AADE-20-FTCE-099

Optimized Reservoir Drill-In Fluid and Breaker System Design focused on Maximizing Productivity in Open-hole Completions

Leigh Gray, Lucio Bussaglia, Chris Detiveaux, Ryan Riker, Andrew DeFrees, Newpark Fluids Systems*; Ralph Harris, Ian McKay, Cleansorb

Abstract

Reservoir drill-in fluids (RDF) are minimally-damaging fluids designed to meet the drilling performance requirements of drilling engineers while satisfying the reservoir integrity targets of completion engineers. Selection of an appropriate drill-in fluid and subsequent cleanup procedure are critical towards maximizing the productivity of the reservoir interval. This paper discusses important design considerations for the development and use of these reservoir-centric technologies in open-hole completions, to include both production and injection wells. Monovalent brine-based RDFs are often used in reservoirs having lower formation pressures, while divalent systems are typically used in higher pressure wells. An innovative divalent brine-based RDF system has recently been developed specifically for use with high density, divalent completion fluids. Filter cake breakers are designed to remove specific components of RDF and facilitate the removal of the RDF filter cake in order to maximize productivity or injectivity of the reservoir interval. A tailored suite of innovative filter cake breaker solutions were designed in conjunction with these new RDF systems, driving significant operational as well as HSE performance.

Introduction

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 and breaker technologies, help 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.[1,2]

RDFs are the first and most obvious extension of drilling fluids technology into the reservoir interval. These fluids are designed to minimize formation damage, facilitate the installation of completion assemblies and demonstrate compatibility with the completion fluids used in subsequent completion activities. Key features of RDF's include minimally damaging to the reservoir interval, minimizing skin, robust filtration and rheological profiles, readily removable filter cakes, wellbore stability and flow initiation pressure reduction.

RDF are designed to deposit a thin and relatively impermeable filter cake, sealing the wellbore and minimizing leak-off into the formation. Uniform and effective removal of the filter cake is often difficult to achieve, particularly in low permeability formations. Approaches taken to remove filter cake include the use of hydrochloric acid, organic acids, chelating and oxidizing agents, enzymes and delayed release organic acid precursors. It is commonly accepted that rapidly reacting, neat acids do not provide uniform filter-cake removal.[3,4]

Traditionally, these filter cakes were designed to have low liftoff pressure for ease of removal upon initiation of production. In practice, filter cake cleanup is often non-uniform due to differences in reservoir characteristics across the length of open-hole interval. This can result in variable drawdown and create formation damage prior to production.

Placement of corrosive acids to dissolve acid soluble components of the RDF filter cake is problematic particularly in highly deviated and horizontal wells. In-situ or "in-place" acid generation technology has been developed and is proven to be effective at providing uniform removal of an RDF filter cake along the length of the reservoir interval.[5] This technology generates an organic acid (typically acetic or formic) in-situ, thus providing a controlled acidizing process for filter cake removal. The technology can also incorporate enzymes to remove specific biopolymers utilized in a water-based RDF, or surfactant technology when a non-aqueous RDF system used.

Reservoir Drill-in Fluid Design

Optimized RDF formulation design and testing occurs in a specialized laboratory that has the equipment and capabilities to characterize the reservoir and perform the necessary sequence of tests. The Technology Center shown in Figure 1 is equipped with the instrumentation designed for use in the development of RDF and breaker solutions for use in open-hole completions.

*Newpark Fluids Systems is a mark of Newpark Resources, Inc.

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 facility operates within ISO 9001:2015 and API Q2 certified Quality Management Systems (QMS). The facility 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.

