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AADE 2009 NTCE-15-02: THE USE OF SMART-FILTER-CAKE RESERVOIR DRILLING FLUID IN THE WILMINGTON FIELD

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Abstract

A novel reservoir drilling fluid has been developed and used for the purpose of lessening the potential for formation damage and at the same time mitigating risk of damaging the completion tools. This reservoir drilling fluid (RDF) was developed initially to use in wells where the filter cake is confined by completion methods such as a gravel pack or expandable screens, but its use has been expanded to wells where other completion techniques are utilized.

The Smart-Filter-Cake (SFC) RDF system deposits a filter cake which is predominantly impermeable to aqueous fluids, thus reducing fluid loss into the producing formation. At the same time, since the filter cake is formulated to be less water wetting, it tends to adhere less strongly to the wellbore. Finally, because the filter cake is permeable to formation hydrocarbons, produced fluids preferentially flow through the cake once the production process is initiated. This system utilizes organophilic material to modify the wettability of the filter cake, thereby decreasing adhesion of the filter cake on the formation and facilitating transport of hydrocarbons through it; consequently, the need for stimulation to remove the residual filter cake is greatly reduced.

This paper details the use of the SFC RDF system in the Wilmington Field off the coast of Long Beach, California over a four-year period. Conditions for the initial application of the SFC RDF system are discussed, along with expansion of its use and its performance in the field.

Introduction

One of the primary functions of a reservoir drilling fluid (RDF) is to minimize the potential damage to the production/injection zone by limiting the amount of invasion of liquid and solid material. This is achieved by depositing a filter cake across the wellbore with properly designed bridging material[1] whose function is to temporarily seal the open pore spaces in reservoir. Along with the bridging material, a water-based RDF will usually possess a starch, a biopolymer, and drill solids that become incorporated in the fluid during the drilling process.

While there is a strong emphasis on placing a thin, tough impermeable filter cake on the wellbore in the reservoir section to seal exposed pore spaces, there remains the issue of removing this barrier to allow hydrocarbon flow once the well is put on production.[2] This is especially true in openhole completions where perforating and/or fracturing past the filter cake is not done.

There are two common methods used to remove a RDF filter cake barrier. One method is to spot an external breaker to disperse the filter cake or/and solubilize bridging components. While this method is often successful, it has many risks: inability to place the breaker where desired due to mechanical restrictions in the completion assembly design, difficulty with pumping enough breaker due to volume restriction (as in openhole gravel packs), and difficulty transporting the breaker to the filter cake through a tortuous path (as in expandable screen completions). The type of breaker used can also pose a risk. If external aggressive breakers such as acids or oxidizers are used there is the risk that these breakers may react with the metal tubulars. The use of aggressive breakers can also cause premature breakthrough in one spot, causing the rest of the breaker volume to be lost into the formation and leaving the residual filter cake intact.

The second method to remove the filter cake is to simply flow the well back. This method can work depending on the type of completion used and the quality of the filter cake. When a well is flowed back in a barefoot completion there no restraint on the filter cake. Its removal depends on the flow initiation pressure, which itself can depend on the formation pressure, formation permeability, and the integrity and composition of the filter cake. If the filter cake detaches or lifts off the formation face in a barefoot completion, there is no risk in it plugging the lower completion hardware. In wells where the completion method used is an openhole gravel pack, or an expandable screen, detachment of the filter cake can cause plugging of the completion hardware (*e.g.*, sand-control screen), thus impeding flow of hydrocarbons from the formation into the wellbore. If the filter cake pinholes or blisters instead of detaching, then the threat of plugging the completion hardware is minimized especially if the pin holing is uniform.

The combination of relatively low formation pressure (*i.e.*, depleted) and low formation permeability can yield less than anticipated flowback of a well. While artificial lift can help to alleviate these negative aspects, the removal of a residual filter cake can impede and result in a difficult startup.[3] The difficulty increases when the filter cake is confined, resulting in high flow initiation pressures.

