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Tailored for Success: Reservoir Drill-In and Breaker Fluids Customization to Achieve Optimized Well Productivity—A Case Study

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Abstract

The Frio formation is one of the largest hydrocarbon producers in the Texas Gulf Coast and Gulf of Mexico region. This formation can be a challenging environment with high inclination wells, varying formation pressures, and potential for wellbore instability in highly reactive, stressed interbedded shale and sandstone sections. Overcoming this challenging environment requires the need for specially designed and tailored reservoir fluids to maintain wellbore stability while protecting the reservoir from drilling fluid damage to drive maximum productivity of the reservoir interval.

Using the reservoir rock morphology, lithology and calculated pore size distribution, fluids were designed and optimized in the lab. Careful design and significant lab testing was conducted to develop a tailored suite of fluids using a divalent reservoir drill-in fluid (RDF) and acid precursor chemistry breaker to provide exceptional wellbore stability while minimizing the risk of damage to the production zone. Both the RDF and acid-precursor breaker were designed to meet the temperature and targeted time before acid hydrolysis requirements, without damaging the reservoir.

This paper highlights the technological and HSE advantage of using a tailored RDF and acid-precursor breaker composed of divalent and/or monovalent base brine types, the laboratory testing performed to develop the systems, and how the fluid designs led to productivity enhancement and sustainable oil production.

Introduction

When drilling into the reservoir in the Frio formation of East Texas, many challenges are faced that require an extensive amount of planning and thorough testing. The Frio sand is known to have areas of pressure depletion which require monitoring of wellbore indicators. The Marg and Anahuac Shale just above the Frio sands is a highly reactive bentonite area requiring a fluid designed with mindful consideration of shale reactivity. This bentonitic area includes a frequent fault crossing in the horizontal lateral introducing significant drilling and completion risks by faulting out above into shale sections above the Frio. These lateral projections can be observed in Figure 1 below.

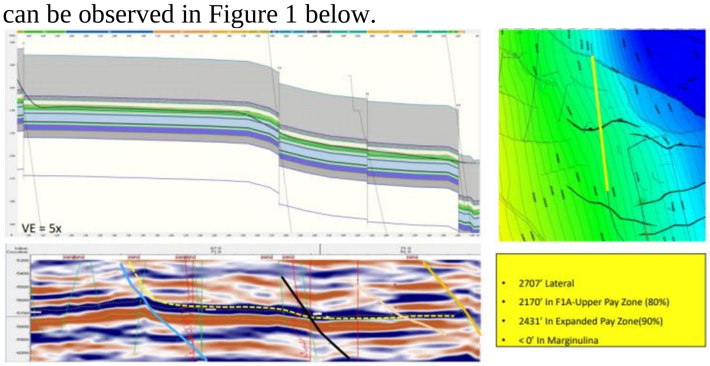


Figure 1: Wellbore Planning and Projected Faulting

To overcome these challenges and more, a specialized divalent RDF was tailored for this East Texas Producer to work in conjunction with a delayed acid-precursor breaker. These fluids were designed to provide an RDF with reduced near-wellbore damage while achieving a uniform removal of the deposited filter cake during the completion phase. Wellbore stability concerns stem from a MEM study that indicated a tight window between pore and fracture pressure. Proper fluids management allows for better control of mud weights, filter cakes, more efficient trips and proper displacements.

When designing the RDF and completion fluid, it is essential to firstly protect the reservoir zone during drilling, then facilitate unimpaired production post-completion. The divalent-based RDF's and breaker fluids are designed utilizing plant-based chemistries from renewable resources to not only optimize the drilling process but reduce the exposure risks and environmental impact associated with the use of drilling fluids.