Figure 1 – Technology Center in Katy, Texas

The RDF design procedure for a given reservoir is driven towards satisfaction of a number of performance criteria. Key parameters include density, rheological and filtration control properties, deposition of a thin and pliable filter cake, and compatibility with reservoir fluids. These must be achieved in a manner that will ultimately facilitate efficient removal of the filter cake without creating subsequent problems such as plugging screens once in place. Additional operational objectives are then defined for drilling the reservoir, displacing the fluid from the well, and addressing completion operations to include running screens and gravel packing, before finally placing the well into production.[6]

A team of chemists and engineering professionals developed three new RDF systems at the Newpark Technology Center. Key design parameters included rheological properties (gel strengths, plastic viscosity (PV), yield point (YP) and 6/3 rpm readings), bridging, return permeability, and breaker testing for filter cake removal. The design team used novel and proprietary chemistry and evaluated individual components, as well as combinations of components, to achieve the design objectives. Additionally, state-of-the-art instrumentation such as the M9100 Return Permeameter & the VHX6000 Digital Microscope facilitated development of the new RDF. Table 1 presents rheological test results of a newly developed monovalent RDF. This fluid was designed for a potential Gulf of Mexico deepwater application and the design approach centers on fluid performance under low temperature conditions.

Table 1 – Monovalent WB RDF Test Parameters

Rheology @ 120°F			
	Initial	**After Hot Roll**	**After Static Age**
600	**35**	**35**	**35**
300	**25**	**26**	**26**
200	**21**	**22**	**22**
100	**16**	**16**	**16**
6	**6**	**7**	**7**
3	**5**	**5**	**5**
PV	**10**	**9**	**9**
YP	**15**	**17**	**17**

Table 2 presents rheological and filtration control tests of a new divalent-brine based, aqueous RDF fluid. The fluid is unique and innovative given that rheological and filtration control properties are achieved with a single additive, one that readily activates at room temperatures and does not require an external heat source or the use of specialized mixing equipment. The fluid properties from Table 2 were taken from yard tests performed at the Port Fourchon offshore supply base, where the ability to scale up and prepare large quantities of the fluid were successfully tested.

Table 2 – Divalent WB RDF Test Parameters

Aged @ 190°F	Initial	After Hot Roll
600	**109**	**90**
300	**75**	**60**
200	**60**	**47**
100	**42**	**33**
6	**14**	**10**
3	**12**	**8**
PV	**34**	**30**
YP	**41**	**30**
HTHP FL (1 hr)		**3.9**

Lastly, a new non-aqueous RDF was also developed utilizing Gulf of Mexico compliant isomerized olefin base fluid. Table 3 presents yard test results of this fluid prepared at the Port Fourchon supply base utilizing conventional mixing equipment.

Table 3 – Non-aqueous RDF Test Parameters

Rheology @ 120°F			
	Initial	**After Hot Roll**	**After Static Age**
600	**63**	**61**	**62**
300	**44**	**39**	**40**
200	**36**	**30**	**32**
100	**27**	**23**	**23**
6	**11**	**8**	**9**
3	**9**	**7**	**7**
PV	**19**	**22**	**22**
YP	**25**	**17**	**18**

Bridging Technology

Various bridging theories are utilized to generate a recommendation for effective sealing against formation losses. One such theory is the Ideal Packing theory (IPT). The IPT can be used to optimize the bridging of permeable formations and functions equally well for high and low-permeability reservoirs. The IPT is best described as the full range of particle size distribution necessary to successfully seal all voids, which includes those voids that may be created by the bridging agents themselves. Subsequently, this bridging agent layering results in a more compact and less invasive filter cake. The IPT uses either pore sizing or permeability information in addition to particle size distribution (PSD) of the bridging material to determine the “Ideal Packing”.[7,8,9]

The initial step in the process of forming an effective seal is to identify the “worst-case” scenario based on the largest pore size or fracture width. The known permeability of the formation can be used if the pore size is not available, although this is not the preferred method. If a range of permeabilities is provided, then the largest value should be used as the “worst-case”. Median pore size given in microns can be estimated from permeability by taking the square root of the permeability in millidarcies. This pore size value is only a rough guide for the average (median) size of the pores commonly referred to as the D50.

The solids distribution is normally represented by an “S-shaped” curve indicating the range of particles present in the fluid. This “S-shaped” curve is plotted on semi-log coordinates. Ideal packing can be achieved by blending various sized bridging agents to seal a broad range of permeabilities, pore sizes or fracture widths. It has been found that typically 6%-9% by volume or 20-30 lbs/bbl of a proper blend of bridging agents can provide an optimum seal on the face of permeable zones in clean fluids. In heavier, weighted fluids such as those containing barite, the guidelines are more flexible with the emphasis on larger diameter particles. The majority of other methods often recommend 3%-5% by volume of properly sized solids.