Changes in the composition of a RDF filter cake can help decrease the strength of the filter cake,[4] which in turn lowers the flow initiation pressure. The organophilic components of the Smart-Filter-Cake (SFC) RDF system and incorporation of bridging material of the proper size and concentration contribute to lowering the strength of the filter cake and its adhesion to the wellbore. Furthermore, the organophilic components provide hydrophobic paths that allow hydrocarbons to flow through with relative ease.

Comparative return permeability testing was performed on a SFC RDF system and a conventional RDF system prepared in the laboratory.[5] The testing was performed using Berea sandstone. First the neat RDFs were tested, then 40 lb/bbl of OCMA clay was added to both systems to simulate contamination with drilled cuttings, and a second set of tests was performed. A third set of tests was performed using 40/60 sand and a screen with the contaminated fluids. In all three series of tests, the flow initiation pressure was lower with the SFC RDF than with the conventional RDF (**Figs. 1-3**). A similar SCF RDF used in these analyses was formulated for the Wilmington Field.

Wilmington Field

Wilmington Oil Field is the third largest oil field in the contiguous United States, located about 35 miles south of Los Angeles, California. The Long Beach Unit (LBU) makes up the southern third of this 10 billion bbl field. The City of Long Beach is the Unit operator and Thums Long Beach Company is the field contractor. The LBU originally contained about 3 billion bbl of oil-in-place and has been producing under waterflood since the start of production in 1965. Adequate water injection is essential to maintain reservoir pressure, enhance oil production, and prevent subsidence. Wells are primarily drilled from four artificial islands constructed in Long Beach Harbor.

More than 2 billion bbl of the oil-in-place are contained within the largest reservoir, the Ranger Zone. The Ranger sands are poorly consolidated to unconsolidated, from 100 to 200 feet thick and are separated by shales 20 to 30 feet thick. These sands contain the highest permeability, some approaching 1 Darcy. Consequently, water cycling is inevitable due to the difficulty in controlling the water injection profile. Average Ranger reservoir properties are as follows:

Depth (TVD, ft)	2,800
Reservoir Pressure (psi)	1,250
Reservoir Temperature (°F)	125
Oil Gravity (°API)	17
Porosity (%)	27
Permeability (mD)	50-1,000

Horizontal wells have played a critical role in optimizing recovery from the LBU, especially in the mature crestal and south flanking blocks of Ranger West, to capture by-passed oil. More than 100 of these wells have been drilled and completed to date, with horizontal well lengths ranging from 800 to 1,800 feet. Most of these wells were oriented in the east-west direction. The well design consisted of a 20-in. conductor set at 80 ft, a 12¼-in. hole drilled directionally and cased with 9⅝-in. surface casing, and an 8¾-in. hole drilled to the top of the target sand and cased with 7-in. production casing. Finally, a 6⅛-in. hole was drilled laterally into the production interval and fitted with a 3½-in. wire-wrapped screen liner, then gravel-packed.

Field Trials

The first SFC RDF field trial took place in 2004 in the East Wilmington Field in the Long Beach Unit. The zone of interest was the Ranger zone, and a 6⅛-in. horizontal path was to be drilled through the G sand. The anticipated formation pressure for the first well was 0.28 psi/ft (6.7 lb/gal equivalent density). Due to this low formation pressure, there was concern about the drawdown pressure and the ability to remove the filter cake. The SFC system was chosen over a conventional RDF system that was being used at the time in the East Wilmington field. The estimated average permeability of the G sand in the section to be penetrated was 100 mD. The completion method employed was an openhole gravel pack with 20/40 mesh gravel and a 3½-in. wire-wrapped sand screen. A solids-free version of the SFC system was placed in the openhole section and 200 ft inside the existing casing before the sand screen was run.

A second field trial took place shortly after the first well was put on production. This next well was a re-drill of a former well, but this time the 6⅛-in. path would be S-shaped instead of horizontal, and two sand markers would be penetrated in the ranger zone, the FO sand and the G 5. The formation pressure was low again, ranging from 0.32 psi/ft to 0.37 psi/ft. The same type of completion method that was utilized on the first well was utilized on this well.

