

Overcoming the Temperature Limitations of Brine-Based Reservoir Drill-in Fluids

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Abstract

For application at temperatures above 300°F, conventional brine-based reservoir drill-in fluids often use formate brines and supplemental thermal stabilizers. These fluids may survive dynamic ageing or short term static periods but break down after extended periods.

A novel brine-based system, featuring a newly developed synthetic polymer, has been developed to provide enhanced rheological profiles and fluid loss control, along with long-term stability under elevated temperature and pressure conditions. The system has been designed to minimize formation damage by forming a thin and ultra-low permeability filter cake and provide stability for logging runs at elevated reservoir temperatures- even those above 400°F.

The versatility of the developed polymer allows the new system to be formulated at a wide range of densities using most conventional oilfield brines including monovalent and divalent halides and the formate brines. The spectrum of the new system is not limited to only drill-in operations, but to a wide range of applications such as drilling, logging, completion and coiled tubing fluids.

A new breaker package was developed along with the system to slowly and uniformly clean-up its deposited filtercake, reducing near wellbore damage and maximizing production when the system is used to drill openhole completion wells.

This paper summarizes the development and presents performance data on the newly developed system formulated with different types of oilfield brines.

Introduction

Conventional brine-based reservoir drill-in fluids (RDFs) are typically based on biopolymers such as xanthan, diutan or starch to provide viscosity and solids-suspension properties. Such biopolymers suffer from thermal instability and undergo

degradation when exposed to temperatures above 300°F for extended periods of time ⁽¹⁾ due to oxidation and hydrolytic processes. This degradation results in a dramatic decrease in the rheological properties and suspension capabilities of the fluid along with an increase of the fluid loss filtered into the formation and the filtercake thickness. **Figure 1** shows the difference between a thin filtercake developed at low temperature (good fluid-loss control) versus a thick filtercake developed by the same fluid at high temperature conditions.



Figure 1. Thick filtercake vs. thin filtercake

Conventionally, formate brines and supplemental thermal stabilizers have been the most common solutions when water-based systems are needed in applications at high temperatures ⁽²⁾. However, these solutions not only resulted in high costs because of the use of expensive formate brines and thermal stabilizers, but also provided very limited long-term stability. See **Figure 2** for examples of unstable systems after HPHT ageing versus a stable system.



Figure 2. Unstable systems vs. stable system

A new system has been developed that overcomes the temperature limitations at high pressure, high temperature (HPHT) conditions (**Figure 3**) of brine-based RDFs, providing long-term stability, fluid-loss control, and suspension properties.

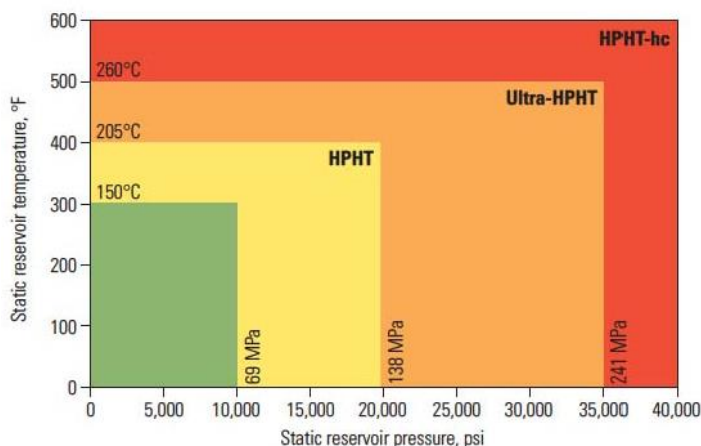


Figure 3. HPHT Interval (300°F to 400°F)

The new system is based on a newly developed synthetic polymer (*Polymer A*) able to provide long-term stability and fluid-loss properties for both monovalent and divalent brine-based systems.

The new system has been tested in the laboratory for its performance at temperatures between 300°F and 400°F. Brine compatibility, long-term stability, suspension capabilities, HPHT fluid-loss control, and contamination tests were performed in the laboratory to validate the system.

