, the development team subjected the formulations to a robust program of contamination testing in order to stress and determine durability of the system in harsh operating conditions.

Table 1 presents laboratory data of the FR-SBF and shows the near-independence of temperature and pressure effects on the flow properties and gel strengths of the fluid. One can clearly see that YP, 6 & 3 rpm readings and gel strength measurements are nearly flat with changing temperature and pressure conditions.

Table 1 – Rheological Properties of FR-SBF

Temperature, °F	Pressure, psig	6 rpm	3 rpm	10 sec gel, lbf/100 ft^2	10 min gel, lbf/100 ft^2	Yield Point, lbf/100 ft^2
40	4,000	11	9	10	23	15
70	4,000	8	7	10	23	9
120	8,000	8	7	10	20	9
150	17,500	10	9	12	23	11
180	22,000	10	8	10	22	12
200	25,000	10	8	10	22	12
225	28,000	9	8	10	23	15
250	28,000	9	8	11	23	16
275	28,000	9	7	10	22	17

A signification breakthrough was demonstration of a flat rheological profile using a variety of base fluids, presenting the opportunity for global use of the system. Additionally, in parallel to building the spectrum of FR-SBF formulations, the development team also designed an analog, low-ECD SBF that used a smaller grind-size of barite and was designed to reduce ECD in a narrow pressure window.

Another design criterion was the minimization of barite sag. The financial consequence of barite sag can be significant due to additional rig-time required to circulate and condition the fluid to manage the event. Barite sag causes density fluctuations in the annulus, often leading to problems such as lost circulation, well control and stuck pipe. These fluctuations in fluid density are typically the first indicator of a barite sag event. First, the fluid density falls below the nominal (surface) density and then it rises above nominal when circulating bottoms-up. Plotting fluid density vs time (or pump strokes) captures barite sag incidences. The resultant sinusoidal plot is a classic fingerprint of barite sag.

Direct and indirect test methods have been developed to characterize the potential of a fluid to exhibit dynamic and static barite sag. The standard indirect test for dynamic barite sag is the "Sag Window", a viscosity-based test designed to predict the onset of dynamic barite sag.[7,8,9] Figure 1 shows the viscosity profile of the FR-SBF plotted against the upper and lower limits of the "Sag Window" and, from this, one can see that the FR-SBF has a low potential for exhibiting dynamic barite sag.

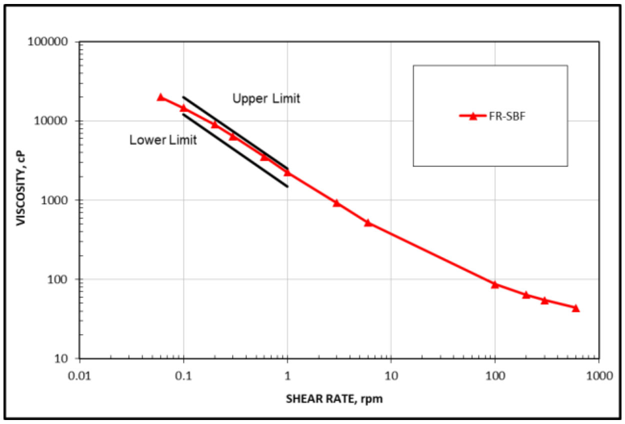

Figure 1 – Viscosity profile of FR-SBF vs "Sag Window"

The Viscometer Sag Shoe Test (VSST) is a density-based test designed to measure the tendency of a drilling fluid to exhibit dynamic barite sag.[9] The test uses a rotational viscometer and a thermoplastic inset for purposes of concentrating sediments and facilitating ease of sampling fluids for testing. Field experience shows that fluids having density variations <0.5 lbm/gal in VSST tests also exhibit a low potential to exhibit dynamic barite sag. Table 2 below presents results of VSST testing of a typical FR-SBF and the low tendency of the fluid to exhibit dynamic barite sag.

Table 2 – VSST sag test results of FR-SBF

	VSST
Initial MW (lbm/gal)	13.55
Final MW (lbm/gal)	13.90
Delta (lbm/gal)	0.35

Measurement of static barite sag potential was also part of the formulation design process as shown below in Table 3. Static sag tests conducted at periods ranging from 24-168 hours demonstrate the performance of the FR-SBF in minimizing density variations arising from static barite sag.