Experimental Evaluation- Fluid Design and Tailoring

A few key factors must be considered when designing an RDF including minimizing skin, robust filtration and rheological profiles, readily removable filter cake, wellbore stability and flow initiation pressure reduction (Gray et al. 2020). Designing the RDF and breaker fluid with consideration of the reservoir's chemical and mechanical properties is

essential to ensuring the integrity of the wellbore and maintaining stability.
The requested scope of the RDF design included

- 10.6-10.8 lb/gal RDF
- 14-25 µm pore size
- 200 to 600 mD permeability
- BHST 140-164°F
- HTHP Fluid Loss ALAP
- 30-60 ppb CaCO3
- Shale stability
- Environmentally friendly drilling fluid compared to OBM

Optimized formulating of the RDF began with utilizing bridging software shown in Figure 2 to match the particle size distribution of the bridging agents used in the formulation of the RDF to the pore size distribution of the reservoir. This proprietary software is based on the model of the Ideal Packing Theory (IPT) which can be defined as the full range of particle size distribution required to effectively seal all voids, including those created by bridging agents (Lai, 2015).

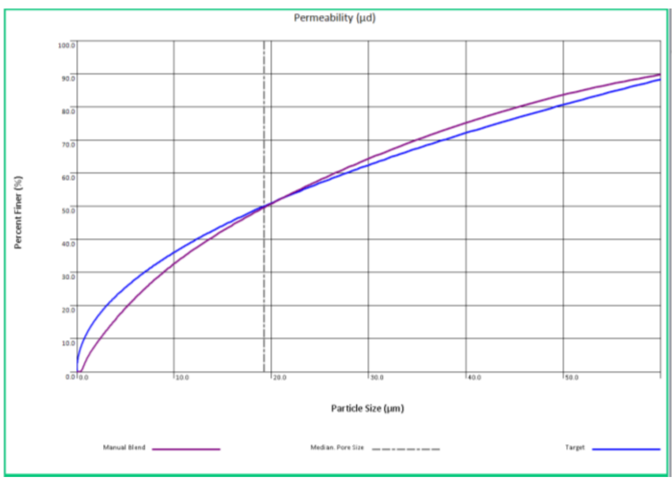


Figure 2: Particle Size Distribution Modeling Using Bridging Software

Laboratory Fluid Design

Once the RDF conceptual design was established based on the specifications set forth by the customer and geological characteristics, lab testing was conducted at the Technology Center in Katy, TX. With the challenges set before the technology team, a rigorous design and selection process of divalent brine-based RDF and divalent and monovalent based delayed acid breaker systems began. This comprehensive laboratory testing led to a finalized fluid sequence tailored to the challenging Frio formation ready for field trial application. The final RDF and breaker fluid formulation designs are below.

Table 1: RDF Fluid Design

10.6-10.8 ppg Reservoir Fluid Design	
Component	**Description**
11.6 lb/gal Calcium Chloride Brine	Base Fluid
Water	Dilution Base Fluid
Magnesium Oxide	pH buffer
Proprietary Starch for divalent brine	Fluid Loss Polymer
Clarified Xanthan	Viscosifier
Calcium Carbonate	Bridging Package
Shale Inhibitor	Inhibits shale reactivity
Biocide	Bacteria Prevention

Table 2: Breaker Design

8.8 ppg Delayed Acid Precursor Breaker Design	
Component	**Description**
4% KCl Brine	Base Fluid
Acid Precursor	Dissolution of acid soluble materials
Buffer	Acid Precursor Buffer
Starch enzyme	Starch breakdown
Xanthan Enzyme	Xanthan breakdown

Laboratory and Field Testing

➢ Rheological Properties, pH, Chlorides

Fluid preparation for the $CaCl_2$ based RDF consisted of utilizing a Multimixer in one lab barrel aliquots with shear rates of ± 11,500 rpm. All lab pilot samples were dynamically aged at BHST of 164°F.