Overbalance pressure in the wellbore causes fluid invasion into the formation, resulting a filtercake being formed on the walls of the reservoir. A new breaker package has also been developed and tested in the laboratory to remove the filtercake and restore the permeability properties of the formation.

The new breaker Package required a combination of different chemicals, stable at HPHT conditions, to dissolve the solids present in the filtercake and degrade and disperse the synthetic polymer.

This paper describes performed laboratory testing and results for the new HPHT brine-based RDF and the breaker system developed to clean-up the produced filtercake under HPHT conditions.

New Brine-Based RDF Description

The new brine-based system has been developed along with the new *Polymer A* that overcomes the high-temperature limitations of conventional brine-based RDFs. The new brine-based RDF system is based on *Polymer A*, a customized, fully branched synthetic co-polymer.

Synthetic polymers typically have higher thermal stability than biopolymers. However, most of the commercially available synthetic polymers have demonstrated limitations such as low low-shear rheology, high-temperature gelation, poor suspension, and sagging issues, and can potentially cause formation damage. These limitations are mainly due to the linearity of these synthetic polymers.

To overcome these issues, the highly branched synthetic *Polymer A* was developed. The general structure of a highly branched polymer is illustrated in **Figure 4**.

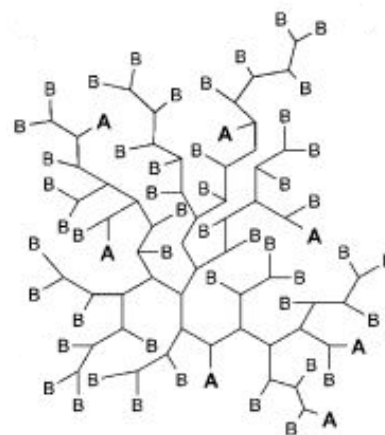


Figure 4. Highly branched synthetic polymer structure

Polymer A provides excellent low shear rate viscosity, almost zero sag potential, and no high temperature gelation, while minimizing potential formation damage. The newly developed polymer is compatible and disperses in most of the commonly used oilfield brines, including monovalent halide brines, divalent halide brines, and formate brines.

The new synthetic polymer also imparts excellent fluid-loss control to the system which, combined with correctly selected bridging agents, allows the system to develop an ultra-thin, impermeable filtercake; an important feature to minimize formation damage.

The new HPHT RDF system is simple with only the basic components required such as base brine, polymer, and bridging solids. A typical formula is shown in **Table 1**. Depending on

the application, a pH buffer is included when needed in the formulation for laboratory testing with positive results.

Table 1. RDF Main Components and Functions

Component	Function
Base Brine	Density
Polymer A	Long-term stability / Fluid-loss control
pH Buffer	Maintain pH
Calcium Carbonate	Bridging

New Brine-Based Reservoir Drill-In Fluid Evaluation

The newly developed brine-based RDF was evaluated for performance under HPHT conditions. The system was validated for:

- Brine compatibility
- Long-term stability
- Fluid-loss control
- Contamination / stress test

Brine Compatibility

RDFs use different types of base brines to achieve required density and shale inhibition. The density of the base brine is selected to minimize solids content and achieve optimal filtercake quality (thin and ultra-low permeable).

The new synthetic polymer was tested for compatibility using various monovalent and divalent oilfield brines to ensure that the new system can be formulated using any of these brines at different densities.

Results

The compatibility tests confirmed that the new synthetic polymer is compatible with most oilfield brines (both halide and formate brines) with slight variations in behavior depending on the type of brine.

Tables 2 and 3 show rheological properties of the HPHT RDF formulated using monovalent and divalent oilfield brines,

respectively, with the new synthetic polymer (concentrations of the polymer and rest of the additives were kept constant among all the formulations).

The results proved that the new polymer can also easily disperse/yield in the tested brines producing the desired rheological properties.