Table 3 – Static Sag Tests (FR-SBF)

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Test Temperature, F	275		
Initial Weight, ppg	13.55		
Cell Number	6	33	34
Test Hours	24	72	168
Syneresis, ml	1	2.4	13.6
Top Layer (150 ml), ppg	13.13	12.97	12.58
Middle Layer (100 ml), ppg	13.4	13.4	13.64
Bottom Layer (100 ml), ppg	13.62	13.97	14.1
Δ Density, (Bottom - Initial), ppg	0.07	0.42	0.55
Sag Factor (Bottom / (Bottom + Top))	0.509	0.518	0.528

The team developed the SBFs at a recently commissioned Technology Center in Katy, Texas. The Technology Center is a 102,685 square-foot complex which features 37,000 square feet of laboratory space for product development, testing and training. The lab is also home to a one-of-a-kind drilling simulator and a full range of world-class analytical capabilities. The Technology Center shown below in Figure 2 operates within an ISO 9001:2015 and API Q2 certified Quality Management System (QMS).

Figure 2 – Technology Center

The Technology Center is equipped with high-temperature, high-pressure viscometers capable of measuring rheological properties at temperatures ranging from 40°F to 600°F, and pressures up to 30,000 psi. One of these can perform pressure-volume-temperature (PVT) tests and another is able to perform dynamic sag tests over a range of inclinations. In addition, static barite sag tests can be performed up to 500 °F and 30,000 psi. Additional capabilities and instrumentation in the Technology Center include:

- Downhole Simulation Cell (275°F and 5,000 psi)
- HP-HT Lubricity Tester (HLT)
- Consistometer
- Dynamic Fluid Loss Tester
- Permeability Plugging Tester (2,000 - 6,000 psi)
- High Pressure Liquid Chromatograph
- Ion Chromatograph
- Auto titrator
- Gas Chromatograph Mass Spectrometer
- Spectronic 20D Spectrophotometer
- Helium Pycnometer
- Brookfield DV-III Viscometer
- Linear Swell Meter
- Inductively coupled plasma-optical emission spectrometer
- Return permeability tester
- Digital microscope
- Scanoelectric Microscope (SEM) with Electron Dispersive Scanner (EDS)

Other sample analysis capabilities include Dynamic Image Analysis of individual particles to determine particle size distribution, morphology and classification between 1 and 2000 micrometers. Elemental composition is determined using X-Ray Fluorescence and ranges from Beryllium to Uranium at concentrations between $1.0\text{x}10^{-3}$ to 100%. Sample topography including pore throat analysis using SEM can be characterized up to 130,000-x magnification with maximum resolution of 20 nm. Energy Dispersive Spectroscopy is available for elemental analysis at a point, along a line or in an area. The development team used much of the instrumentation listed above in the course of their system design activities.

Port Fourchon Facilities

Key enablers in the drilling and completion fluids value chain include facility placement, capability and capacity. Liquid mud plants (LMPs) are strategic drilling and completion fluid facilities located in close geographic proximity to the operational area. Operators place importance on capacity, the ability to mix specialized fluids, to transfer fluids at high pump rates and to simultaneously mix, load and transfer fluids.

Operational efficiencies in deepwater are improved when leveraging the distribution and logistical benefits of best-in-class facilities, such as the newly commissioned offshore supply base in Port Fourchon shown below in Figure 3.

Figure 3 – Port Fourchon LMP

The facility was designed following Design for

Manufacturing (DFM) concepts and processes such as process automation, Lean principles and Six Sigma process for reducing variability in preparing the SBF for offshore use.[10]

The facility has over 80,000 bbl of fluid storage and the ability to mix up to 16,000 bbl/day depending on fluid type and density. The facility has three stations that can transfer up to 2,000 bbl/hour using Coriolis mass fluid meters (CMFM) as shown in Figure 4. These features allow the facility to simultaneously support five GoM deepwater rigs.

Figure 4 – In-line Coriolis meter (flow rates & density)

The highly-tailored nature of SBF creates a compelling case for repeatability of formulations to deliver consistency in results. Standardization in the SBF preparation process becomes a requirement in order to drive predictability and reduce variability of fluids prepared at the LMP. Automation enhances both consistency and repeatability of processes and activities at the LMP, providing standardized and reproducible SBF preparation. Figure 5 shows the control center at the facility, where an on-site supervisor electronically controls mixing and pumping operations.

Figure 5 – LMP central control center

The fully automated Port Fourchon facility has the ability to simultaneously mix, transfer and off-loads fluids. Mixing and storage tanks are closed-top, which improves health, safety and environmental (HSE) performance and eliminate incorporation of debris. The storage tanks are equipped with electronic volume meters and alarms.