Field Trial Results 2004

Evaluation of the first two field trials of the SFC system was carried out after the wells were put on production. No external chemical breakers were used to stimulate either well. The initial oil production on the first well exceeded the targeted initial production by 41%. The initial oil production on the second well exceeded the expected initial production by 126%. It should be noted that both wells were expected to be relatively low producers, so even a modest increase over the expected production target numbers was considered significant.

As mentioned earlier, water injection is used to maintain reservoir pressure and to prevent subsidence in the Wilmington field. Initial water production rate on the first well was 250 bbl/day, which was significantly lower than the expected rate of 900 bbl/day. This initial reduction in the water cut was first thought to be a result of the hydrophobic material in the Smart Filter Cake and that reduction of water production might be a general consequence of using the SFC RDF. However, water production on the second well was within 5% of the anticipated rate.

Field Trial Results Post 2004

Since the initial two tests in 2004, the SFC system has been used to drill 32 more wells in the Wilmington field. Thirty one of the wells were drilled horizontal in the Ranger zone. All the wells were completed as openhole gravel pack using 20/40 sand and a 12-gauge sand-control screen. None of the SFC RDF wells in the Ranger Zone required post stimulation to initiate oil production and/or remove skin.

The SFC system was also used recently to drill into the 237 Shale Zone. The 237 Shale Zone is described as a naturally–fractured shale and it is the deepest zone in the Long Beach Unit. The four zones above the 237 Zone are described as sandstones.[6] The production results of this well and the performance of the SFC RDF in this zone are still being evaluated.

Comparison of SFC and Conventional RDF

The SFC system was compared to two other RDF systems used to drill horizontal wells in the FO sands in Ranger West Recovery Blocks 502, 504 and 505 (**Table 1**). The first system was described as a "Drilled-in Fluid" (DIF), of which three cases are reported here; the other was a system described as "Sized Salt". The sized-salt system referred to in **Table 1** was used ten years prior to the first SFC system to drill a horizontal well in the same section. The first and last DIF wells were drilled and completed four and two years, respectively, before the first Smart-Filter-Cake (SFC) well. The time difference between these four reference completions and the two SFC completions added to the intricacy of the comparison.

During this period, the reservoir depleted significantly and the water injection rate increased annually (**Fig. 4**). As a result of this rate increase, the more recent completions produced more water. Proximity to the injector well is also a factor with respect to the water production. Due to the continual depletion of the reservoir, the anticipated crude production on the more recent wells was lower than the wells drilled years earlier. Well B-571, which utilized a SFC RDF, exhibited relatively high water production, as this well was completed close to the water injectors (**Fig. 5**). Note that for reference the injector wells are marked with a + sign, and the horizontal injectors are marked with a blue line. However, when comparing the SFC RDF well J-511A to two of the earlier DIF wells (J-460 and J-467A) in the same area, this well exhibited superior initial production as well as higher production rates for up to 26 months, in spite of this depletion (**Fig. 6**).

Another factor that was assessed when comparing performance of the SFC, DIF, and sized-salt systems was the length of the horizontal section. For example, there was a substantial difference in the length of the section drilled between wells B-571 and D-725 (**Fig. 7**). Well D-725 (drilled with a DIF) had a lateral length of 1,879 ft, while well B-571 (drilled with SFC RDF) had a lateral length of only 1,061 ft. Although D-725 was 44% longer, the initial oil production in well B-571 was approximately equal to well D-725. When comparing oil production on a footage basis, well B-571 initially produced 0.69 bbl/ft of oil while well D-725 initially produced only 0.34 bbl/ft of oil.

In the comparison of the SFC well J-511 to the two DIF wells – J-460 and J-467 – and the sized-salt well J-439, the contrast in initial crude production (**Fig. 6**) and the production after 26 months is significant. Well J-511 (SFC) had an initial oil production of 0.76 bbl/ft, while the DIF wells exhibited initial production of 0.11 bbl/ft and 0.23 bbl/ft, respectively. The sized-salt system exhibited initial production of 0.21 bbl/ft. The well using the SFC system produced at more than three times the rate that was obtained with the conventional RDF systems.

Summary

- The Smart-Filter-Cake RDF has been used successfully a total of 33 times in the East Wilmington field Ranger zone where open hole gravel pack completions have been employed without the need of any post stimulation to initiate production.

