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Invert Emulsion Drilling Fluid Recovery

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Abstract

After multiple uses, reclaimed invert emulsion drilling fluids contain a high level of internal phase (e.g. brine) and colloidal solids, which results in a high-density fluid that has unfavorable fluid properties and poor performance. In most cases, reclaimed invert emulsion fluids are subsequently diluted and reconditioned. A conventional way to treat these heavy drilling fluids is by dilution and addition of emulsifiers and other additives to achieve acceptable fluid properties. However, the dilution method tends to be very costly, driven by large additions of the base oil, as well as costs related to storage, transportation, and waste disposal.

This paper discusses a novel process developed to recover invert emulsion drilling fluids. The process combines a chemical treatment and mechanical separation to remove water (brine) and colloidal solids from the reclaimed oil-based mud without completely breaking the emulsion. Laboratory results and large-scale tests have proven that the reclaimed fluid density could be reduced from densities characteristic of heavy invert emulsions (such as 17 lb/gal to about 9 lb/gal) by using a novel chemical treatment that removes high colloidal solids content and the excess of internal aqueous phase that was incorporated during multiple usages of the invert emulsion fluids.

Introduction

Invert emulsion drilling fluid has always been a more preferable choice than water-based counterparts due to its high level of drilling performance. Invert emulsion drilling fluid, known as synthetic or oil-based mud (S/OBM), can be designed to operate in a wide range of conditions and under extreme drilling challenges. Superior properties of these fluid systems include increased lubricity, enhanced shale inhibition, high rate of penetration, and withstanding greater heat condition. Another attractive benefit of S/OBM is their ease of use, because they can generally be employed in multiple drilling operations with minimal maintenance.

Fundamentally, SBM or OBM are stable macroemulsions consisting of emulsified internal brine droplets in a continuous oil phase. Among S/OBM additives, emulsifier agents play an essential role in the stabilization of the brine droplets in the continuous oil phase of the invert emulsion.. During performing its function, OBM is contaminated with water and drill solids, hence resulting in undesirable fluid performance after multiple uses. In most cases the reclaimed drilling fluid is diluted with base oil to restore the fluid properties. However, the conventional dilution method tends to be costly, environmentally unfriendly, and insufficient for large-scale operations. High costs are driven by large additions of additives to the invert emulsion as well as costs and issues related to storage, transportation, and waste disposal.

In the body of this work, a novel approach has been developed to recover high-quality base fluids from spent OBM. The treatment process comprises two steps – chemical treatment and mechanical separation via centrifuge. A proprietary chemical treatment formulation was developed using the hydrophilic-lipophilic balance concept (HLB) [1-3] to maximize demulsification performance. Then, mechanical solid-liquid-liquid separation equipment, like a centrifuge was sequentially used to accelerate the separation of coalesced water droplets and colloidal solids out of treated drilling mud.

Uniquely in this work, the designed treatment technique removes excess water (brine) and colloidal solids from the mud without completely breaking the emulsion. This distinct process offers major advantages in reusing the base fluids to formulate new OBM without the addition of costly OBM emulsifiers.

Experimental Procedures and Materials

Invert emulsion drilling fluid

Invert emulsion drilling fluids samples tested in this work were field OBMs from the Middle East and the North-Sea. A retort analysis was used to determine the initial oil/water ratio (OWR) and compositions of the OBM. **Table 1** shows the initial OBM properties of the two base fluids before the treatment.

Table 1. Field OBM initial properties determined by retort

System	Density (lb/gal)	Oil/water ratio (OWR)	% Solid
ME OBM	10.28	74/26	10.8
NS OBM	12.5	72/28	10.6

Laboratory test procedure

The treatment formulation was an acid-free formulation comprising a sequent addition of two surface active additives or surfactants (SA 1 and SA 2). Approximately 1 to 4% vol of the first additive (SA 1) and 1 to 3% vol of the second additive (SA 2) were added to 100 ml of OBM sample. The sample was then mixed at 2,000 rpm for 5 minutes using a Prince Castle mixer and instantly transferred into the 50 mL centrifuge tube for mechanically enhanced separation via centrifugation (Beckman Model J-6B with 13.335 cm rotational radius) at 2,600 rpm for 20 minutes. After centrifugation, samples were separated into many layers. Depending on the treatment formulations, these layers might include the recovered oil, rag layer, oil-wet solids, water, and water-wet solids. The example of samples after centrifuge is illustrated in **Figure 1**. In the case that the separated sample consists of recovered oil and rag layers, both layers were considered as recovered oil in this work. The OWR of the recovered oil was further determined by retort and used as an indicator to select the most efficient breaker formulations.