Table 2. RDF system formulated in monovalent brines properties

Property	K-Formate		NaCl		NaBr	
Density	11.5		10.5		12.5	
Ageing Time (hr.)	0	16 HR	0	16 HR	0	16 HR
HR Temperature	350 °F					
Rheology Temp.	120 °F					
600 RPM	82	96	159	188	143	172
300 RPM	53	63	112	136	99	125
200 RPM	42	49	92	112	80	100
100 RPM	28	32	65	81	56	70
6 RPM	9	8	22	28	16	22
3 RPM	8	7	18	24	14	18
Gel 10" (lb/100 ft ²)	8	6	17	22	13	17
Gel 10' (lb/100 ft ²)	8	7	18	23	13	18
Plastic Viscosity (cP)	29	33	47	52	44	47
Yield Point (lb/100 ft ²)	24	30	65	84	55	78
pH	9.3	9.9	9.2	9.2	8.9	8.7

Table 3. RDF system formulated in divalent brines properties

Property	CaCl ₂		CaBr ₂	
Density	11.5		13	
Ageing Time (hr.)	0	16-HR	0	16-HR
AHR Temperature	350 °F			
Rheology Temp.	120°F			
600 RPM	116	140	142	168
300 RPM	77	94	94	113
200 RPM	60	75	74	90
100 RPM	39	50	48	61
6 RPM	8	12	10	14
3 RPM	6	9	7	11
Gel 10" (lb/100 ft ²)	5	8	7	10
Gel 10' (lb/100 ft ²)	5	8	7	11
Plastic Viscosity (cP)	39	46	48	55
Yield Point (lb/100 ft ²)	38	48	46	58
pH	8.1	7.7	8.3	7.7

Long-Term Stability at HPHT Conditions

Long-term stability at high temperature conditions is a real challenge for brine-based RDFs. They generally suffer from rapid degradation when exposed to high temperatures downhole, breaking down and losing the rheological properties and their solid-suspension abilities.

The rapid degradation of these fluids at high temperature conditions prevents these type RDFs from being used in applications where long-term stability of the fluid is needed.

The novel RDF system was tested in the laboratory for long-term stability at different temperatures and periods of time. The system was tested over a temperature range of 330-425°F for periods of 16-hr to 7-days, under both dynamic and static conditions.

Long-term stability evaluation of the system in the laboratory requires several steps that can be summarized in the following sequence:

- Fluid was formulated for a specific base brine and density and mixed in the lab following the formulation sequence.
- Initial properties of the fluid were taken. Main properties taken for fresh fluids were:
 - Density
 - Rheology 70°F and 120°F
 - pH
- Fluid was pressurized at 300 psi and set to age for different periods of time at temperatures between 330°F and 400°F. For the 16-hr ageing time, fluids were tested under both static and dynamic conditions; for longer periods of time, all tests were performed at static conditions.
- After the ageing period, the samples were cooled down to ambient temperature and depressurized.
- After depressurizing the sample, final properties were recorded:
 - Top density
 - Bottom density
 - Sag test
 - Top fluid separation

- pH
- Rheology at 40°F, 70°F, and 120°F

Results

The newly developed brine-based RDF shows excellent stability at HPHT conditions for extended periods of time under both dynamic and static conditions.

During the static ageing process, the new RDF did not suffer from degradation (i.e., rheological properties of the fluid were maintained). **Figure 5** shows the rheological properties at 120 °F of the fresh RDF formulated in divalent brine compared to the properties of the fluid aged at 360 °F for different periods of time up to 7 days.

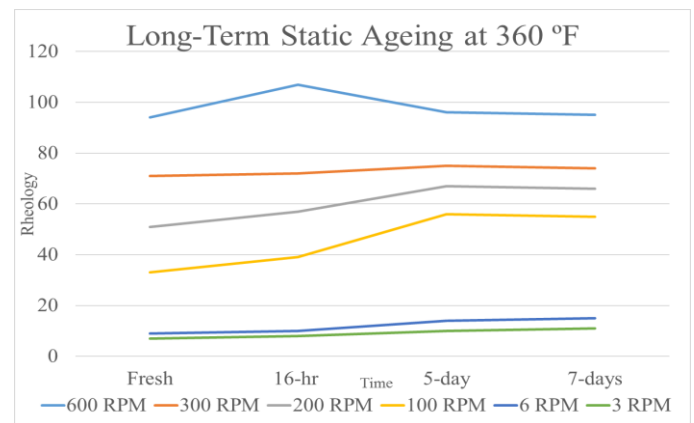


Figure 5. Rheology measured at 120°F for long-term ageing

Rheological properties of the fluid were maintained at temperatures between 300°F and 400°F and no degradation was observed. Also, minimum top fluid separation was observed after the longer-term static ageing periods. **Figure 6** shows stability of the new HPHT brine-based system compared to a conventional brine-based system after static ageing at 360°F for 4 days.