- The use of the Smart-Filter-Cake system has been expanded to the naturally fractured shale 237 zone in the East Wilmington field.

- Water production comparison is difficult due to intricate issues including continual depletion of the reservoir and differences in proximity to water injectors, time frame and rate of water injection.

- The SFC system had a higher initial rate of oil production when compared to other RDFs that had been used to drill horizontal wells in the Ranger zone.

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Table 1 – FO Horizontal Well Completion Details				
Well #	**Completion Date**	**Mud Type**	**Lateral Length (ft)**	**Max Mud Wt (lb/gal)**
J-511A	Nov 05	SFC	1,266	9.2
J-460	May 01	DIF	1,330	9.6
J-467A	May 01	DIF	1,665	9.7
J-439A	Jul 95	Sized Salt	1,376	10.5
B-571	Oct 07	SFC	1,061	9.0
D-725	Sep 03	DIF	1,879	10.2

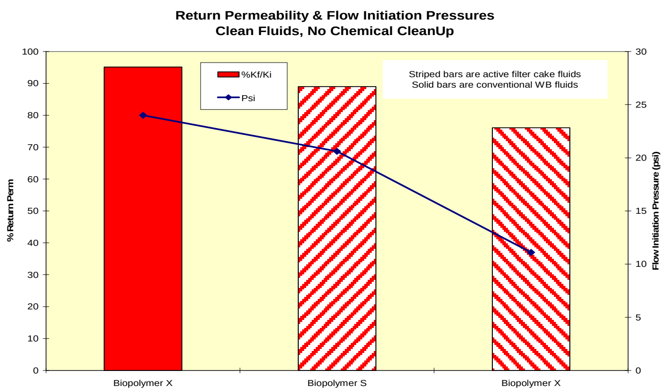

Figure 1 – Virgin Conventional RDF (solid bar) and SFC (striped bar) Systems.

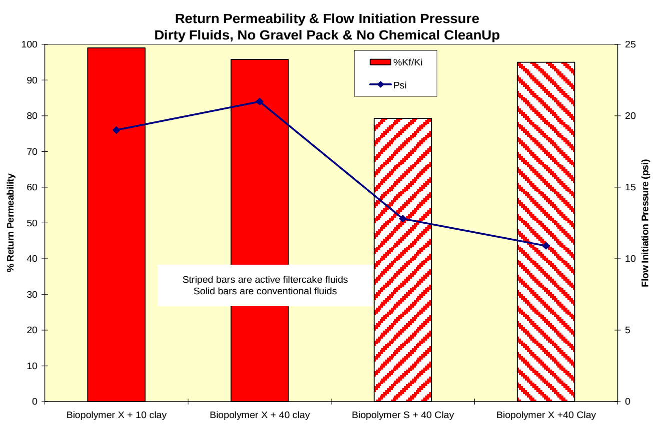

Figure 2 – Virgin Conventional RDF (solid bar) and SFC (striped bar) Systems with 40-lb/bbl OCMA clay.

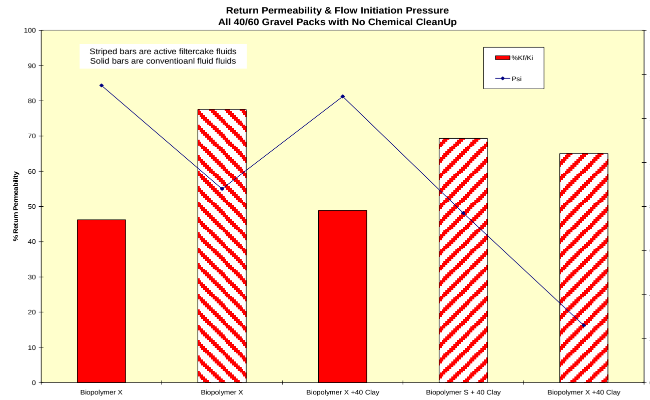

Figure 3 – Virgin Conventional RDF (solid bar) and SFC (striped bar) Systems with 40/60 sand and screen.

