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Single-phase Microemulsion Technology for Cleaning Oil or Synthetic-Based Mud

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Abstract

Efficient filter cake and formation clean-up is required for production and water-injection wells drilled with synthetic/oil-based mud (S/OBM). Most invert emulsion skin damage removal or filter cake clean-up methods require multiple soak treatments. Typically the first treatment is designed to break the invert emulsion and water wet the filter cake residue. The second step is generally designed to remove soluble particles with acid and/or barium sulfate dissolvers. In many cases, these steps are repeated to improve performance.

A microemulsion technology was developed for removal of filter cake deposition, reversal of wettability and removal of wellbore skin damage in oil wells drilled with S/OBM. These microemulsion fluids, combined with conventional acids, allow a single-stage S/OBM clean-up process. The development work included formulating fluid designs, controlling the destruction rate of the filter cake with additives that prevent massive completion fluid losses and return water-injection permeability.

The results of laboratory tests and field trials using the single-stage method prove that, when using this technology to clean-up the filter cake or skin damage by S/OBM, (1) the invert emulsion is incorporated into the microemulsion, (2) the solids become water-wet, and (3) the majority of acid-soluble particles are removed. In conclusion, this technology maximizes skin damage removal and increases hydrocarbon recovery and water-injection rates.

Introduction

Many operators are interested in improving filter cake clean-up after drilling into reservoirs with invert emulsion drilling fluids. More efficient filter cake clean-up is desired for a number of open hole completions, including stand-alone and expandable sand screens, as well as for gravel pack applications in both production and water injection wells.

S/OBM filter cake clean-up technology uses a single-phase microemulsion (SPME) to incorporate the oil into the SPME by a solubilization process[1-3] (**Figure 1**)

In addition, the single-phase microemulsion and conventional acid packages are used in a single blend to solubilize the oil into the SPME, reverse the wettability of the filter cake solids, and simultaneously decompose its acid-soluble components. Reversing the wettability of the filter cake, using surface active chemistry, facilitates acidizing by preventing a sludge that could form between the acid and the emulsified cake and by making acid-soluble particle surfaces available to unspent acid.

In addition to the advantage of reduced skin damage, increased hydrocarbon recovery or increased water injection rates, a single-stage near-wellbore clean-up method will save an operator valuable rig time.

Fundamental Theory

In the 1950s, Schulman and co-workers added alcohol to surfactant-stabilized oil-in-water (o/w) emulsions to obtain very stable homogeneous fluids that he called microemulsions.[4] These microemulsions had an average droplet size of 10-100 nanometers (nm), much smaller than conventional emulsions.

The first studies of microemulsions in the oil industry were in the 1970's for enhanced oil recovery (EOR) applications.[5-11] Many oil operators and universities invested considerable time to researching this topic. The research group led by Schechter and Wade at The University of Texas at Austin made important contributions to the understanding of the mechanism of increased production by microemulsions. However, interest dropped due to crude oil price decreases and because the technology was expensive, mainly due to the high concentrations of surfactants required. Since then, the oil industry has conducted only a small amount of research on microemulsions.

In the past 25 years, surfactant manufacturers, universities and research institutes have greatly increased the knowledge of microstructures and the phase behavior of microemulsions, and have made surfactants available that are more efficient for microemulsion formulations.[12-18]

A microemulsion is a thermodynamically-stable complex fluid system typically composed of a non-polar oil phase, a polar water phase, surfactant and an optional co-surfactant. They are macroscopically homogeneous and, at the microscopic level, heterogeneous, consisting of individual domains of the non-polar oil phase and polar water phase, separated by a monolayer of surfactant (amphiphile).[1, 2, 14, 15] Microemulsions are typically clear solutions, because the droplet diameter of the organized phase is approximately 100 nm or less, and contain two immiscible fluids, in contrast to micellar solutions, which are considered to be one-phase fluids and may be either water or oil.