Figure 6. New HPHT RDF versus conventional brine-based system

The new RDF was also tested under dynamic ageing conditions for 16 hours at different temperatures.

Figure 7 highlights the new HPHT RDF rheological properties after 16 hours of dynamic ageing at different temperatures between 350°F and 400°F compared to the fresh fluid properties formulated in monovalent brine.

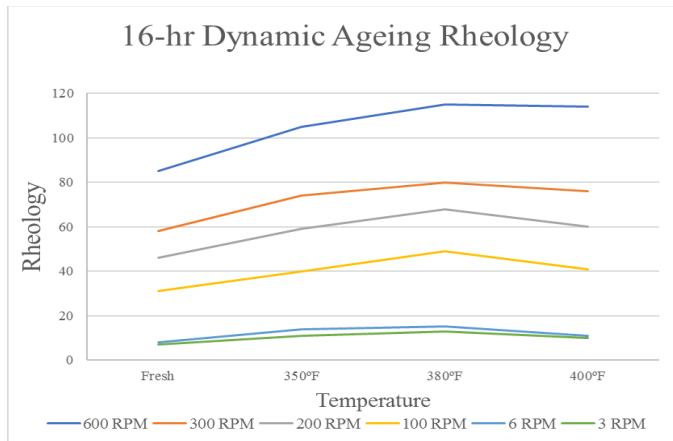


Figure 7. Rheology measured at 120°F for long-term ageing

The RDF system also maintained an almost constant pH after being exposed at high temperature conditions for different periods of time.

Sag testing showed no solids settling after static ageing at temperatures between 300°F and 400°F for different periods of time. Density was also maintained uniform with no differences between top and bottom densities.

Fluid-Loss Control at HPHT Conditions

Fluid-loss control is a crucial property when drilling through the reservoir. Minimization of fluid invasion into the formation is crucial to reduce potential formation damage and to optimize productivity. Invasion of large amounts of fluids into the formation can produce an irreversible damage to the formation compromising well integrity and future production.

The formation of a thin, compact filtercake, coupled with a low filtrate loss over time when tested in the laboratory under HPHT conditions indicated excellent fluid loss properties and minimum fluid invasion. Apart from the measurement of the filtercake, the volume of fluid invading the formation can be quantified respect to the diameter of the disk.

The system was tested in the laboratory for fluid-loss control performance at high temperature at different permeabilities. See **Table 4** for the different disks and

permeabilities used to test the fluid-loss properties of the fluid.

Table 4. Disks and Permeabilities used in the Laboratory

Disk	Permeability
Aloxite FAO-Special	775 mD (Mercury)/400 mD (Air)
Aloxite FAO-00	850 mD (Mercury)/750 mD (Air)
Aloxite FAO-05	3 D (Mercury)/2 D (Air)
Sandstone Buff Berea	150-350 mD- Brine Permeability

A 16-hr dynamically aged HPHT RDF system at temperatures between 330°F and 425°F was used to evaluate the fluid-loss performance of the new system.

Fluid-loss control properties of the RDF system were at an overbalanced differential pressure of 500 psi for periods of time between 1 and 16 hours.

Results

The new HPHT RDF system showed excellent fluid-loss control capabilities when tested in the laboratory. The fluid built a thin filtercake minimizing the losses at HPHT conditions (**Figure 8**).