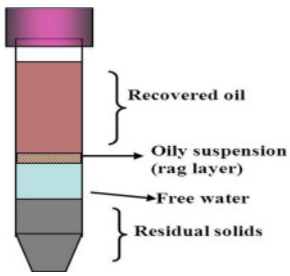

Figure 1. Example of treated sample after centrifugation.

Pilot test procedure

The two-step process was evaluated in a pilot plant following the successful lab tests. A batch process was developed for the pilot tests to evaluate the chemical and mechanical separation. The process involved mixing the OBM with the treatment formulation in a 350 L mixing tank with agitators for approximately 30 min. The mixed batch volume of mud was pumped using a progressive cavity pump to a decanter centrifuge at a variable feed rate of 400-700 L/hr. The separated oil, water, and solids from the decanter are further analyzed by retort and particle size analysis.

Laboratory Results

Formulating robust treatment formulation

One of the goals of this project was to develop a robust treatment formulation to remove significant amounts of water (brine) and colloidal solids from spent mud. Selecting a chemical treatment formulation was found to be a key element that influences the OWR of reclaimed oil. As mentioned previously, excess water and colloidal solid contamination remain suspended in the OBM primarily due to the presence of OBM emulsifiers. Therefore, to remove substantial amounts of water and solid suspension, adsorbed oil-mud emulsifiers must be diminished from the oil-water interface, thus destabilizing the emulsion. As a result, contaminated water and solids can be easily coalesced and removed from drilling mud by a simple centrifuge technique. An increase in the coalescence rate of water droplets and colloidal solids led to higher OWR and lower solids content of the recovered oil.

In this part, we demonstrated that a proper selection of the chemical treatment could effectively destabilize invert emulsion without the addition of acid. The chemical treatments studied included various types of surfactants. Drilling mud evaluated in this part was the 10 lb/gal ME field mud with initial OWR of 74/26. The final OWR of the recovered oil was determined by retort analysis. The high OWR of recovered oil indicates a better efficiency of the formulation in destabilizing invert emulsion.

Table 2 shows the final OWR of recovered oil after treatment with a variety of chemical formulations. The results demonstrate that the addition of acid (40% vol formic acid) plays a critical role in destabilizing invert emulsions, thereby achieving high OWR of 94/6 as compared to the OWR of 79/21 of the acid-free formulation (Test 1). This finding is similar to that observed by Ezell *et al.* [4]. Moreover, the destabilization performance of the acid-included formulations (Test 2 vs. Test 3) is not affected by changing the HLB of surfactants. Unlike the acid-included system, switching from SA 2-A to SA 2- B strongly affects the OWR value in the acid-free formulations. Comparing between two acid-free treatment formulations (Test 1 vs. Test 4), the OWR of recovered oil increases with increasing HLB of the surfactant, suggesting more effective destabilization. The highest OWR of 96/4 can be achieved by using a combination of SA 1 and SA 2-B and without involving acid addition. To further explain these results, we refer to the surfactant HLB concept: emulsion stability can be minimized by shifting the HLB of the emulsifier blend away from the optimal condition. Since surfactant B has slightly shorter tail (higher HLB value), these surfactant molecules preferably adsorb at the oil-water interface. The presence of SA 2-B at the interface results in a shift in the HLB of the emulsifiers to higher value, leading to an imbalance HLB value of oil-emulsifiers at the interface. As a consequence, the invert emulsion eventually breaks.

Even though the effective destabilization was achieved by the use of SA 1 with intermediate hydrophilic surfactant SA 2-B, the key component for destabilizing effectiveness is the surfactant SA 1, Test 5 reveals that high OWR of 95/5 can be obtained by using only SA 1. However, it is important to highlight that the residual solids, after centrifuging exhibit water-wet characteristics when the formulation comprise consisting of both SA 1 and SA 2- B surfactants.