Table 3: RDF Properties Lab vs Field

	10.6 ppg Lab Pilot Pre-Dynamic Age	**10.6 ppg Lab Pilot** Post 16 hr Dynamic Age	**10.8 ppg Field Sample** at TD
Temperature of Dynamic Age	-	164° F	-
Properties, °F	120	120	120
600 rpm	94	98	79
300 rpm	66	65	53
200 rpm	53	50	41
100 rpm	35	34	27
6 rpm	8	7	6
3 rpm	6	5	4
PV	28	33	26
YP	38	32	27
10 sec gel	7	5	5

10 min gel	9	7	9
pH	8.57	8.49	9.2
Chlorides (Mg/L)	-	121,000	175,000

➢ *Modified HTHP Fluid Loss for Lab Pilot*

Fluid loss testing was conducted (post dynamic aging) at 164°F with 500 psi differential pressure on a 3µm (old) Aloxite disc using the 10.6 lb/gal RDF.

Table 4: HTHP Fluid Loss

Density of Fluid, lb/gal	**10.6 RDF**
Aloxite Disc Size:	3 µm (old)
Temperature (F)	164°F
Spurt HTHP (ml)	1.6
30 min HTHP (ml)	6.2
Filter Cake Thickness (32nd)	1

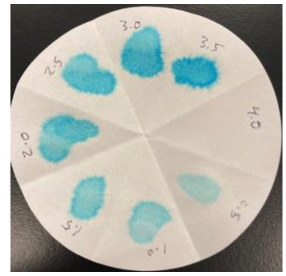
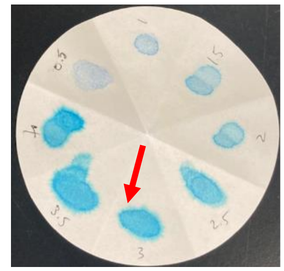
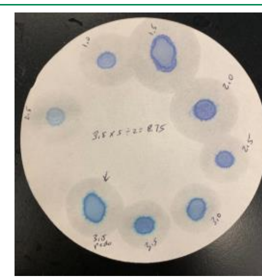
➢ *Methylene Blue Test Lab vs Field*

The methylene blue testing (MBT) was conducted on two lab pilot RDF samples and a sample from the active field system for comparative analysis. The MBT test is a method of measuring the absorption of methylene blue by cation exchange to clay minerals in a fluid. One sample of lab pilot RDF contained no clay while the other sample contained 4% w/w clay contamination.

MBT Results Lab vs Lab with Solids Contamination vs Field Sample

Table 5: MBT Results, ppbe

	Methylene Blue Concentration, ppbe		
	Lab Pilot Base	Lab Pilot Contaminated	Field Sample
MBT, ppbe	0.0	15.0	8.75

RDF	**Photo of MBT Results**
No Clay **Lab Pilot Test**	
4% w/w API Clay Contamination **Lab Pilot Test**	
Fluid – ~1,900 feet lateral drilled **Field Sample**	

➢ *Production Screen Test (PST)*

PST was conducted on the 10.6 lb/gal lab pilot RDF to determine any adverse plugging effects from the RDF on the screens supplied by the customer. The supplied screens were a 233 x 30 mesh count reverse dutch twill weave type. The time to flow 1000 mL of fluid through the screen at 10 psi was recorded four consecutive times. There was no significant lag in flow time or plugging observed during testing.

The lab pilot RDF was next contaminated with 4% w/w clay. PST testing was repeated for the contaminated fluid. Overall, the flow rates were considerably slower than the uncontaminated sample but did not fully plug off the screens. The field RDF PST results passed and was similar to both lab sample test results. The field RDF PST had to pass three times before approval was given to pull out of the hole and run screens. Please see table below for a comparison of lab samples and field samples.

Table 6: PST Results; Lab Pilot vs Lab Pilot with 4% Clay Contamination vs Field

Cum. Volume, mL	RDF, sec	RDF with 4% Clay Contam, sec	RDF at TD while circulating the hole clean, seconds		
	Lab Pilot	Lab Pilot	Active	Active	Flowline
1,000	26.76	31.51	29.1	30.1	30.5
2,000	26.92	36.81	30.3	30.4	30.8
3,000	29.05	42.67	30.5	30.5	31.3
4,000	31.80	46.59	30.8	30.7	31.7