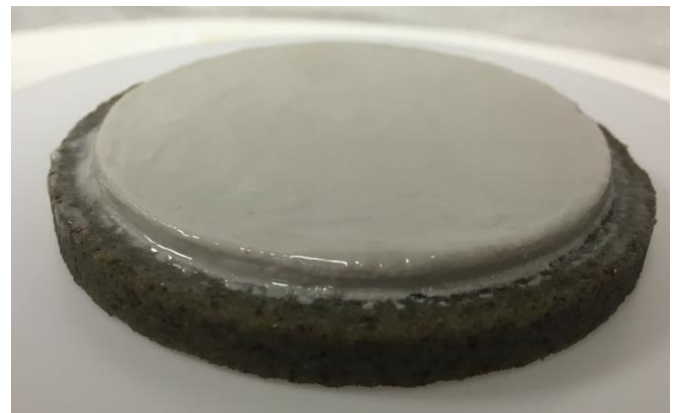


Figure 8. 16-hour Filtercake on a Buff Berea Disk

The collected volume was minimized optimizing both the new polymer concentration and the selection of bridging materials to also provide a small spurt loss when the fluid was exposed to the disk at 500 psi differential pressure and various temperatures. **Figure 9** shows fluid-loss control performance at 360°F and 500 psi differential pressure.

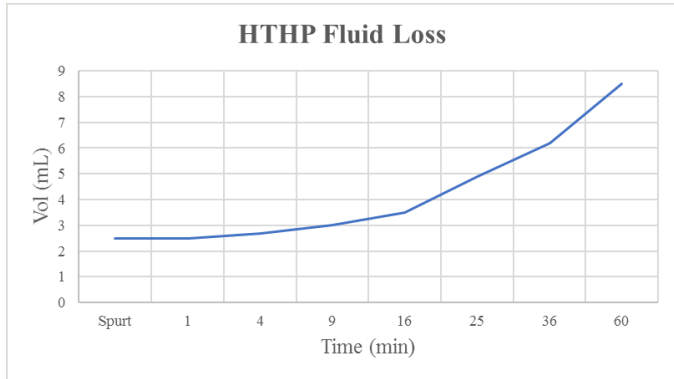


Figure 9. HPHT Fluid-loss at 360°F and 500 psi

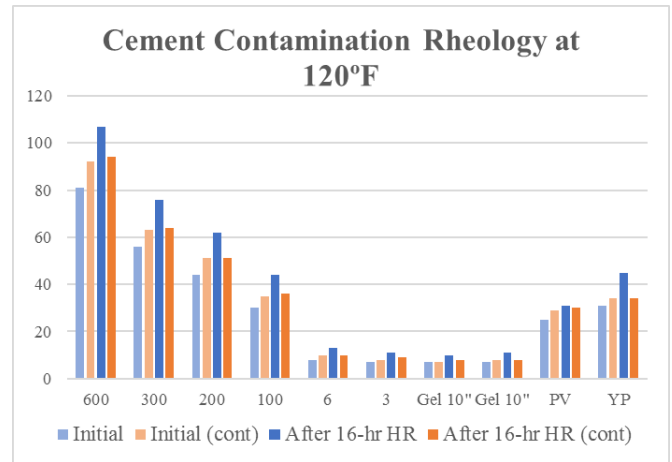


Figure 10. After 10 lb/bbl Cement Class H contamination (Fluid Pre-treated with Soda Ash)

Contamination / Stress Test

During drilling operations, various contaminants (such as drilled solids and cement) are introduced into the drill-in fluid system and can negatively affect its properties. The new HPHT RDF was subjected to stress tests to assess the effect of the drilled solids and cement contamination on the system formulated using the new synthetic polymer.

Results

Figures 10 to 12 show rheological properties of a NaBr-based RDF with and without contamination with class H cement (Figure 10) and drilled solids (4% rev dust Figure 11 and 5 lb/bbl reactive clay Figure 12), before and after 16-hr dynamic ageing. The results show that the new system, if pretreated with soda ash, can be used to drill cement with no negative effect.