The surfactant molecules in these microemulsion systems lower the interfacial free energy to nearly zero, which induces

spontaneous microemulsification when the components are brought together. These fluids may be classified into three categories according to Winsor definitions.[16] Winsor I microemulsions consist of oil-swollen micelles in a water phase in equilibrium with excess oil. A Winsor II microemulsion consists of water-swollen reverse micelles in an oil phase in equilibrium with excess water. A Winsor III microemulsion is a middle-phase microemulsion, with excess water and oil. The Winsor III microemulsion systems can be understood as an accumulation of swollen micelles, so numerous that they touch one another, forming a perfectly bicontinous structure.[17, 18] **Figure 2** shows a photograph with Winsor I, Winsor III and Winsor II microemulsion.

A single-phase microemulsion (Winsor IV) is obtained by increasing the surfactant concentration of a Winsor III microemulsion fluid. [1, 2, 19]

Experimental Procedures

Single-phase microemulsions were formulated with surfactants, co-surfactants, brine and oil, and then were used as a soak solution to remove oil-based drilling fluid filter cake. The brines tested were calcium chloride, sodium chloride, sodium bromide, and potassium formate. The soak solutions were formulated in an acidic media, which was designed to dissolve the bridging particles in the filter cake.

The clean-up tests were performed using filter cakes obtained from oil-based drilling fluids formulated either with barite, calcium carbonate, or barite/calcium carbonate blends. Fluid formulations with various base oils with densities between 9 and 11 lb/gal were formulated to evaluate the filter cake clean-up efficiency.

The concentration of SPME in the brine was selected by a series of screening bottle tests in which the criteria was to incorporate all of the oil from oil-based drilling fluids into the soak solution and change the wettability of the solids from oil-wet to water-wet. In these tests, a certain volume of OBM is placed in a glass bottle, and then the SPME in brine (soak solution) is carefully added on top of the OBM. These bottles are placed in an oven at a specified temperature to observe oil solubilization into the SPME and wettability changes of the solids with time.

Filtration tests were performed in a double-ended HPHT filtration cell to evaluate the efficiency of the soak solution to remove the filter cake. The procedure included a mud-off at 500 or 1000 psi to deposit a filter cake. Then, the excess mud was removed and the SPME soak solution was added. Tests were performed with the leak-off valve opened to simulate the case for filter cake clean-up in new wells or with the leak-off valve closed, which is the case in remediation wells.

A Sandpack Permeameter was used to evaluate the efficiency of the OBM filter cake removal and water-injection. A schematic diagram of the Sandpack Permeameter is shown in **Figure 3**. The Sandpack Permeameter tests were run using 3, 10 or 20-micron discs, 140/270 simulated formation sand, and 40/60 gravel.

The filter cake clean-up evaluation was based on water-injection permeability. Injection tests were chosen instead of production permeability tests because injection is considered a "worst case" scenario from the viewpoint of return permeability. The test procedure begins with the measurement of the initial seawater injection permeability. Next, a filter cake is deposited on a ceramic disc or Berea sandstone, followed by treatment with the soak solution for a specified period of time. The mud-off time for deposition of the filter cake ranged from 3 to 16 hours. The soak time for the tests is in the range from 3 to 20 hours. The last step of the procedure is the water-injection measurement to determine the final injection permeability.

Results and Discussion

Screening tests of filter cake clean-up with SPME

The first part of the filter cake clean-up study included a series of screening bottle tests with the SPME in brine. **Figure 4** shows photographs of clean-up evaluations of a 10 lb/gal OBM using a 20% SPME in $CaCl_2$ brine. A 1/10 proportion of OBM/soak solution was used in these tests. In **Figure 4**, the photograph on the left side was taken after initial contact of the OBM with the soak solution. The photograph on the right side of **Figure 4** was taken after 3 hours of phase contact. The results indicate that after contact of the soak solution and the OBM: (1) the soak solution destabilizes the invert emulsion, (2) the oil from the OBM is incorporated into the microemulsion and (3) the solid particles became water-wet.