The facility design enables "hands-off" operations as a means to drive quality and HSE performance. From the control center, the supervisor has the ability to electronically open and close valves in the mixing, storage and transfer workflow using actuators shown in Figure 6. The "hands-off" operational environment reduces hand injuries and enables simultaneous mixing and transferring fluids to multiple offshore supply vessels.

Figure 6 – Automated control valves

The LMP design also includes a bulk salt delivery system which safely and rapidly consumes super-sacks of salt when preparing large volumes of riserless kill fluids (RKF). Furthermore, the rapid salt delivery system, shown in Figure 6, can transfer salt to any and all of the mixing pits facilitating parallel processing of drilling fluids; providing both flexibility, and redundancy in process features.

Figure 7 – Bulk salt delivery system

Traditional mud plant processing equipment, to include impellers, low-pressure jet nozzles, and mechanical agitators, present opportunities for improvement in the FR-SBF preparation process. An innovative and inherently safe, low-pressure solution, utilizing controlled cavitation has been shown to be an effective method of improving fluid preparation.[11] The high-shear, controlled-cavitation (HSCC) mixer, shown in Figure 8, optimizes LMP efficiency in the preparation of the SBFs.

Figure 8 – In-line shear device (HSCC)

Many GoM operators see intrinsic value and operational efficiencies in seamless integration of drilling fluid and completion fluid solutions from a single service provider. Key drivers on the preference to bundle purchases of drilling and completion fluids include ease of contract management, risk reduction and the ability to use the same offshore personnel when transitioning operations from drilling to completions. Operators also place great importance on capacity and proximity of drilling and completion fluids facilities in Port Fourchon as means to drive logistical efficiencies. With this in mind, a new completion fluids facility, with 17,000 bbl of fixed mixing and storage capacity, has been commissioned to service the GoM market (Figure 9). The new facility has 5,000 bbl of total mixing capacity and is capable of preparing custom blends of completion fluids, as well as preparation of special fluids such as wellbore cleanup (WBCU) displacement spacers.

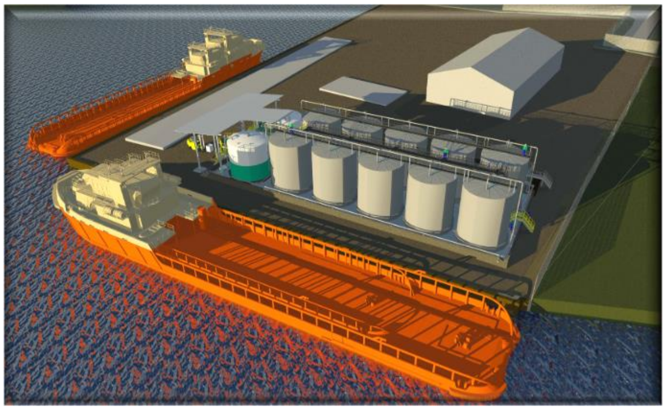


Figure 9 – Completion Fluid facility (Port Fourchon)

The completion fluids facility is adjacent to the drilling fluids facility as shown in the aerial view of Port Fourchon shown below in Figure 10. Efficiencies in distribution and logistics arise with placement of the completion fluids facility (below left) and drilling fluids facility (below right) in close proximity to one another.

Figure 10- Aerial photo showing the 2 Fourchon facilities

Engineering Solutions

Proper planning and execution for deepwater wells keys on annular pressure management because of problems related to wellbore ballooning, lost circulation, and shallow water flows.[12] Because non-aqueous fluids (NAF) are sensitive to temperatures and pressures, both density and rheological properties of these drilling fluids fluctuate with changing downhole conditions. Modelling software predicts, monitors, and helps manage annular pressures. Figure 11 presents a three-dimensional surface plot of the rheological properties of the FR-SBF over the range of downhole temperatures and pressures in a planned GoM deepwater well. The model curve fits each rheological set of high pressure, high temperature (HPHT) data at different pressures and temperatures to a Herschel Bulkley model, converting the 3-fit parameters over pressure and temperature to stress surfaces. The conversion uses a tension spline procedure to preserve the interpolation of the original data and achieve the desired smoothness. The modeling software controls extrapolation by fine-tuning a tension factor. Later, the hydraulics solver samples these surfaces to produce smooth friction factors that help yield accurate prediction of downhole frictional pressure losses. The surface plot of rheological properties shown in Figure 11 depicts the spline-fit shear stresses over expected wellbore pressures and temperatures. The software numerically solves a system of two-phase, non-isothermal hydrodynamic equations. The model segregates the wellbore into discrete cells, from which it considers fluid density and rheology based on local temperature and pressure conditions. The model also considers cuttings loading and drill string interaction within each cell.