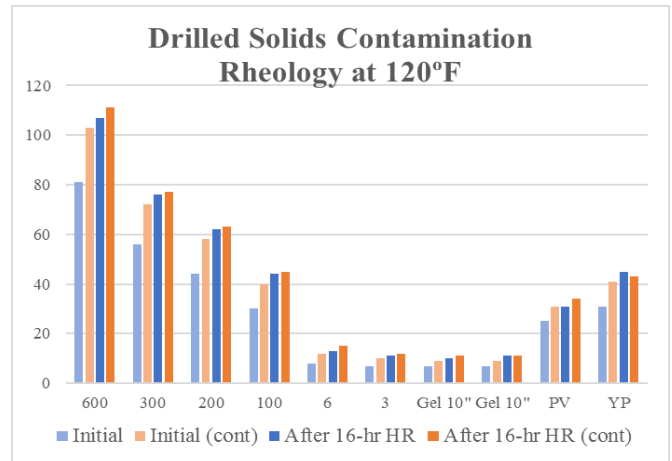


Figure 11. After Contamination with 4% Drilled Solids

Although the system can tolerate a high concentration of drilled solids, drilled solids content should be controlled using adequate solids control equipment, especially if reactive formations are anticipated.

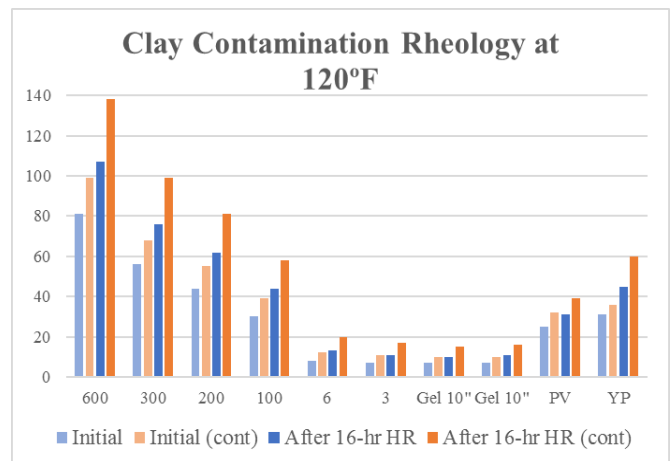


Figure 12. After Contamination with 5 lb /bbl highly reactive clay

HPHT Brine-Based RDF Breaker Package

A breaker package was developed and exposed to the filtercake to evaluate its ability to dissolve and disperse the components of the HPHT RDF deposited during the fluid-loss evaluation.

The breaker chemistries were selected to target specific components of the filtercake to either, break, dissolve, or disperse them. In the example case, the main components of the filtercake to target were the synthetic polymer and the bridging agent.

The main objectives of the breaker test are summarized as follows:

- To clean the filtercake without producing by-product precipitates and plugging the disk.
- To test the ability of the breaker package to restore the initial permeability of the disk allowing the flow of production or injection fluids through the disk.
- To minimize corrosion of the completion hardware at HPHT conditions.

Most of the conventional chemicals and breaker chemistries currently used to clean-up filtercakes for most commercial brine-based RDF did not produce successful results when tested with the new HPHT RDF.

The breaker package for the new RDF required the combination of different products (such as acid, HT acid precursor, and oxidizer) to achieve the filtercake clean-up by dissolving the bridging components and breaking and dispersing the synthetic polymer.

Development

The use of the new synthetic Polymer A in the fluid formulation presented a challenge in the development of the breaker system. Polymer A is a very resistant synthetic polymer especially developed to resist high-temperature conditions. These polymer resistant properties represented a challenge developing the breaker system for the HPHT RDF.

The breaker package evaluation involved several steps to test the ability of the components to clean the filtercake and restore the permeability of fluids through the disk.

All the breaker package evaluation tests were performed over filtercakes formed on buff Berea disks during 16-hour fluid-loss tests at 360°F and 500 psi differential pressure.

Flowback testing was used to evaluate the different breaker systems capabilities to clean up the filtercake and restore the permeability of the disk. For the flowback test, 7% KCl is flowed through the buff Berea disk used in the test at ambient temperature to set a baseline flow rate. This flow is established before the filtercake is deposited.

After filtercake formation, the remaining HPHT RDF on top of the filtercake is decanted and the tested breaker package placed on the top of the filtercake without disturbing it. The HPHT cell is then closed and reset to testing temperature and pressure. The breaker is allowed to soak for a specific period. For the breaker system development, filtercakes were soaked between 3 and 6 days.

After the soaking period, 7% KCl was again flowed through the disk at room temperature without decanting the remaining spent breaker fluid in the cell for a better replication of downhole conditions.