Figure 5 shows the photographs of bottle tests using a combination of SPME with formic acid in $CaCl_2$ brine. This SPME/acid blend demonstrates that this combination is capable of rapid oil-based filter cake clean-up (incorporation of oil into the soak solution), and calcium carbonate removal.

OBM filter cake evaluation with HPHT filtration cell

Figure 6 shows the filtration rate obtained when the SPME soak solutions were placed on the top the filter cake in the HPHT filtration cell. The filter cakes deposited in these tests were formed with a 10 lb/gal OBM at 1,000 psi at 150°F for 3-hours. Even if the three SPME/brines blends achieved good filter cake clean-up, the filtration rates obtained indicates that, for this particular SPME, the time required to destroy the filter cake is similar for the NaBr and $CaCl_2$ brine-based systems, but a longer time is required for the SPME in potassium formate brine. This is not surprising because the behavior of microemulsions change with changes in the types of ions and cations in the soak solution.

The mud cake appearance after mud-off and after treatment with the single phase microemulsion is shown in **Figures 7a and 7b**. Upon removal of the filter cakes and discs from the cell, it was observed that the filter cakes were water-wet, as evidenced by the easy dispersion of the cake particles in water (**Figure 8**). When the filter cake samples were dispersed in water, no sheen was observed, indicating that all of the oil was incorporated into the SPME soak solution

Injection permeability tests in the Sandpack Permeameter

OBM filter cake clean-up and water injection was evaluated in the Sandpack Permeameter. The first part of the filter cake clean-up and water-injection included a series of screening tests with the single phase microemulsion in brine without acid in the formulation. A cake deposition time of three-hours at 150°F and 1,000 psi was used to obtain a filter cake with a reasonable thickness to "break" in order to verify the cleaning efficacy.

Table 1 shows injection permeability data after tests were performed on 20 μm ceramic discs. The soak solution, containing 20% microemulsion mixed with a 10 lb/gal brine, was allowed to soak at 150°F and 360 psi for up to 20 hours. Even if the filter cake remained in place, because it cannot be displaced due to equipment limitations, the filter cake after treatment was very porous and loosely consolidated. As a result, it was possible to obtain a high percentage of water injection. The remaining filter cake residue in these tests were water-wet

The second part of the filter cake clean-up study was the evaluation of the single-stage soak formulation, an SPME in conjunction with an acid package in brine. A number of laboratory tests were performed using SPME together with various types of acid treatments on OBM filter cakes.

Table 2 shows the injection permeability results after 3-hr mud-offs and 3-hr or 20-hour soak times using 10 lb/gal OBM and soak solutions formulated with 20% SPME and 10% acid in $CaCl_2$ brine**.** The injection return permeability was only 69.3% in the case of 3-hour soak time, because this was not enough time to completely dissolve the calcium carbonate particles. The reduced size of $CaCO_3$ caused blockage of the pores. This was proven when the test was repeated with a longer soak time (20 hours), which resulted in an injection return permeability of 177.8%. After the test, photos of the ceramic disc with the filter cake show that the acid-soluble particles were removed and only a small amount of barite is observed (**Figure 9**)

Table 2 also shows the results of a test performed with an in-situ acetic acid generator, which exhibited a rate of 96.7% of the original water-injection return permeability.

Conclusions

1. The injection permeability test results prove that the SPME clean-up technique removes OBM and OBM filter cakes and water-wets the solid particles
2. The OBM filter cakes treated with the single-phase microemulsion resulted in a loose, porous filter cake that exhibited high injection permeability.
3. OBM filter cake clean-up was efficiently achieved using SPME and acid blends in brine.
4. The single-phase microemulsion, with an acid in brine, incorporates the oil phase of an OBM filter cake into the aqueous soak solution and acidizes the calcium carbonate in one step.
5. Because invert emulsion systems are the drill-in fluids of choice to drill pressure depleted reservoirs in many global operations, the SPME technology presented in this paper appears to be an excellent approach to remove near wellbore damage and prepare the reservoir for water-injection.