The bridging software shown in Figure 2 matches the particle size distribution of bridging agents used in formulation of the RDF to the pore size distribution of the reservoir, allowing for engineered use and custom design of the RDF for a given reservoir. The software determines the appropriate size and concentration of acid-soluble materials for use in 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 lost circulation. Through the use of a particle size distribution (PSD) database, the bridging software calculates the appropriate type & concentration of bridging agents for use in RDF for each reservoir.

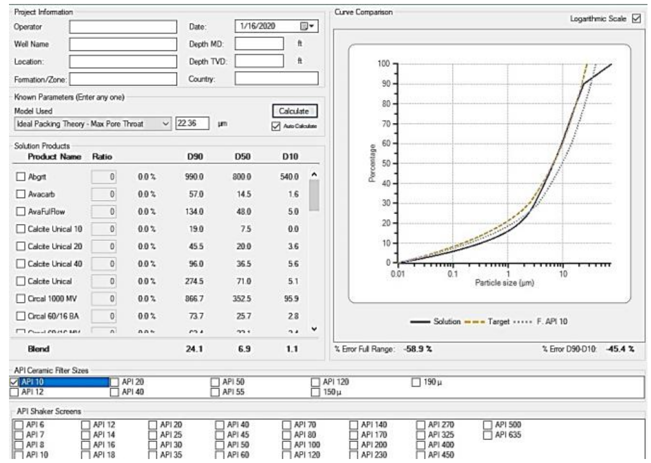

Figure 2 – Bridging software

The Permeability Plugging Apparatus (PPA) is a modified high-temperature, high-pressure filter press used to evaluate filtration through various types of filter media at pressures of up to 2,000 psi and temperatures from ambient to as high as 500 °F. Similar to the standard HTHP filter press, the PPA is suitable for use in either the field or the laboratory. The PPA is designed to provide improved static filtration measurements. It can be operated at pressures and temperatures approximating those prevailing downhole and it permits the use of filtration media chosen to simulate exposed sands. Spurt loss is often looked at in addition to total filtrate volume and cake quality.

A suitable non-damaging fluid should establish a filter cake on the face of the formation but should not penetrate too far into the formation. The fluid filtrate should inhibit or prevent destabilization of reactive clay particles within the pore throats. So, for bridging optimization the following are critical determinations when designing an RDF:

- Concentrations and types of bridging agents
- Particle Size Distribution (PSD)
- Time required for forming a bridge
- Effectiveness of the bridge

Uniform Filter Cake Removal (Breaker Systems)

Upon completion of drilling the reservoir section with an RDF, the interval is lined with an external filter cake. Breakers, which decompose (destroy) specific components of RDF filter cake, aid in the removal of the filter cake in order to improve productivity or injectivity of the reservoir interval. Breakers are applied across the reservoir section after the completion assembly is in place, and the reservoir is prepared for production. The breaker is normally designed along with the RDF, and a variety of breaker technologies are used depending on the RDF and type of brine used. Breaker formulations may vary based on individual components of the RDF. Breaker chemicals that can dissolve calcium carbonate include hydrochloric acid, organic acids (such as acetic or formic acid) organic acid precursors (which typically generate acetic, formic or lactic acid) or chelating agents such as EDTA or GLDA.[10]

Barite may be dissolved through the use of chelating agents, and ilmenite similarly dissolved by suitable acids. Breaker chemicals are used to degrade polymers, to include enzymes (amylases to break starches, cellulases to break celluloses, xanthanases to break xanthans) or suitable oxidizing agents. To more readily dissolve calcium carbonate, the surface of the mineral particles should be water-wet. This may be achieved by incorporating suitable surfactants, mutual solvents or solvents into the breaker formulation.

Acid precursors have seen widespread use in applications such as matrix acidizing, the stimulation of natural fracture networks and damage removal over long horizontal intervals. The generation of acid in-situ following placement of the fluid ensures even delivery of acid over the length of the treated zone.[11] Biopolymers such as starch, xanthan, and cellulose are widely used to provide rheological and filtration control with aqueous RDFs. Figure 3 demonstrates the effectiveness of a breaker system in removing the RDF filter cake with a time delay of seven (7) days.