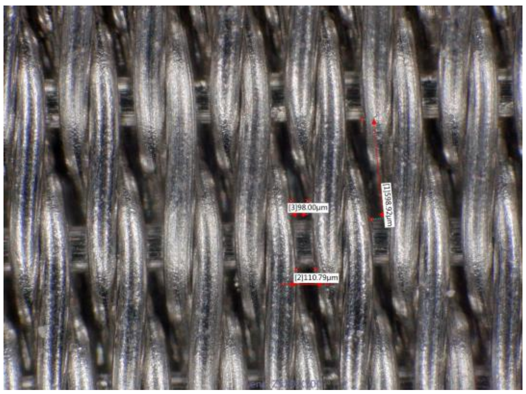


Figure 3: 100X Magnification Screen with Uncontaminated RDF

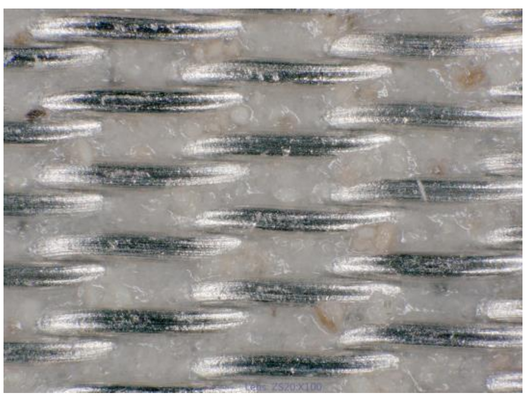


Figure 4: 100 X Magnification RDTW Screen with 4% Solids Contamination RDF

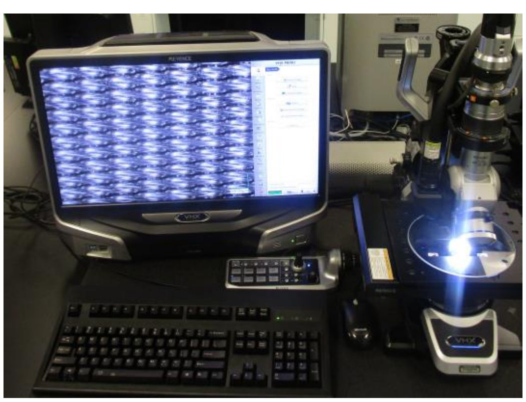


Figure 5: Keyence VHX-6000 Digital Microscope

➢ *Semi-quantitative FlowThrough Lab Pilot Test*

As part of the scope of work, a breaker system was formulated to remove the RDF filter cake. Flow through testing was conducted using a 3 µm aloxite disc pre-soaked in base fluid, then placed into a double-ended HTHP cell. Initial permeability rates were collected by recording the time in seconds to flow 200 mL of base fluid at 5 psi in the production direction, then calculating an average rate. Using the RDF, a 4-hour filter cake was built on the disc using 500 psi differential at 164°F.

The next step was to decant the residual WB RDF, leaving the filter cake on the aloxite disc, then carefully pour the formulated breaker along the inside side walls of the cell, being careful to not disturb the filter cake. The cell was next heated to 164°F with a differential pressure of 300 psi. After observing 10 mL of breakthrough, the cell was shut in and the breaker allowed to soak for 48 hours. After the prescribed soak time, the final permeability rates were established. Upon removal of the disc from the cell after permeability was established, a 15% HCl solution was slowly dropped onto the disc face to observe any potential reaction caused by remaining $CaCO_3$. No reaction occurred, indicating no $CaCO_3$ remained. An iodine solution was also placed onto the disc, as seen below to test for presence of residual starch. The iodine will turn a deep purple when starch is present. As seen in the Figure in Table 7, there was no starch remaining.