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SI Metric Conversion factors

psi x 6.894 757	E +03 = pa
mL x 1.0*	E -06 = m^3
mD x 9.869 233	E -16 = m^2
µm x 1.0*	E -06 = m
lb/gal x 1.198 264	E +02 = kg/m^3
°F (°F-32)/1.8	= °C
in. x 2.54*	E +00 = m

* Conversion factor is exact.

Tables

Table 1 Water injection permeability using SPME for clean-up OBM filter cake

Soak density, lb/gal/ brine	Permeability		
	Initial, mD	Final, mD	% Injection
10/ $CaCl_2$	217.3	183.3	84
9.3/ NaCl	280.7	253.8	90.4

Table 2 Water injection permeability using SPME with acid as clean-up soak

Soak time, hr/ type of acid	Permeability		
	Initial, mD	Final, mD	% Injection
3 (formic acid)	407	282.1	69.3
20 (formic acid)	201.4	358	177.8
20 (acid generator)	684	661.5	96.7

Figures

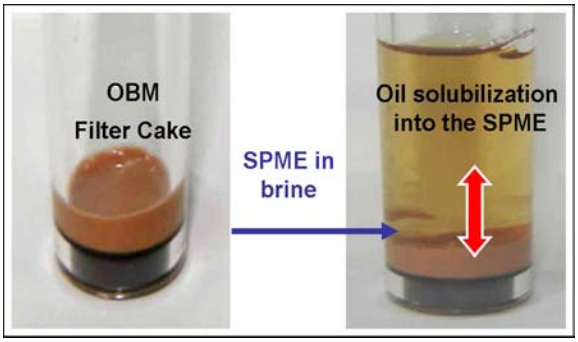