Flowback return was calculated by comparing the flow rates after the breaker soak with the initially calculated baselines.

There were three main milestones in the process of developing the breaker:

- Selecting the base brine of the breaker system to obtain density, brine properties, and compatibility with the rest of the fluids (such as the RDF and completion fluids).
- Selecting the active chemical to dissolve and/or disperse the filtercake based on the filtercake composition and to minimize corrosion of downhole tools.
- Evaluating and validating the breaker's effectiveness by testing its ability to clean-up the filtercake and to restore the disk permeability.

Brine selection tests led the authors to conclude that most of the monovalent and divalent brines can be used as base brine for the HPHT breaker system. The breaker package can be formulated at a wide range of densities with different monovalent and divalent brines.

As mentioned previously, the use of the new developed synthetic polymer challenged the selection of the active components of the breaker system. Acidic systems are common breakers for brine-based RDF. Acidic systems dissolve the calcium carbonates present in most of the RDF systems along with breaking and dispersing the polymer residue of the filtercake.

Acidic systems tested in the laboratory achieved acceptable flowback rates by dissolving the carbonates present in the

filtercake. However, the acidic systems alone were not able to dissolve or disperse the synthetic polymer present in the filtercake resulting in very poor clean-up. Refer to **Figure 13** for an example of acidic breaker test result.



Figure 13. Disk after acidic breaker system treatment

Chelants are also commonly used products for breaker systems. Most common chelants used in breaker systems were tested in the acidic breaker to improve the cleaning of the filtercake while maintaining the good flowback rates obtained before. However, none of the chelants tested improved the filtercake clean-up.

Several experimental solvents and esters were tested as part of the breaker package to help disperse and dissolve the synthetic polymer residue in the filtercake to achieve a better clean-up and improve the flowback rates. Some of the solvents showed a dramatic improvement in the flowback rates and achieved better clean-up. However, these solvents generated a semi-solid by-product in the spent fluid that represented a risk. An example of the generated by-product is shown in **Figure 14**.



Figure 14. By-product generated after breaker reaction

A novel acid precursor, able to release acid at high temperature conditions, was introduced as part of the breaker package to improve the action of the system at high temperature. The acid precursor combined with the previously tested acidic breaker component resulted in an improvement of the flowback rates and filtercake clean-up. **Figure 15** shows a disk after acid/acid precursor treatment. However, some polymer residue was still left in the disk.



Figure 15. Disk after acid/acid precursor treatment

Oxidizers had shown an ability to degrade the polymer, decreasing the rheological properties of the fluid, when included in the reservoir drilling fluid formulation as internal breakers. However, the combination of an oxidizer as internal breaker with the application of an external breaker was not a viable solution. The oxidizer degraded the polymer at a fast rate, annulling the long-term stability properties of the RDF.

Different common oxidizers were introduced in the acid/acid precursor breaker package to test their capacity to degrade and disperse the polymer when used in the external breaker instead of internally. Inorganic oxidizers previously used as internal breakers to degrade the polymer did not show successful results when used as part of the external breaker system. Most of these oxidizers were not compatible with the breaker package at high temperature or did not have an effect in the polymer degradation and filtercake removal.

Commonly used organic oxidizers were also evaluated for their potential to be integrated into the breaker system. One of the tested organic oxidizers, selected based on compatibility with the breaker system, produced excellent results removing and dispersing the polymer from the disk.

The selected oxidizer, designed to be able to release free radicals at high temperature conditions, was introduced as a component of the breaker package. The new breaker system was tested for its capacity to evenly remove and disperse the filtercake without releasing new by-products and for its ability

to restore the permeability of the disk.

Results

The newly developed breaker package shows the ability to dissolve and disperse the HPHT RDF filtercake restoring the permeability properties of the disk.

The new breaker package consists of a combination of different chemicals needed to achieve efficient filtercake cleanup. Combination of these components is necessary for total bridging agent dissolution, polymer degradation and dispersion and to restore the permeability of the disk/formation. **Table 5** describes the main components of the breaker package and their function.