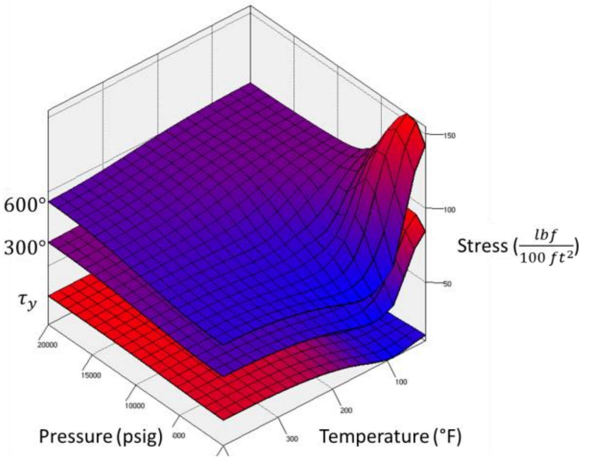
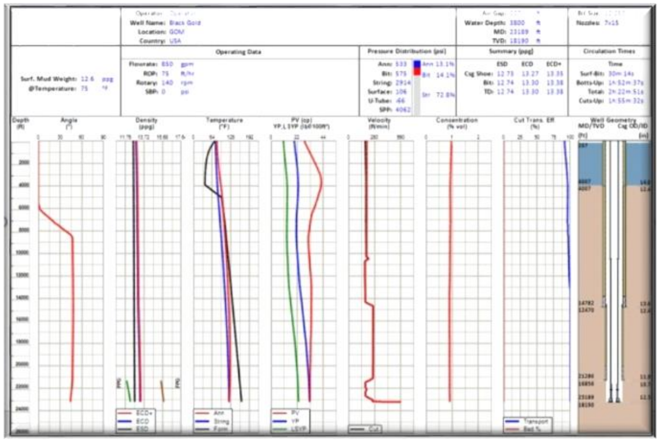


Figure 11 – Surface plot of rheological properties

Figure 12 compares the pressure management performance of the FR-SBF in a narrow pressure window, presenting a single-page summary of key and important hydraulic modeling parameters in deepwater drilling operations, to include predicted ECD, rheological profile, temperatures, annular velocities and hole cleaning profiles aligned with wellbore geometry.


Well Name: Black Gold
Location: GOM
Country: USA
Water Depth: 3800 ft
MD: 23189 ft
TVD: 18190 ft
Nozzles: 7x15
Surf. Mud Weight: 12.6 ppg
@Temperature: 75 °F

Operating Data
Flowrate: 850 gpm
ROP: 75 ft/hr
Rotary: 140 rpm
SBP: 0 psi

Pressure Distribution (psi)
Ann: 533
Bit: 575
String: 2914
Surface: 106
U-Tube: 66
SPP: 4062
Ann 13.1%
Bit 14.1%
Str 72.8%

Summary (ppg)

	ESD	ECD	ECD+
Csg Shoe:	12.73	13.27	13.35
Bit:	12.74	13.30	13.38
TD:	12.74	13.30	13.38

Circulation Times
Surf-Bit: 30m 14s
Botts-Up: 1h:52m:37s
Total: 2h:22m:51s
Cutts-Up: 1h:55m:32s

Figure 12 – Summary of key hydraulic parameters

The modelling software includes a portfolio of ancillary technologies designed to deliver incremental value from use of the FR-SBF, including engineered wellbore strengthening (WBS) solutions. An important drilling fluid design consideration is minimization of filtrate invasion to the porous rock matrix in order to reduce the risk of differential stuck pipe, downhole losses, formation damage and excessive filter cake.[13] A proprietary WBS modelling software identifies the appropriate bridging utilizing the Ideal Packing Theory (IPT).

After drilling to a planned total depth, operations move towards completions by preparing the reservoir interval for production or injection. The initial phase of the completion operations is WBCU, to include displacement (removal) of residual fluids and materials from the wellbore, followed by placement of clear-brine completion fluid (CBF). The WBCU process for cased and open hole sections requires careful planning from chemical, rheological and mechanical perspectives. Poor displacements often create problems in completion operations including stuck packers, corrosion of tubulars, issues with setting completion tools and cement placement, increased filtration time and cost, increased disposal costs and the inability to deliver expected production or injection. Operators generally recognize that engineered displacements reduce operating costs and the risk of failure.

Engineering software for WBCU operations model placement, pump rates, flow profiles, riser boost, as well as annular velocity, coverage and contact times for elements of the spacer train. It models as many as nine flow paths and twelve fluids used in a deepwater WBCU displacement. The software calculates circulating temperatures, pressures, ECD, volumes, horsepower and fluid compressibility and graphically presents the results to facilitate delivery of a competent displacement process, leading to reduced operational costs and improved project economics. The WBCU software allows the user to run animated, two-dimensional simulations of the displacement as shown below in Figure 13.