Table 7: Breaker Results using 10.6 ppg RDF with 8.83 ppg Breaker for 48-hour soak

Breaker Number	Units	8.83 lb/gal Breaker
WB RDF Density	lb/gal	10.6
Temperature	ºF	164
Initial pH	-	5.51
Post Soak pH	-	3.19
Production	**%**	**87.5**
Photo		

➢ *Formation Damage Lab Pilot Test*

Formation damage testing was conducted using the Grace M9100 HPHT Core Flow Tester. Core test samples used were sandstone samples with similar properties to the reservoir such as lithology, permeability and porosity. Testing conditions were set to simulate the conditions of the reservoir. The fluid used to simulate production was LVT-200 mineral oil. Initial permeability was measured and recorded when stabilized. The RDF was then applied to the core according to the customers directions to build the mud cake. During this period the fluid leakoff was measured. The breaker was then applied and allowed to soak for a given period of time. When the breaker soak was concluded the regain permeability was measured, taking care to note the lift off pressure needed to begin flow.

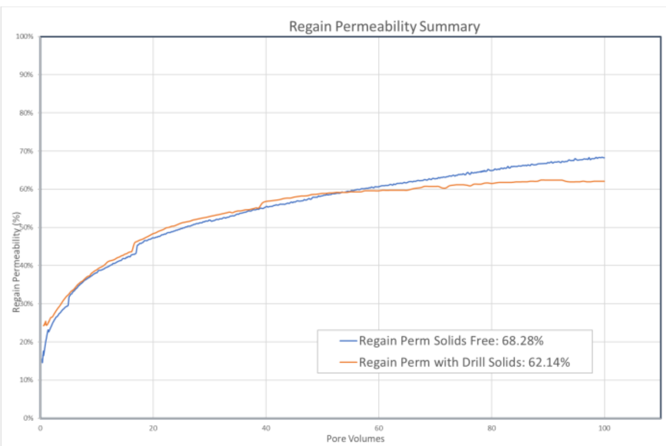


Figure 6: Regain Permeability Results

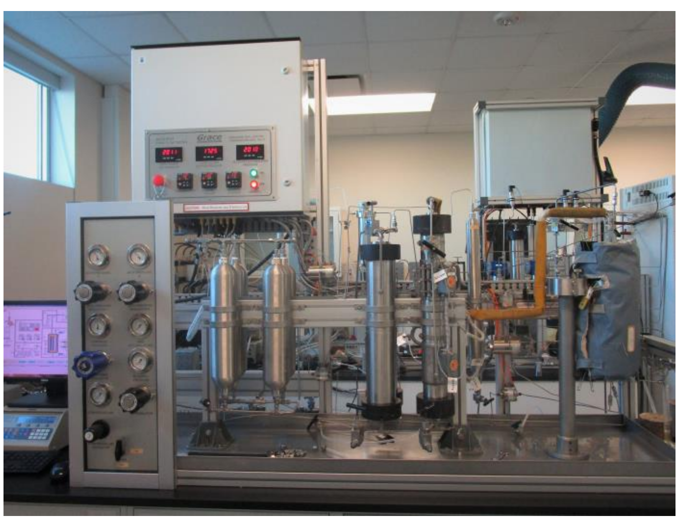


Figure 7: Grace M9100 HPHT Core Flow Tester

Case History-Field Trial

While drilling the intermediate intervals on the pad, all RDF and breaker and sweep base fluids were built on location. Building on location allowed for better logistical management. The RDF was built in 200 – 400 bbl batches which took approximately 4 to 6 hours each to build.

Prior to drilling out of the intermediate casing shoe, the wellbore was displaced from freshwater to RDF with two cleaning spacers preceding. Cement, casing shoe and formation were all drilled prior to performing a successful FIT. Drilling of the well to TD and cleaning of the well with a reamer run were both performed without issue.

Prior to pulling out after the reamer run, three PST tests were performed with all tests passing. Testing results can be found in Table 6.

While drilling the well, all key properties were maintained within desired specifications. Key properties included mud weight (10.6 to 10.8 ppg), LGS% (less than 8%), MBT (less than 10.0 ppbe) and average particle size distribution (14 – 25 microns, see figure 8).