Table 2. Final OWR of recovered oil with various treatment formulations

Formulation	Acid	SA 1	SA 2	Final OWR
Test 1	–	SA 1	SA 2-A	79/21
Test 2	40%vol HCOOH	SA 1	SA 2-A	94/6
Test 3	40%vol HCOOH	SA 1	SA 2-B	94/6
Test 4	–	SA 1	SA 2-B	96/4
Test 5	–	SA 1	–	95/5

Optimizing treatment concentration

The foregoing study indicates that, in order to achieve high OWR of 96/4 and have water-wet residual solids, the treatment formulation should contain SA 1 and intermediate HLB SA 2-B. In this part, the effect of treatment concentration was examined, with an objective to obtain most effective destabilization performance with the minimal treatment concentration used.

Testing was carried out by varying the total treatment concentration used while keeping the SA 1-to-SA 2-B ratio constant. The baseline formulation is 7% vol and consists of both SA 1 and SA 2-B.

Figure 2 illustrates the effect of total treatment concentration on the OWR of recovered oil. Test results suggest that the developed treatment formulation works effectively in a wide range of concentrations. The OWR of recovered oil is slightly decreased, from 96/4 to 91/9, when the total treatment formulation concentration is deceased from 7% vol (baseline) to 1.75% vol. Furthermore, despite reduced treatment concentration, all residual solids fractionated after centrifuging exhibit the water-wet property. These results demonstrate the great robustness and economic feasibility of the treatment formulation in reclaiming oil from off-spec oil-based drilling fluid.

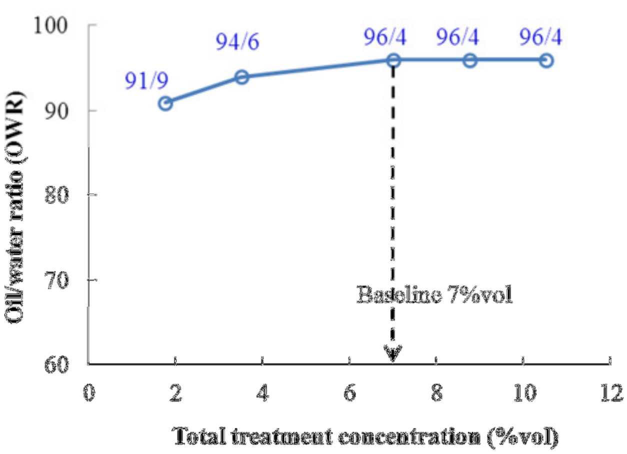

Figure 2. Effect of total treatment concentration on the OWR of recovered oil.

Pilot Tests Results

Although the treatment formulation developed in this study provides sufficient destabilizing capability, mechanically enhanced separation equipment, like a centrifuge, is the key complementary element for expediting the separation of coalesced water droplets and colloidal solids out of the treated drilling mud. Shorter operational time and simpler mechanical equipment operated a mean larger volume of contaminated mud treated, resulting in a more economical treatment process.

The pilot test of the OBM recovery process was performed with field mud to optimize various mechanical parameters of the decanter centrifuge. Retort analysis indicated that field mud has the initial OWR of 72/28 and 10.6 % vol solid content. Upon mixing, it was realized that the mixing time must be increased in order to ensure well-mixed condition between the treatment formulation and mud sample. The mixing time for the large-scale test was approximately 30 minutes before transferring to the centrifuge.

A series of tests were carried out with two optimized treatment formulations (the SA 1 only system and a combination of SA 1 and SA 2-B). With the optimal mechanical setup, the two-step process successfully separated and recovered good quality oil from original field mud. **Figure 3** shows the retort analysis of the recovered oil at various feed flow rates. Increasing feed flow rate from 400 to 700 L/hr slightly decreases the OWR of the recovered oil from 95/5 to 91/9. All recovered oil samples contain 4 to 5% solid content.