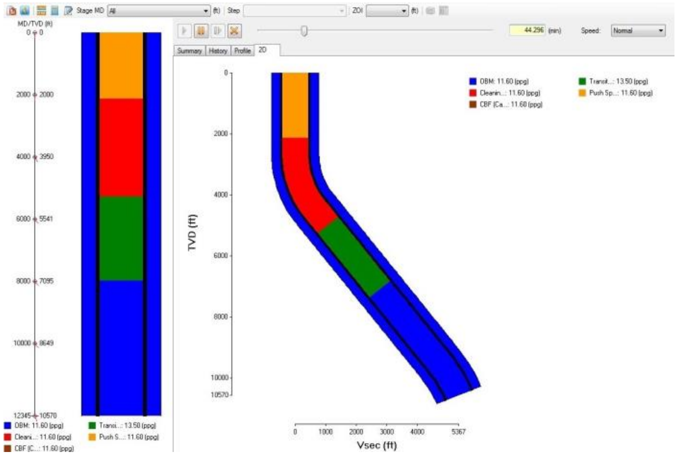

Stage MD: All
44.296 (min)
Speed: Normal

Figure 13 – WBCU displacement animation

Reservoir Fluids

The transition from the drilling phase to the completion phase is a distinct, discrete operation requiring specialized expertise as the reservoir is prepared for completions. Focus in this area allows operators to realize the full potential of their reservoir assets through the provision of an array of reservoir-focused solutions. A portfolio of integrated reservoir-focused solutions including RDF, WBCU and CBF ensure the reservoir section is successfully drilled and prepared for completion. It is important to drill and complete the reservoir section with products and systems engineered to protect the reservoir from damage, and maximize the productivity and injectivity of the reservoir asset.

RDF are the first and most obvious extension of drilling fluids technology into the reservoir interval. RDF must meet the drilling performance requirements of drilling engineers, while also achieving the reservoir integrity goals of completion engineers. RDF are designed to minimize formation damage, facilitate the installation of a successful completion and exhibit compatibility with the completion fluids used in subsequent completion activities. Key features of RDF include: minimally damaging to the reservoir interval, reduced skin, robust filtration and rheological profiles, readily removable filter cakes, wellbore stability and flow initiation pressure reduction.

Optimized RDF formulation and testing occurs in a specialized laboratory that has the equipment and capabilities to characterize the reservoir and perform the necessary sequence of tests to design and qualify the RDF. The Technology Center, introduced previously in this paper, is equipped with the instrumentation designed for use in the development of RDF tailored towards GoM open hole completions including:

- M9100 Return Permeameter
- VHX6000 Digital Microscope
- PPT and Modified HTHP Test Cells

Return-permeability testing is the standard to measure the properties of minimally damaging RDF. Return permeability methods using Hassler-type cells are cost-effective and timely when employed in RDF design. Attempts to standardize, establish repeatability or reproducibility, and improve return permeability testing are well documented.[14] The reservoir scientist establishes the base permeability of the core with a reference fluid at the bottom hole temperature of the target reservoir. It is essential that the fluid selected to establish the base permeability does not damage in the core. After capturing the breakthrough pressure and associated permeability, the reservoir scientist measures the return-permeability with the RDF using the same conditions as the base permeability test. The ratio of the RDF to base values gives the percent return permeability.

The return permeability unit shown in Figure 14 operates at temperatures up to 350°F and pressures up to 3,000 psi while testing a wide variety of fluids across a number of test scenarios. These fluids include both water-based and non-aqueous RDF, as well as breakers and acids.

Figure 14 – Hassler-cell permeameter

Figure 15 presents results of return permeability testing for an RDF designed for use in the GoM.