These properties were controlled with whole mud dilution and screening up or down on the shakers as needed. Initial planning estimated a whole mud dilution amount of 218 to 364 bbl for the lateral lengths planned. Dilution rates averaged about 10 to 12 bbl of fluid per 100 feet drilled.

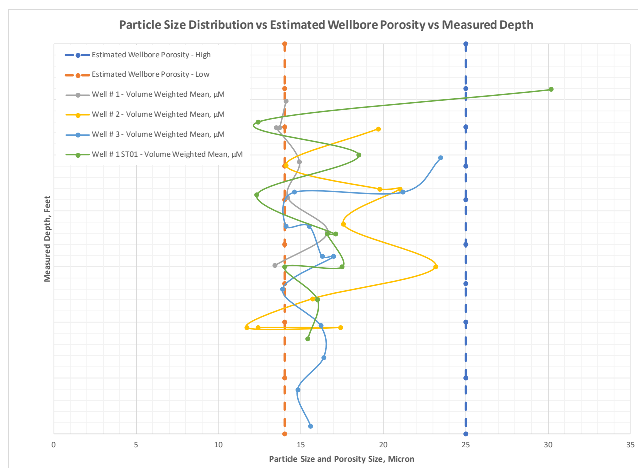


Figure 8: Average ROP of subject wells with estimated wellbore porosity

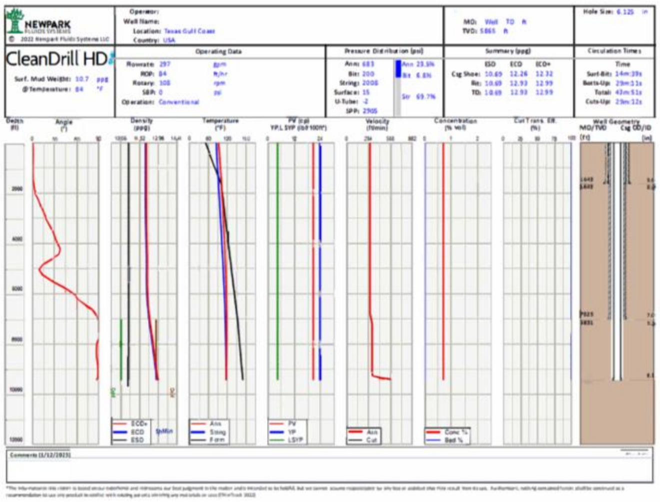


Figure 9: Estimated Hydraulics at well TD

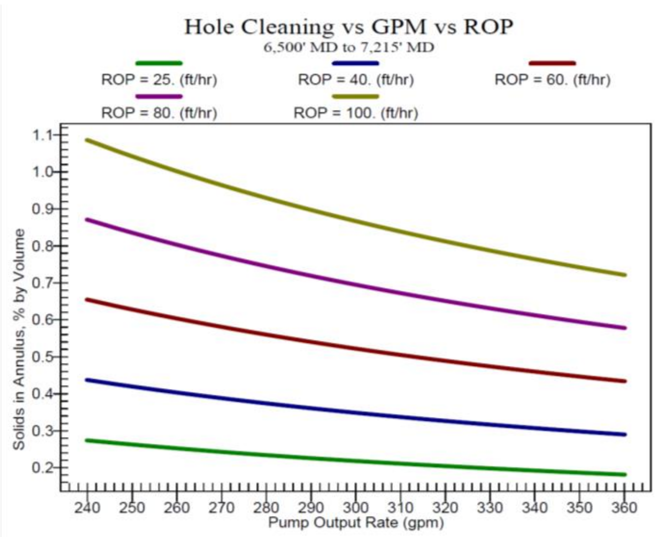


Figure 10: Hole Cleaning Models based on ROP and Flow Rates

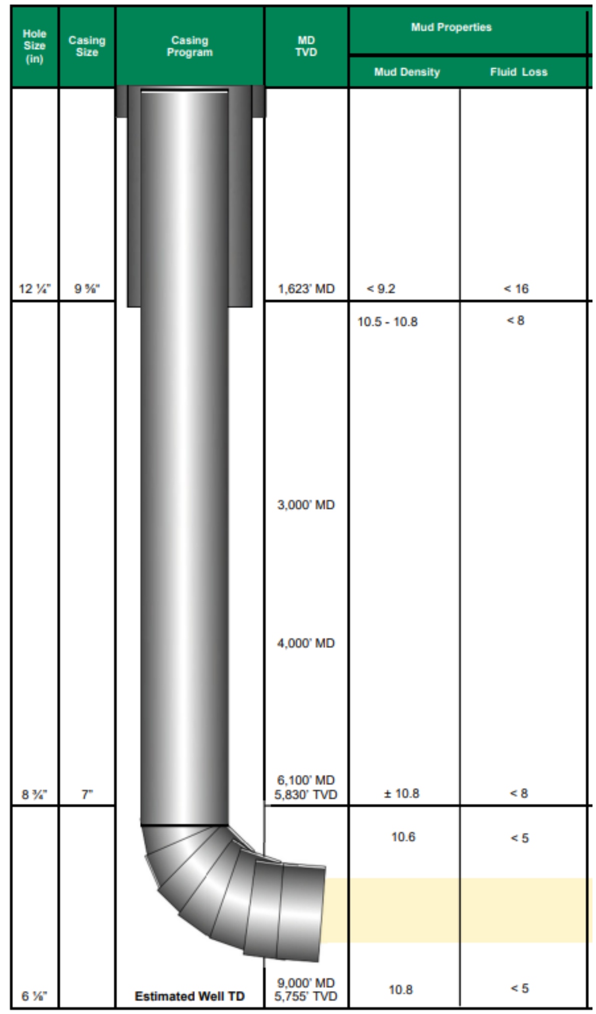


Figure 11: Wellbore Schematic for Well Planning

Conclusions

- RDF and breaker fluids designed in the lab meet all customer specifications and expectations.
- RDF and breaker fluids were deployed successfully in the field applications, achieved expectations.
- Increased productivity by significantly reducing positive skin.
- Operator A delivered twice as much completed lateral with fewer wells as Operator B in the same area of field
  - Operator A drilled 6000' completed lateral with 3 wells (2000'/well)
  - Operator B completed 7000' with 7 wells (1000'/well)
- Fluid volumes, properties, management, and performance were all maintained throughout the well.
- Able to run completion screen assembly to TD without incident
- Maintained superior fluid loss control while drilling interval