Figure 3 – Filter cake breaker test results before and after 7 day soak period

Conventional treatments such as the use of neat acid (for removal of acid soluble particles), as well as oxidizing agents (to remove water-soluble polymers) are often limited in their effectiveness. Breaker technology based on the use of highly purified, specific enzymes provide improved removal of polymer residues. However, use of enzymes alone are not as effective as treatments that also include acid precursors to dissolve calcium carbonates.[12]

There is generally a significant benefit in using combinations of breaker chemistries in a single stage treatment. For example, when treating filter cakes generated by aqueous RDF it is beneficial to include an acid precursor, and at least one polymer breaker. Similarly, when attempting to uniformly remove non-aqueous RDF it is beneficial to include an acid precursor plus a water-wetting and/or hydrocarbon solubilizing agent.

When using 2 or more components in a breaker, there is a need for them to be compatible with each other. Enzyme polymer breakers cannot be used in combination with hydrochloric acid, for example, but may be used with an organic acid precursor plus a suitable buffer.

There is an advantage in using breakers that are designed to exhibit a delay mechanism. If breakers work too quickly, premature loss of breaker fluid into the near wellbore can occur while the breaker is being placed into the open-hole. Ideally, there should be a sufficient delay to allow placement of the breaker system and pulling out of hole before significant leak-off occurs. Slower acting breakers can also deliver better zonal coverage, allowing uniform treatment of the filter cake over the whole length of the wellbore. The HSE risks and operational challenges associated with use of conventional, neat acids for filter cake removal include:

- Exposure to corrosive acids
- Uncontrolled and localized reactions
- Increased risk of worm-holing
- Stimulation of unwanted water production
- Specialized delivery vessels, tanks and equipment

HSE and Operational Benefits of Acid Precursors

Use of acid precursors in filter cake breaker formulations delivers significant health, safety and environmental advantages. Notable characteristics of the in-situ acid generator technology include: a) near-neutral pH at surface, b) environmentally acceptable, c) controlled, delayed reaction, d) uniform removal of RDF filter cakes, e) elimination of “hot spots” and f) prevention of acid “worm-holing”. All components of the filter cake breaker system are environmentally acceptable, offering minimal exposure risk to workers at the rig-site, and can readily be mixed on surface without the use of specialized equipment.

Use of organic acid precursors allows for production of acid into the area of interest at a controlled rate and with uniform coverage. Acid can be generated and distributed evenly through the length of the reservoir, providing for uniform filter-cake removal.[13] With this technology, the acid is generated after placement of the breaker system in the reservoir. The breaker can be positioned in the reservoir where it is difficult, if not impossible, to place conventional acids. This technology is highly effective for use in open-hole completions, horizontal wells, deepwater, mature well stimulation and gravel-packed wells. These breakers are particularly useful in injector wells, expandable screen applications and in a variety of formations to include sandstone, dolomite, and carbonate reservoirs.

Better zonal coverage may be achieved using acid precursors compared to neat hydrochloric acid. It has been reported that an average of 88% higher production was obtained from open-hole horizontal wells treated with an organic acid precursor compared to wells treated with hydrochloric acid.[13] Use of hydrochloric acid leads to the risk of breakthrough to water-bearing zones and unwanted stimulation of water production. Using acid precursor-based formulations, there have been no reports of massive stimulation of water. Several publications suggest that acidizing of the rock matrix behind the filter cake by filter cake breaker formulations based on acid precursors are believed to remediate a "low permeability crush zone" arising as a result of drilling into a carbonate formation.[10] It is believed that the crush zone in limestone can have a permeability upwards to 1000-times less than the undamaged rock.[14]

Filter cake breaker formulations based on acid precursors may be used in both sandstone and carbonate formations. In sandstone formations, properly designed breaker formulations based on acid precursors can achieve return permeabilities of up to 100%. In carbonate formations, there is the possibility of in-situ generated organic acid increasing the permeability of the rock matrix or remediating damage (for example any low permeability crush zone) leading to a return permeability approaching 100%.