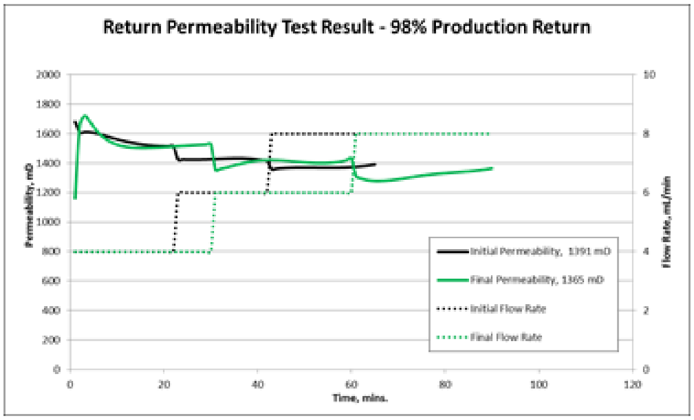


Figure 15 – Return permeability tests results

The scientist also uses a digital microscope to analyze the pores within the reservoir. The microscope has a 2000X magnification and utilizes 3D measurement software, as shown in Figure 16. Pre-analysis, the scientist prepares a thin section to evaluate the clean pores apparent within a formation, including the size of the pores and the identification of pores lined with clay mineral aggregates that have potential for plugging. This pore size analysis aids in optimizing the bridging package chosen to seal off the formation without plugging the internal structure. Subsequent, post-analysis evaluation provides information such as depth of invasion, extent of internal or external damage and a determination of clay minerals redistribution within the pores, potentially causing blockages.

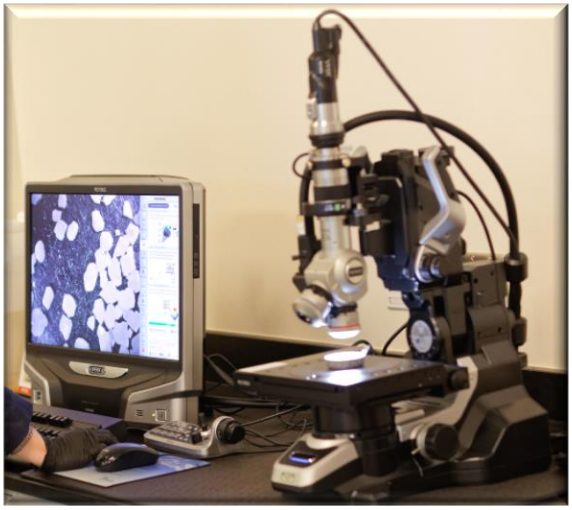


Figure 16 – Digital Microscope & Analysis Software

Acid soluble bridging additives mitigate lost circulation in highly fractured reservoir formations. Bridging software matches the particle size distribution of bridging materials to the pore size distribution of the reservoir as part of the RDF design process. The software design allows for use of the appropriate size and concentration of acid-soluble materials in the RDF solution for a given reservoir. High quality and acid-soluble ground marble bridging agents provide an efficient, cost-effective solution to mitigate downhole losses in the reservoir. These additives minimize formation damage and also reduce the risk of a lost circulation.

After reaching total depth in the reservoir section, the RDF filter cake is typically removed. Breakers, which decompose specific components of RDF filter cake, aid in the removal of the RDF filter cake in order to improve productivity or injectivity of the reservoir interval. The reservoir scientist typically designs the breaker in tandem with the RDF. Varieties of breaker technologies are available for use depending on the RDF type and CBF used.

Field Transformation

In the same timeframe as the development of the next-generation SBF and RDF solutions, facility upgrades and software deployment, two key international deepwater projects were undertaken using SBF. Case History #1 (Black Sea, Romania) and Case History #2 (Uruguay) briefly describe these projects. These global field applications captured lessons learned and best practices to facilitate progression of the new SBF to the GoM market. Case histories are also presented describing the FR-SBF and low-ECD SBF systems deployment in four GoM projects. Use of these SBF in conjunction with modeling software, WBS programs, and facilities drove operational efficiencies and cost reductions. Key deliverables from these projects include:

- Full environmental compliance
- Value delivery in narrow pressure window
- Reduction in downhole losses while cementing
- Reduction in downhole losses in depleted zones
- Elimination of stuck pipe in depleted zones
- Optimized hole cleaning efficiency
- Management of static & dynamic barite sag
- Improvements in operational efficiencies
- Reduction in non-productive time (NPT)

Case History #1

This first project in the program was a seven-well deepwater exploratory campaign in the Black Sea, offshore Romania.[1] The challenges inherent to the wells in this campaign included ECD management, downhole losses, wellbore instability, gas hydrate formation and shallow hazards. No dedicated facilities existed in this area to support large-scale deepwater projects. Infrastructure preparation in this project included the design and construction of two supply bases with the capacity to mix, condition and store large volumes of drilling and completion fluids for the multi-well campaign. All planned operational objectives were safely achieved because of detailed planning, commitment, and capital investments in assets and the infrastructure to support operations. All fluid volumes were safely prepared and delivered to the 5th generation semi-submersible for use in the target intervals.