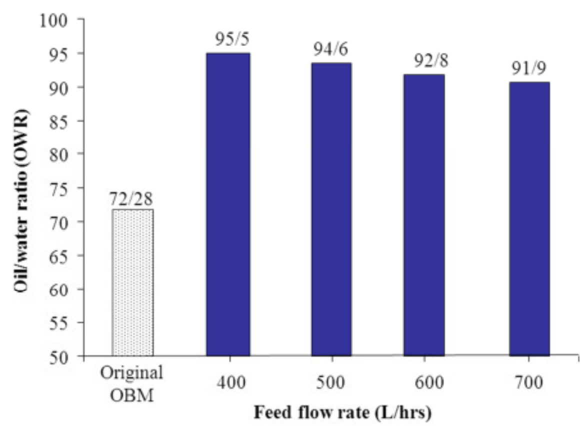

Figure 3. OWR of recovered oil as a function of feed flow rate.

Similar OWR results were observed with each of the optimized treatment formulations (the SA 1-only and a combination of SA 1 and SA 2-B). However, to obtain the water-wettability of residual solids, the treatment formulation must include both SA 1 and SA 2-B. From the results, it is shown that the two-step treatment process developed here is viable for field operations. It provides an alternative approach for removal of large volumes of water and colloidal solids, thus recovering good quality oil from spent mud.

Reformulating drilling fluid with recovered oil

After remediation, the recovered oil sample from the pilot test was mixed with reclaimed mud (OWR of 72/28), organophilic clay, and weighting material to formulate 10 lb/gal OBM mud with 90/10 OWR. The formulation for one barrel OBM with recovered oil was summarized below:

Recovered oil (OWR 95/5):	0.714 bbl
Pre-treated mud (OWR 72/28):	0.206 bbl
Organophilic clay:	8 lb
Weighting material:	0.079 lb

Table 3 shows the properties of the reformulated mud measured at 120°F. The results demonstrate that the formulated OBM has acceptable rheological properties, good emulsion stability and low HTHP fluid loss characteristic. Furthermore, it is important to highlight that the formulated OBM system does not require addition of oil-mud emulsifiers and brine. These findings emphasize that the chemical treatment developed in this work does not destroy the functionality of the original oil-mud emulsifiers, but rather lower their affinity at the oil-water interface. Next, since one of reformulating components is the pre-treated mud with low OWR of 72/28 (seed mud), it is advantageous that an excess volume of water (brine) has already existed in the system. Results from this study demonstrate the feasibility of formulating oil-based drilling mud with oil recovered from our technique.

Table 3. 10 lb/gal OBM formulating with recovered oil – property check at 120°F

Properties	OBM formulated with recovered oil
Mud Weight, lb/gal	10.6
Type of Based Oil	Diesel
Electrical Stability, volts	1241
Rheological Properties @ 120 °F	
600 rpm reading	75
300 rpm reading	50
200 rpm reading	39
100 rpm reading	28
6 rpm reading	13
3 rpm reading	12
Plastic Viscosity, cP	25
Yield point, lb/100 sq ft	25
10-sec Gel, lb/100 sq ft	13
10-min Gel, lb/100 sq ft	17
HPHT fluid loss @ 250F, ΔP 500 psi, mL	3.0

Conclusions

This work developed a novel approach for recovery base fluids from invert emulsion drilling mud

The novel treatment technique involves a two-step process – chemical treatment and mechanical separation via centrifuge. The chemical treatment, consisting of two surfactants was optimized to achieve maximum destabilization performance, thus enhancing coalescence of excess water droplets and colloidal solids. The solid-liquid-liquid mechanical separation via centrifuge enhanced the separation of the coalesced phase for operational use.

The combination of laboratory and large-scale test results demonstrate that the two-step treatment process enables recovery of good quality base oil from spent OBM.

In general, the base fluid recovered from this process has a high oil/water ratio (>90/10) with a low solids content (<5%). In addition, the technique is proven to be viable for field operation.

Uniquely in this work, the designed treatment technique removes excess water (brine) and colloidal solids from seed mud without completely breaking the emulsion. This distinct process offers major advantages in reusing the base fluids to formulate new OBM without addition of costly OBM emulsifiers.

Acknowledgments

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Nomenclature

OBM = *Oil-based mud*
S/OBM = *Synthetic or Oil-based mud*
OWR = *Oil/water ratio*
SA = *Surface active agent or surfactant*
ppg = *lb/gal*
bbl = *barrel*
ppb = *lb/barrel*

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