Return Permeability Tests

Tests routinely performed to aid in the RDF design process typically include an evaluation of the rock characteristics, such as composition, grain size distribution, and pore size distribution. Removal of skin damage resulting from external and internal filter cake deposition while drilling the reservoir is vitally important to enhance production. Formation damage on the surface of the reservoir created by exposure to the drilling fluid is called skin and can often be remediated through use of an acid-precursor technology.

Return-permeability testing is the standard to measure the properties of minimally damaging RDF. This single number is typically focused upon due to its simplicity, however the testing procedure and intermediate data provide additional insights into formation damage mechanisms and their overall impact on potential reservoir performance.

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.[15] The base permeability of the core is measured with a reference fluid at the bottom hole temperature of the target reservoir. It is essential that the fluid selected and flow rates used to establish the base permeability do not damage the core. After capturing the breakthrough or flow-initiation pressure and associated permeability, the return-permeability with the RDF using the same conditions as the base permeability test is then measured. The ratio of the RDF to base values gives the percent return permeability.

The return permeability unit shown below in Figure 4 operates at temperatures up to 350°F and pressures up to 3,000 psi while testing a wide variety of RDF across a spectrum of operating conditions in the reservoir.

Figure 4 – M9100 Return Permeameter

A digital microscope is used to analyze the pores within the reservoir, having a 2000X magnification and utilizing 3D measurement software for core analysis. Pre-analysis, a thin section is prepared 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 the 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 5 – VHX6000 Digital Microscope

Petrographic observation of thin sections can provide valuable information regarding the compositions of reservoir rocks. Thin section analysis can also directly characterize pore systems, including porosity, pore types, shapes, pore-size distribution, and connectivity. In addition, it can provide data on the grain size, sorting, and rounding of sedimentary grains and information on the post-depositional alteration, which includes compaction, cementation, dissolution, leaching and fracturing.

Optimizing the particle size distribution of the RDF can improve leak-off control and minimize formation damage from solids invasion, thereby increasing well production. As pore throat size decreases due to deposition of particles the largest particles begins to form an external filter cake. This process repeats itself for smaller pore throat sizes. Therefore, a variety of particle sizes are required in the fluid. Particles should be large enough not to invade, yet small enough to prevent polymer and fines from reservoir invasion.

Filter cake breaker solutions were designed in conjunction with the new RDF systems. Breaker systems designed for use with the aqueous RDF utilized acid precursors, plus enzyme technology. This treatment allowed the removal of both the carbonate and polymeric components, delivering uniform filter cake removal.

Similarly, breaker systems designed for use with the non-aqueous RDF also included acid precursors, plus a micro-emulsifying surfactant. This approach ensured solubilization of residual fluid, along with water-wetting of the filter cake particulates, allowing the acid precursor to more dissolve calcium carbonate materials. Water wetting non acid-soluble mud cake solids also aids their dispersion when wells are first flowed, again aiding filter cake removal and minimizing damage.

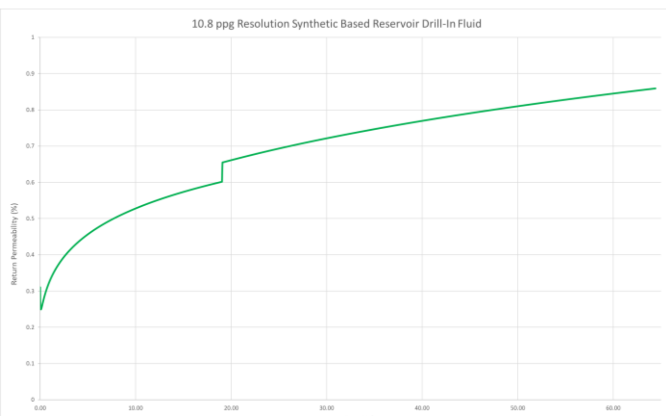

Figure 6 – Return-perm Tests of Non-Aqueous RDF

Figure 6 presents the results of return permeability testing of a non-aqueous RDF. The 10.8 lb/gal RDF designed for potential use in the Gulf of Mexico had a return permeability of 92.4% following treatment with an acid precursor-based breaker system.