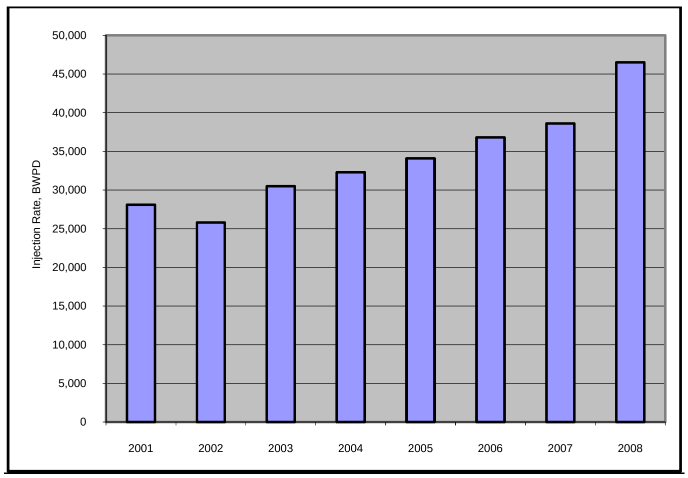

Figure 4 – Total water production rate vs time in the Wilmington Oil Field.

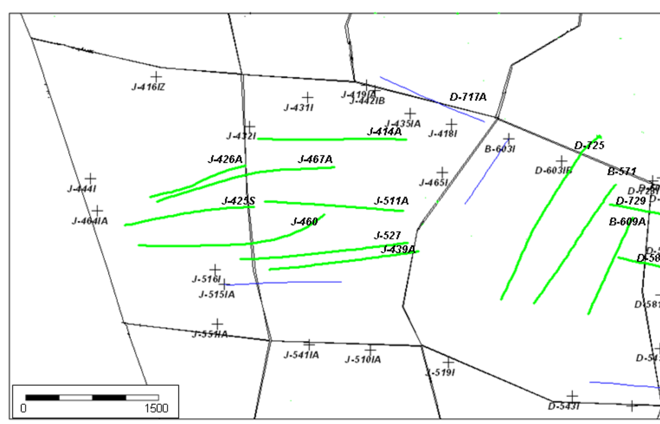

Figure 5 – Well locations for Ranger West showing relative locations for injection wells (+) and horizontal injectors (blue).

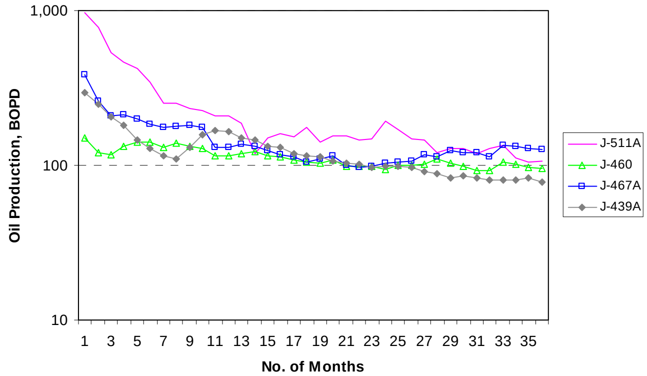

Figure 6 – Comparing SCF RDF (J-511A) crude production vs. three selected conventional RDF systems.

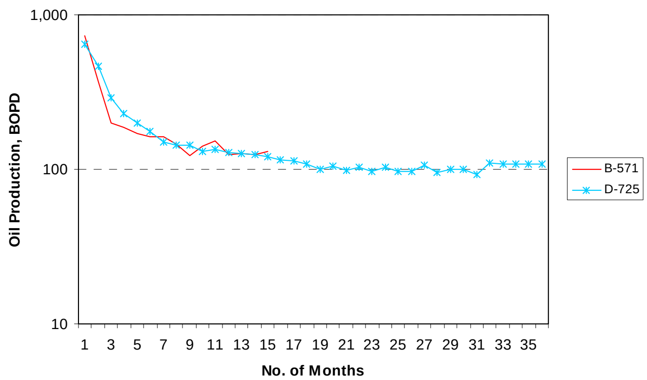

Figure 7 – Comparison in oil production between SFC (B-571) and DIF (D-725) RDF systems.