- Approximately 4,500 bbl of RDF fluid, 190 bbl of

breaker and 300 bbl of cleaning sweeps were all built on location while managing logistical and supply chain challenges to decrease trucking and improve ESG

- RDF and breakers are designed to be safe for the environment adhering to government regulations and ESG requirements

Acknowledgments

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Nomenclature

Define symbols used in the text here unless they are explained in the body of the text. Use units where appropriate.

RDF= Reservoir Drill-In Fluid
µm= micron
mD= milli Darcy
BHST= Bottom Hole Static Temperature
HTHP= High Temperature High Pressure
ALAP= As Low As Possible
$CaCO_3$*= Calcium Carbonate*
OBM= Oil-Based Mud
WBM= Water-Based Mud
BHA=Bottomhole assembly
MEM = Mechanical Earth Model
ECD= Equivalent circulating density
ROP= Rate of Penetration
HSE= Heath, Safety, and Environmental
TD= Total Depth
Bbl= Oilfield bbl, 42 gallons
PV= Plastic Viscosity, cP
YP= Yield Point, lbf/100ft^2
Rpm= Revolutions per Minute
TVD=True Vertical Depth
FIT= Formation Integrity Test
ppge=Pound per Gallon Equivalent
ppg= Pound per Gallon
ppbe= Pound per Barrel Equivalent
LGS%= Low Gravity Solids percent
MEM= Mechanical Earth Model

References

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2. D. Lai: “How to Optimize Bridging Blend to Seal the Formation Surface (Part I)”, Available from pvisoftware.com, September 2015