Case History #1

A major operator in Australia successfully drilled and completed a campaign of 12 offshore wells in water depths of upwards to 3,300 feet; six of which were water injector wells. All wells were drilled with an aqueous (monovalent) RDF technology, designed with a $CaCO_3$-based bridging package. The water-injector wells were drilled in an 8-½" (21.6 cm) open-hole diameter with intervals ranging from 1,200 - 6,600 feet (365 – 2,012 m) in length. Reservoir temperatures varied in these twelve wells, ranging in BHST from 155-190°F (68-88°C). The RDF filter cakes on both injector and production wells were treated and removed with breaker systems using in-situ acid precursors and enzyme technologies.

The operational workflow in the water injector wells consisted of:

- Condition wellbore and displace to solids-free fluid in the open-hole interval
- Run stand-alone screens with internal wash pipe
- Set the packer and release service tool
- Displace open hole to a delayed filter cake breaker
- POOH and close the fluid-loss device; allowing the breaker to soak and uniformly remove the filter cake

A key risk identified by the operator was the loss of primary well control while pulling internal wash pipe after displacing the delayed breaker system into the open-hole. To manage this risk, the breaker formulation was designed with delays ranging from 5-15 hours depending on the interval length and BHST. Other considerations on the filter cake breaker systems were:

- Inability to conduct well clean-up before the water-injection tests were completed
- Limitations in available injection equipment required that injection had to occur with less than 50 psi
- Matrix injection across the entire interval was critical to ensure the reservoir was swept efficiently toward the producer wells.

All of the products in the breaker system were CEFAS – OCNS registered Gold or PLONOR, with no substitution warning. On the first injector well after breaker treatment, the "Well Injectivity" test was completed and the results exceeded the operator expectations. Following confirmation of matrix injection, injection rates in excess of 350% of expected rates were achieved. Similar results were achieved on all six of the water injector wells utilizing the new RDF and breaker systems.

Case Histories #2 - #3

The breaker technology outlined in this paper has been used for uniform cleanup of RDF filter cake in applications around the globe. This section will outline examples of these applications in West Africa, North Sea and the Middle East.[16,17] The first offshore application was use of the enzyme-based process for in-situ acid generation in a low permeability reservoir, offshore Congo. All prior wells utilized acid stimulation in order to establish economic production rates. The in-situ acid generating technology was used to increase production on a well that was originally acidized with 15% hydrochloric acid (HCl). The objectives of the enzyme-based acid treatment were to remove residual damage (oil-based mud filter cake containing carbonate arising from drilling), reduce draw down along the whole of the wellbore, minimize gas coning, and increase oil production. The well was treated, shut-in for 48 hours and afterwards the well experienced a large and sustained increase in oil production following the stimulation. Well tests as high as 759 BOPD have been recorded after the treatment compared to less than 100 BOPD before the treatment.

The 2nd application was in the Norwegian sector of the North Sea. The wells were in the second largest gas fields in the Norwegian continental shelf, at depths approaching 3,300 ft (1,100 meters) and at temperatures as low as 34° F (1° C). The wells' designs were "big bore" and designed to supply 20% of the gas requirements for the United Kingdom (UK). Each of the big bore wells are designed for production rates up to 10 MSm^3/day. Therefore, an optimized breaker system designed for uniform removal of near-wellbore damage was instrumental in optimizing well productivity, and achieving production targets. The breaker system had to be sufficiently delayed to allow the gravel pack to be placed and close the formation isolation valve in the lower completion before losses would commence. Return permeability testing was conducted and results indicated that use of the breaker system increased the permeability by over 30%. The breaker design screening was carried out with the filter cake exposed to the enzyme breaker formulation and left to soak for seven days. The breaker formulation contained three enzymes; one to eliminate xanthan, one to eliminate starch, and the last one to generate acid by converting an acid-precursor into acetic acid. A time delay of eight hours was required in the field to allow the wash pipe inside the gravel pack screens to be removed. Three "big bore" wells were drilled and gravel-packed without issues. Initial production indices (PI) exceeded expectations and were higher than planned. The wells continue to produce above projected production rates.