Use of deepwater drilling and completion fluid solutions helped facilitate achievement of operational objectives on this multi-well, deepwater exploratory campaign. The ability to quickly mobilize and deploy assets, coupled with access to an experienced, multi-functional and multi-national team of drilling and completion fluid professionals served to enable the success of this project. This engineered approach facilitated delivery of operational objectives without incidents of fluids-related NPT.

Case History #2

The second project was a record ultra-deepwater exploratory well in offshore Uruguay, drilled at a water depth in excess of 11,500 ft.[2] Operations on this record well were conducted in a remote frontier area, placing greater importance on thorough pre-well planning and execution to minimize risks. The drilling campaign occurred in an area without an established oil and gas industry, facilities or infrastructure to support an ultra-deepwater drilling program. Additionally, the water depth approached the operational limits of the drillship. Drilling in a frontier offshore area adds layers of complexity due to inherent uncertainties and risks associated with these types of operations. The use of project management techniques, combined with application of FR-SBF technologies, served to mitigate and reduce project risks. A thorough and comprehensive readiness review, coupled with communications processes, reinforced the project management loop. Drilling operations were supported from a supply base equipped with an LMP, bulk facilities, a full service laboratory and raw materials for FR-SBF fluids used in the well construction process. Use of the FR-SBF allowed for achievement of all drilling objectives in this record well. All planned operational objectives were safely achieved in accordance to the project plan, and without incidents of fluids-related NPT.

Case History #3

The third project was the plug and abandonment of a GoM deepwater well in Mississippi Canyon field with a water-depth of 5,500 ft.[3] The operator chose the system following a rigorous and demanding approval process. Key operational parameters in the pre-well planning phase included displacement efficiency, contamination, tight tolerances and management of static and dynamic barite sag. Laboratory testing ensured optimization of rheological, filtration control and emulsion stability parameters towards preparation of the FR-SBF at the Port Fourchon supply base.

The inline shearing device optimized the rheological and emulsion stability properties of the FR-SBF. Placement of the shearing device in the design process ensured delivery of a robust and fit-for-purpose fluid, and reduced the risk of barite sag prior to circulating through the drill bit. The fluid proved to be robust and easy to maintain within specifications in all phases of the operation. The robust nature of the FR-SBF was demonstrated while encountering interfaces and contaminants, such as seawater and cement spacers. The fluid maintained a flat rheological profile despite encountering these contaminants. At the completion of the campaign, the standby FR-SBF volume was offloaded from the supply vessel. Settling or sedimentation did not occur with this fluid despite having been subjected to slow and continual motion on the vessel for 44 days.

Case History #4

The fourth project was a 3-well scope of work, which used the FR-SBF while drilling geological sidetrack intervals in Ewing Bank field of the GoM. While drilling the first well of the project, two geographical sidetrack intervals used the FR-SBF. The operator drilled the first interval through depleted sands with a directional assembly at an inclination of 40° and then set an expandable liner. No downhole losses or NPT events occurred even while cementing the expandable liner. The engineered program included the FR-SBF and WBS additives to facilitate the delivery of the operational objectives in this interval. The second interval maintained the 40° hole angle. Fluid density exceeded 15 lbm/gal prior to running and cementing a 5” liner without the incidence of NPT.

On the second well, the operator set a whipstock, milled a window and then drilled two intervals while building angle to 30°. The Port Fourchon LMP staff pretreated the FR-SBF with WBS additives in anticipation of drilling depleted intervals. While drilling the depleted zones, sweeps of WBS materials prevented losses. After running and cementing a 7-5/8” liner, the operator drilled the second interval. FR-SBF densities exceeded 15.5 lbm/gal prior to running and cementing a 5 ½” liner. Neither interval experienced fluids-related NPT, while minimal losses of FR-SBF occurred during cementing operations.

Like the two preceding wells, the third well of the project also had two geological sidetracks. The operator milled a window in the 9-5/8” casing and drilled the first interval through the depleted zone with the FR-SBF to a hole angle of 37° without the incidence of NPT or downhole losses. On the second interval, which held a 29° angle, fluid density exceeded 15 lbm/gal. The engineered WBS solutions facilitated delivery of all drilling and liner running operations through the known depleted zones.

Case History #5

The fifth project was the first test of the low-ECD SBF in the GoM. For the two riserless sections, the Port Fourchon LMP built 25,000 bbl of high density, salt-saturated RKF. Then, for the intermediate sections, the LMP built and loaded out 14,000 bbl of the low-ECD SBF as designed for the operating conditions of this well.