Table 5. Breaker composition

Component	Function
Base Brine	Density
Acid	Calcium carbonate dissolution
HT Acid Precursor	Filtercake cleanup/ Flowback enhancing
Oxidizer	Polymer degradation

The developed breaker package achieved excellent filtercake removal and disk clean-up. **Figure 16** shows an image of the disk after breaker soak for 5 days at 360°F.



Figure 16. Disk after breaker system application

Flowback testing was also performed for different RDF formulations in different monovalent and divalent brines to

quantify the new breaker package performance. Flowback tests performed at different temperatures for different formulations averaged a 70% production flowback rate.

Corrosion

Corrosion was tested when the new breaker package was exposed to the most common metallurgies used in completion hardware.

Preliminary corrosion tests for the breaker package using carbon steel showed anticipated high corrosion rates when the metal was exposed to the breaker under high temperature conditions. The carbon steel coupons exposed to the breaker package at HPHT conditions lost almost 20% of their weight in a 24-hr period.

Conventional high temperature corrosion inhibitors did not reduce significantly the corrosion rates of the breaker package on the carbon steel metallurgy. The nature of the developed breaker along with the high temperatures tested cancelled the corrosion inhibition potential of most of the tested corrosion inhibitors.

A new experimental corrosion inhibitor package was optimized for the breaker package. The optimized chemical mixture reduced the corrosion rates of the breaker system on the most common metallurgies used in completion hardware to acceptable levels without affecting the breaker performance.

Figure 17 describes the inhibitor package's capacity to decrease the corrosion rates measured in weight loss and lb/ft² on a carbon steel coupon at 360°F for a 24-hr period.

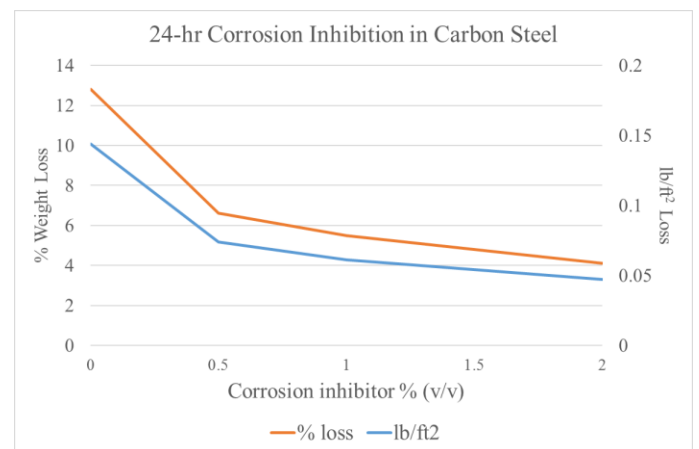


Figure 17. Corrosion inhibition in carbon steel

Table 6 describes the corrosion rates of different metallurgies exposed to the inhibited breaker system at 360°F for different periods of time.

Table 6. Inhibited breaker system corrosion rates

Inhibited Breaker System Corrosion Rates (360 °F)			
Metallurgy	Exposure Time	Weight % Loss	Corrosion Type
C4130	24-hr	4.1 %	General Corrosion
Q125	24-hr	5.1 %	General Corrosion
Q125	60-day	8.9 %	General Corrosion
2535	60-day	0.7 %	General Corrosion

Conclusions

A new brine-based HPHT RDF was developed and tested to overcome the temperature limitations of existing water-based systems.

The newly developed brine-based HPHT RDF, based on the new synthetic Polymer A, is compatible with and can be formulated in most of the oilfield monovalent and divalent brines.

The HPHT RDF showed excellent long-term stability and solid-suspension properties for extended periods of time up to 7 days at high temperature conditions between 300°F and 400°F.

Stress testing showed that the new system can be used to drill through cement without any negative effect. Contamination with drilled solids can also be tolerated by the system.

At HPHT conditions, a low permeability, ultra-thin filtercake is deposited by the new system, minimizing any fluid and filtrate invasion and reducing the risk of formation damage.

A breaker package developed for the system proved capable of removing the deposited filtercake, dissolving the present carbonates, and dispersing the synthetic polymer.

A corrosion inhibitor package was developed and introduced to form an inhibited breaker system that successfully decreased the corrosion potential of the breaker on the most common completion metallurgies.

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