A third application of the technology was on offshore production and injection wells, offshore Saudi Arabia. On these wells the reservoir was drilled with a non-aqueous fluid (NAF) and then treated with a breaker system composed of acid precursors and surfactant technologies. Historically, injectivity of these wells was impaired by residual damage from the NAF unless remedial drilling damage removal treatment was applied. This was a concern since "backflowing" the injection well in the production direction prior to water injection was not possible. The breaker treatment was placed in the reservoir from toe to heel and left in place for roughly one week (7 days) while the upper completion was being run. Following treatment, the water injection rate was increased to levels 10% above target and without exceeding the maximum injection pressure.

Results, Conclusions and Lessons Learned

- Excellent filter cake cleanup may be achieved using filter cake breaker formulations based on organic acid precursors.
- Development of RDFs carried out in tandem with development of the associated filter cake breakers has resulted in a tailored suite of innovative and effective filter cake breaker solutions which deliver excellent results.
- Filter cake breaker formulations based on acid precursors can match or outperform treatments by HCl in carbonate formations, even if the total dissolving capacity of the HCl is higher.
- Filter cake breakers have been successfully used on new wells but can also be successfully used for remedial treatments of wells already on production.
- With suitable design, it has been possible to use filter cake breaker formulations as a gravel packing fluid
- The ideal time to use filter cake cleanup treatments is on new wells, where the presence of an intact filter cake actually assists in the placement of the treatment fluid, improving the eventual zonal coverage that can be achieved.
- The low hazard characteristics of in-situ acidizing fluids simplifies and de-risks treatments enabling successful acidizing jobs in remote locations or with limited equipment and facilities.

Acknowledgments

The authors wish to thank Newpark Resources for permission to publish this paper. We also wish to recognize the contributions of Nathan Emery, Brittany Granger and Josh Harton in support of the new RDF systems. Similarly, we wish to acknowledge the contributions of Christopher Madden, Cristina Ruano and Micaela White in support of the breaker systems designs and formulations.

Nomenclature

RDF – reservoir drill-in fluid
ISO – International Standardization Organization
API – American Petroleum Institute
QMS - quality Management System
PVT – pressure, volume & temperature
F – temperature, Fahrenheit
psi – pressure, pounds per square inch
PV – plastic viscosity, cP
YP – yield point, lbf/100 ft²
IPT - Ideal Packing Theory
PSD – particle size distribution
D50 – diameter, 50%
PAA – particle plugging apparatus
HSE – health, safety and environmental
HTHP – high temperature, high pressure
lb/gal, ppg – density, pounds of mass per gallon
$CaCO_3$ – calcium carbonate
BHST – bottom hole, static temperature
CEFAS - Centre for Environment, Fisheries and Aquaculture Science
OCNS – offshore chemical notification scheme
PLONOR – pose little or no risk

References

1. Smith, S., Kratzer, M., Komaromy, J., Du, H., Gray, L., Miller, M., "An Integrated Approach to Drilling & Completion Fluid Solutions and Facilities Drives Efficiencies in Gulf of Mexico Deepwater", AADE-19-NTCE-035, presented at the 2019 AADE National Technical Conference, Denver, Colorado, 9-10 April