Figure 1 Mechanism of filter cake wellbore clean-up

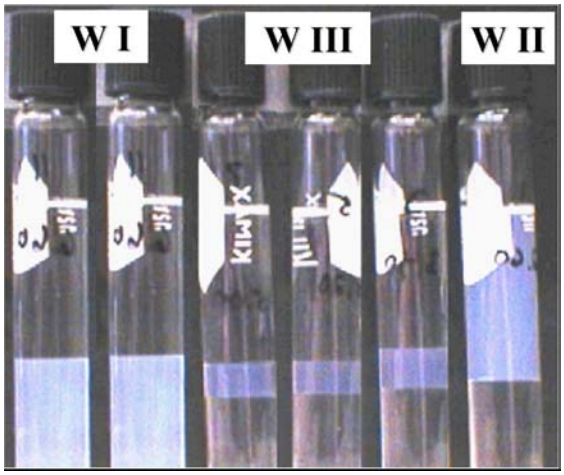

Figure 2 Microemulsion systems according to Winsor definition

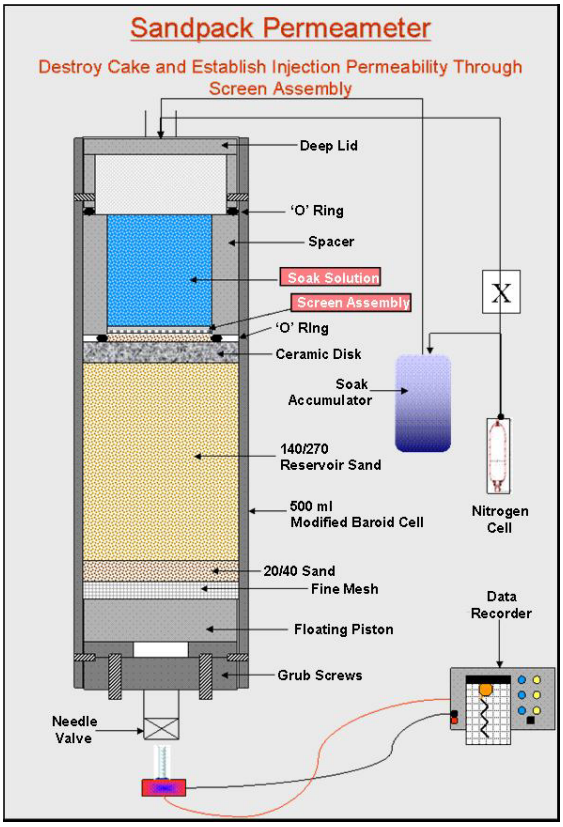

Figure 3 Sandpack Permeameter

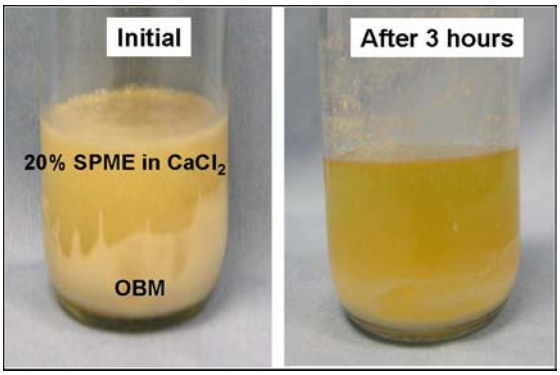

Figure 4 OBM/SPME soak solution contact phase tests

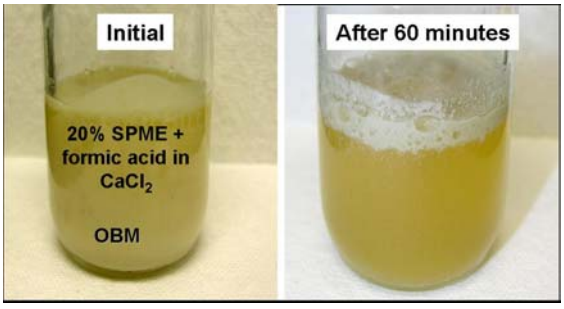

Figure 5 OBM/SPME with acid soak solution contact phase tests

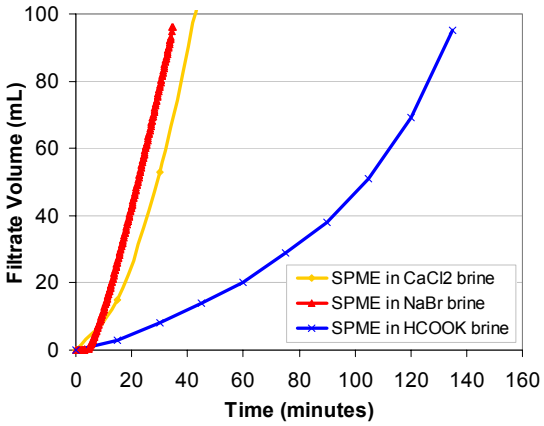

Figure 6 Filtration rate of SPME soak placed on top of OBM filter cake

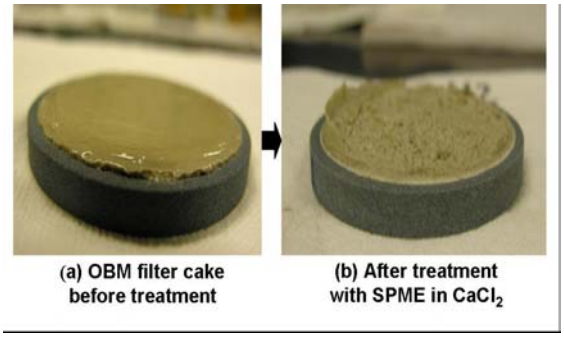

Figure 7 OBM filter cake clean-up with SPME in $CaCl_2$ brine

Figure 8 Filter cake placed in water after the treatment

Figure 9 OBM filter cake after treatment with SPME + formic acid