The application of the system addressed the operator’s requirements of a SBF designed to minimize ECD and surge pressures, while also optimizing hole cleaning efficiency when drilling at high ROPs. A thoughtful strategy for use of WBS additives was developed in anticipation of drilling known depleted intervals. This included maintaining a background concentration of WBS, coupled with use of sweeps of WBS additives while drilling the depleted zones. Use of the fluid, along with the WBS strategy, allowed for drilling the depleted zones without the incidence of NPT or downhole losses. Output from the hydraulics software correlated well with pressure-while-drilling (PWD) tool measurements and the software provided important insights into hole cleaning and ECD performance while drilling. Use of the low-ECD SBF facilitated improvements in operational performance, to include increased ROP and hole cleaning efficiency, along with the ability to maintain ECD and eliminate downhole losses in a narrow margin environment. Use of the low-ECD SBF and adjacent technologies created new standards of operational performance in this field of the GoM deepwater market.

Case History #6

The sixth project, located in the Mississippi Canyon field of the GoM, was the second application of the low-ECD SBF. This well plan presented operational challenges because it was a sidetrack with a complex trajectory, longer hole interval, and greater potential for experiencing losses in the depleted zones.

The first challenge was to re-enter and remove the incumbent fluid the original wellbore. The low-ECD SBF displaced the incumbent fluid in a single circulation, with only minimal interface and contamination. The next phase of the operation was to mill a window and sidetrack the existing wellbore using the system for both operations, which reduced cost and increased logistical efficiencies. The operational performance of the fluid and adjacent technologies allowed the operator to drill at high ROPs while also maintaining ECD and hole cleaning parameters within expected limits. Hydraulics modeling predicted ECD and hole cleaning efficiency across a range of operational scenarios.

The WBS strategy minimized losses while drilling the depleted zones in the last two intervals. The engineered WBS program included types, sizes and concentrations of additives tailored for use on this well. The background WBS consisted of sized ground marble and sized graphite WBS additives. The low-ECD SBF and adjacent technologies allowed the operator to drill the two known zones of depletion without the incidence of NPT and only minor downhole losses. This was the first well in the field not to experience major losses while drilling the depleted zones. This well, like the previous well, created a new standard of operational performance in this field of the GoM.

Results, Conclusions and Lessons Learned

- The GoM deepwater environment presents the potential for a variety of operational challenges.
- The development and field trials of the next generation FR-SBF and low-ECD SBF has driven operational efficiencies in the GoM deepwater market.
- The FR-SBF exhibits a rheological profile that is nearly independent of temperature and pressure conditions typically encountered in deepwater operations.
- The low-ECD SBF manages pressures in a narrow margin environment without greatly sacrificing the consistent rheological profile.
- Both SBF formulations offer significant reductions in fluids related NPT and operational costs.
- Operational efficiencies in deepwater are improved when leveraging the distribution and logistical benefits of best-in-class facilities.
- Newly commissioned facilities for drilling and completion fluids are in place and positioned to support GoM deepwater operations.
- A new family of RDF and breaker technology have been designed to deliver incremental value in GoM open hole completions.
- Use of the FR-SBF solution has facilitated safe delivery of GoM deepwater drilling objectives in narrow pressure environments.
- Use of the low-ECD SBF and adjacent technologies created new standards of operational performance in the GoM deepwater market.

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Nomenclature

GoM – Gulf of Mexico
SBF – synthetic-based fluid
ROP – rate-of-penetration
ECD – equivalent circulating density, lbm/gal (sg)
NPT – non-productive time, hours
FR-SBF – flat-rheology, synthetic-based fluid
RDF – reservoir drill-in fluid
F – temperature, Fahrenheit
TD – total depth, feet
PV – plastic viscosity, cP
YP – yield point, lbf/100 ft^2
lbf/100 ft^2 *- pound force per hundred square feet*
lbm/gal, ppg – density, pounds of mass per gallon
psi, psig – pressure, pounds per square inch
RPM – rotations per minute
ml – milliliter
ISO – International Standardization Organization
API – American Petroleum Institute
QMS - quality Management System
PVT – pressure, volume & temperature
HLT – high pressure, high temperature lubricity meter
LMP – liquid mud plant
DFM - design for manufacturing
bbl – oilfield barrel, 42-gallons
bbl/hr – barrels per hour
CMFM – Coriolis mass flow meter
HSE – health, safety and environmental
RKF - riserless kill fluid
HSCC - high-shear, controlled-cavitation
WBCU – wellbore cleanup
NAF – non-aqueous fluid
HPHT – high pressure, high temperature
WBS – wellbore strengthening
VSST – viscometer sag shoe test
IPT - Ideal Packing Theory
CBF – clear brine fluid
PWD – pressure-while-drilling

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