2019.
2. Bussaglia, L., Di Marino, R., Smith, V., "First Deepwater Campaign, Offshore Romania: Infrastructure, Design and Execution to Deliver Drilling and Completion Fluids", SPE 191447, 2018 SPE Annual Technical Conference, Dallas, Texas, 24-26 September 2018.
3. Nasr-El-Din, H., Al-Otaibi, M., Al-Qahtani, A., McKay, I., "Laboratory Studies of In-Situ Generated Acid to Remove Filter Cakes in Gas Wells", SPE 96965, presented at the 2005 SPE Annual Technical Conference and Exhibition, Dallas, Texas, 9-12, October 2005.
4. Moajil, A., Nasr-El-Din, H., Al-Aamri, A., "Evaluation of In-Situ Generated Acids for Filter-Cake Cleanup", SPE 107537, presented at the European Formation Damage Conference, Scheveningen, The Netherlands, 30, May – 1, June 2007.
5. Harris, R., McKay, I., "New Applications for Enzymes in Oil and Gas Productions", SPE 50621, presented at the 1998 SPE European Petroleum Conference, The Hague, The Netherlands, 20-22 October 2998
6. Russell, C., Sanford, J., Dearing, H, Daniel, S., "Shale Stability Testing of Drill-in Fluids for Deepwater Completions in the Gulf of Mexico", OMC 2007-085, presented at the Offshore Mediterranean Conference, Ravenna, Italy, 28-30 March 2007.
7. Amer, B. Carter, E. Hudson II, H. Du, and C. Judd, "Revisiting the Ideal Packing Theory with a Novel Particle Size Measurement Approach", SPE-182487, SPE Asia Pacific Oil & Gas Conference and Exhibition held in Perth, Australia, 25-27 October 2016
8. Chellappah, K., Aston, M., "A New Outlook on the Ideal Packing Theory for Bridging Solids", SPE 151636, SPE International Symposium on Formation Damage, Lafayette, LA, 15-17 February 2012.
9. Dick, M., Heinz, T., Svoboda, C., "Optimizing the Selection of Bridging Particles for Reservoir Drilling Fluids", SPE 58793, SPE International Symposium on Formation Damage, Lafayette, LA., 23-24 February 2000.
10. Davidson, E., Blattel, St., McMillan, N., Morrison, A., "Optimization of Clean-up of Limestone Production Zones: New Observations", SPE 163344, SPE Kuwait International Petroleum Conference, Kuwait City, Kuwait, 10-12 December 2012
11. Al-Ajmi, A., Al-Rushoud, A., Gohain, A., Khatib, F., Al-Gharib, M., Al-Mekhlef, A., Mustafa, M., Mago, A., Rossi, A., Rane, P., "Drilling and Completion Fluids Customization to Achieve Maximum Well Productivity in Lower Burgan Reservoir, Case Study from Kuwait Field", SPE-187025, SPE/IAMTI Asia Pacific Oil & Gas Conference, Bali, Indonesia, 17-19 October, 2017.
12. Al-Mehailani, M., Al-Anzi, N., Gohain, A., Hussian, I., Haider, B., Davidson, E., MacMillan, B., "Carefully Designed Water-Based Drill-In Fluid and Filter Cake Removal System Improve Reservoir Producibility and Reduce Well Completion Costs", SPE 122327, 2009 SPE European Formation Damage Conference, Scheveningen, The Netherlands, 27-29 May 2009.
13. O'Driscoll, K.P., Amin N.M., and Tantawi, I.Y. "New Treatment for Removal of Mud-Polymer Damage in Multilateral Wells Drilled Using Starch-Based Fluids" SPE 65405 SPE, Drilling & Completion Volume 15 Issue 3, September 2000
14. Leschi, P., Demarthon, G., Davidson, E., Clinch, D., "Delayed-Release Acid System for Cleanup of Al Khalij Horizontal Drains", SPE 98164, 2006 SPE International Symposium and Exhibition on Formation Damage, Lafayette, LA., 15-17 February 2006.
15. Offenbacher, M., Luyster, M., Gray L., He W., Leonard R, and Stephens M., "Return Permeability: When a Single Number Can Lead You Astray in Fluid Selection", SPE-165106, SPE European Formation Damage Conference and Exhibition, Noordwijk, The Netherlands, 5–7 June 2013.
16. Harris, R., McKay, I., Mbala, J., Schaaf, R., "Stimulation of a Producing Horizontal Well Using Enzymes that Generate Acid In-Situ, Case History", SPE 68911, presented at the SPE European Formation Damage Conference, The Hague, The Netherlands, 21-22 May 2001.
17. Vickers, S., Hutton, A., Lund, A., McKay, I., Van Kranenburg, Twycross, J., "Designing Well Fluids for the Ormen Lange Project", Right on the Edge", SPE 112292, presented at the 2008 SPE International Symposium on Formation Damage Control, Lafayette, Louisiana, 13-15, February 2008.